

PRINCIPLES OF RAILWAY LOCATION AND DESIGN

SIRONG YI



西南交通大学出版社



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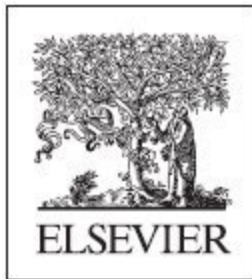
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Principles of Railway Location and Design

First Edition

Sirong Yi



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Table of Contents

[Cover image](#)

[Title page](#)

[Copyright](#)

[Introduction](#)

[1 The Development of Railways](#)

[2 Construction and Planning of China's Railway](#)

[3 High-Speed Railway Development Around the World](#)

4 Railway Location and Design

Chapter 1: Railway Transport Capacity and Construction Standards

Abstract

1.1 Railway Traffic Volume and Design Period

1.2 Railway Carrying Capacity in the Section

1.3 Railway Traffic Capacity

1.4 High-Speed Railway Transport Capacity

1.5 Railway Classification and Main Technical Standards

Chapter 2: Traction Calculation

Abstract

2.1 Forces Acting on the Train

2.2 Train Motion Equation

2.3 Tractive Tonnage

2.4 Train Running Speed and Time

Chapter 3: Railway Plane and Profile Design

Abstract

[3.1 Introduction](#)

[3.2 Design of Plane](#)

[3.3 Profile Design in Section](#)

[3.4 Plane and Profile Design at Bridge, Culvert, Tunnel and Subgrade](#)

[3.5 Plane and Profile Design at Station Site](#)

[3.6 Line Plans and Profile Details](#)

[Chapter 4: Railway Location](#)

[Abstract](#)

[4.1 Basic Principles of Railway Location](#)

[4.2 Selection of Line Strike](#)

[4.3 Distribution and Position Selection of Stations](#)

[4.4 Basic Methods of Railway Location](#)

[4.5 Location in Complicated Geological Conditions](#)

[4.6 Location in Sections of Bridge, Culvert, and Road Intersection](#)

[4.7 Railway Environment Location](#)

[4.8 Computer Aided Railway Location and Alignment Design](#)

Chapter 5: Technical and Economic Comparison of Schemes

Abstract

5.1 Basic Concepts of Technical and Economic Comparison

5.2 Basic Data of Economic Comparison

5.3 Economic Criterion Methods

5.4 Comprehensive Criterion of the Proposals

Chapter 6: Station Design

Abstract

6.1 Passing Station and Overtaking Station

6.2 Intermediate Station Design

6.3 Essentials of District Station Design

6.4 Introduction of the Marshaling Station and Junction Terminal

6.5 Essentials of High-Speed Station

Chapter 7: Strengthening of the Railway Transport Capacity

Abstract

7.1 Principal Measures in Strengthening the Carrying Capacity of the Railway Line

[7.2 Upgrading of Railway Passenger Transport](#)

[7.3 Construction of High-Speed Railway](#)

[7.4 Railway Heavy Haul Traffic](#)

[Chapter 8: Design for Reconstruction of Existing Railways and Building Out of Second Railway Lines](#)

[Abstract](#)

[8.1 Design for Reconstruction of Existing Railways](#)

[8.2 The Design of the Second Railway Line](#)

[8.3 Building the Third, Fourth, and Branching Lines](#)

[Bibliography](#)

[Index](#)

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Introduction

1 The Development of Railways

As a huge achievement of modern civilization, railway develops with the science and technology. In the 1820s, the history of railway began as the invention of the steam locomotive and rail track.

The railway industry usually regarded the standard-gauge railway line from Stockton to Darlington, UK, which started on Sep. 27, 1825, as the very first railway line. This year is regarded as the birth of the world's railways. Up to now, the railway has a history of more than 190 years, and its development may be divided into four stages.

1) The early stage

The progress of science, technology, and commodity production have significantly affected the birth and development of railway. In 1804, Trevithick trialled the first steam locomotive which can run on rail track; in 1825, the first railway line of 32 km was constructed, as mentioned above. A total of 105,000 km of railway lines were constructed in the years 1825–1860. After the Industrial Revolution, the steam engine accelerated the development of transportation, and the railway was created. The United Kingdom constructed the first public railroad in the world, and then other western countries, such as the United States, France, Canada, Germany, and Italy all followed suit.

2) Peak stage

Railway lines developed the fastest before the First World War, from 1870 to 1913, when more than 20,000 km of railway were constructed per year, on average. The operating mileage of the world's railways was 1.104 million km by 1913, most of which were concentrated in the UK, the USA, Germany, France, and Russia. During this period, railway companies competed with each other by upgrading their speed. In 1903, an electric vehicle from Siemens-Halske recorded a speed of 210 km/h, the highest in that period.

3) Steady stage

In the period between the end of the First World War and the start of the Second World War, development of railways in main western countries had basically stopped. However, in colonial, semi-colonial, and sovereign countries, and independent countries, railways were developed rapidly. By 1940, the world's operating mileage reached 1.356 million km.

During the Second World War, railways in most European countries were destroyed and restored the old status before war until around 1955. After the Second World War, with the rapid development of highway and air transport, in major capitalist countries, railway faced intense competition with highway and aviation, and the proportion of railway passenger and freight traffic volume was reduced day by day. Many railway industries became unprofitable, with losses so severe that some countries had to take railway lines back under state control. The operating mileage has been consistent around 1.3 million km from the 1930s to the early 1960s.

4) Modernization stage

The development of world railway began to recovery at the end of the 1960s, especially after the petrol crisis in the 1970s. Due to lower energy consumption than airplanes and automobiles, and less noise pollution, and higher transportation capacity, the railway was returned to as a main means of transportation. Electric traction was determined as the development direction. In the last 30 years, advanced technologies have been widely adopted, such as the revolution of traction power, development of container and piggyback transportation, improvement of communication signal, strengthen of track configuration, and development of management automation. We should note that the high-speed railway and heavy haul traffic are still developed.

Presently, there are about 140 countries and regions operating railway trains, and the overall operating mileage is about 1.2 million km (not including urban rail transport system). According to recent statistics, the top ten countries with longest operating mileage are 228,000 km of the USA, 121,000 km of China (no local railway included), 85,000 km of Russia, 64,000 km of India (state controlled), 52,000 km of Canada, 43,000 km of Germany, 39,700 km of Australia, 34,000 km of Argentina, 30,000 km of France, and 29,400 km of Brazil.

2 Construction and Planning of China's Railway

China's railway is undergoing fast development, especially its high-speed railway. By now, the railway network in China totals 75,000 miles (120,000 km) and is predicted to reach 93,200 miles (150,000 km) by 2020. The train has been the top choice for more and more travelers in China. Every year, China's railway system accommodates over 2500 million passengers, and this number is still growing at a speed of about 10%.

The history of China's railways can be divided into three stages. The first stage, from 1865 to 1949, is featured as the awakening time; only a few railroads were constructed and in use. The second stage, from 1949 to 2004, is a massive construction stage when the old lines were restored and improved, and lots of new lines were built. It was during this stage that the country's railroad network took its shape gradually and was expanded to cover most cities in the country. In the third stage, since 2004, the country has entered the high-speed era. High-speed lines take place of old busy ordinary speed lines, which greatly increases transport capacity and makes train travel much easier than before.

About 150 years ago, the first train station was built in China. The first rail line in China was the Wusong Line, from Wusong to Shanghai with a length of 7.5 miles (12 km). It is regarded as the first chapter of the Chinese rail history. The real chapter of the rail history started with the local

construction of the Tangxu Rail Line in 1881, from Tangshan to Xugezhuang. The first self-designed and constructed rail Line by China, Jingzhang Line (Beijing Fengtai to Zhangjiakou), was put into use in 1909, and was designed by the great rail engineer, Zhan Tianyou. He was appointed to be in charge of the rail construction, and the renowned Reversing Y-shape line was proposed by him, which was widely regarded as the most difficult project on account of the geography barrier, hence Zhan Tianyou enjoys the fame of "The Father and General Engineer of Chinese Railway." In the first place, before 1949, there were only about 14,602 miles (23,500 km) constructed and only 6835 miles (11,000 km) were in service. Most rail lines gathered in northeast and coastal area of China, with only 6% extending to other areas. Secondly, the standards of the rail line were different from each other in specification, for the lines were constructed by different countries. Therefore, the rail network was in a great mess.

After 1949, the rights to the railway were officially brought under state ownership and the Railway Ministry was founded to take charge. The railway construction developed according to the well scheduled plans and programming. The main lines were restored and connected and the construction work was done massively. The first task for Chinese railway career was to restore the main lines and standardize their operation. By the end of 1949, Jinghan, Longhai, Zhegan, Nantongpu, and Xianggui Railways were recovered, and nearly 5143 miles (8278 km) was open to traffic again.

Locomotives powered by electricity: In 1953, China started the first five-year development plan, and the enlargement of the railway network was given priority. In June of 1953, Chengyu Railway (Chengdu-Chongqing) was completed and put into use, and was the first railway built since the

founding of new China. After that, Tiancheng, Tianlan, and Lanxin railways were accomplished one after another. By the end of 1957, the newly constructed rail lines amounted to 3790 miles (6100 km) as part of the plan, which strengthened the links between China's interior and its east coast. It also consolidated communication with neighboring countries, such as Vietnam and Mongolia. However, in 1958, the railway construction work was affected again, and the railway operating order was disturbed gravely as a consequence of trying to achieve too much too soon. Sadly, this also resulted in an increased number of rail accidents. The major focus on coal and mineral freight disadvantaged the transportation of crops and light industrial products which had detrimental effects on the economy. From 1961 to 1965, these problems were overcome, and the railway regained stable improvement and rectification. In 1961, Baofeng (Baoji-Fengzhou) section of Baocheng Railway (Baoji-Chengdu) was finished as the first electrified railway. However, China railway suffered another disaster during the decade from 1966 to 1976. Several of the most important rail terminals were blocked, and the transport and freight suspended for a while. In 1968, the whole undertaking hit rock bottom. From 1978, large resources were put into modernization of the network, and the disproportion in the railway development was readjusted. After long-term restoration and recovery, the development of the rail system regained a good momentum. After the Third Plenary Session in 1978, the railway electrification process was accelerated greatly. Xiangyu, Shitai, Baolan and Chengyu lines were gradually electrified. In just 24 years or so, China had constructed 41 electrified rail lines, with a total length of 11,567 miles (18,615 km). In general, the railway networks extended in all directions during this stage; most finished rail lines were put into operation; the passenger volume and freight forged ahead; while the railway management was inclined to be more scientific in its

approach to the overall organization. The entire rail operation developed at a steady pace as it marched forward into the 21st century.

With the rapid economic development, China's railway capacity is persistently overtaken by demand, especially in the developed economic zones. This makes it urgent for bringing more capacity into service by stepping up high-speed lines construction. In 2004, the State Council approved the Mid-to-long Term Rail Network Plan, ensuring that construction of high-speed lines receives priority. This program led to the construction of a high-speed rail network consisting of four north-south lines and four east-west lines, which connects with most part of the country, namely several intercity high-speed lines among economic regions, such as Bohai Sea Coastal Region, Yangtze River Delta, and Pearl River Delta Economic Zone. Huge investments are put into the construction project. Upgrading and electrifying the existing lines runs in parallel with new additions. In 2007, the Sixth Railway Speed-up plan had addressed the call for increasing transport capacity. Some of the busiest lines were upgraded to accommodate top speed of 124-155 mile/h (200-250 km/h).

In 2008, the high-speed era dawned on domestic travels with the operation of China's first high speed line, Beijing-Tianjin Intercity High Speed Railway. In 2009, the Wuhan-Guangzhou section of world's longest high-speed line, Beijing-Guangzhou High Speed Railway opened. In 2010, Zhengzhou-Luoyang-Xian High Speed Rail Line was operational. In 2011, the Beijing-Shanghai High Speed Railway was inaugurated. And the travel time between the two cities was cut to about 5 h from 15 h. In 2012, the first frigid Harbin-Dalian High Speed Line was functional, and by the end of that year, the high-speed lines had totaled 5800 miles (9350 km). In 2013, the Ningbo-Hangzhou, Panjing-

Yingkou, and Nanchang–Putian high-speed lines followed each other into service. The Four North-South and Four East-West Network has taken shape. In 2014, Lanzhou-Xinjiang, Nanning-Guangzhou, Guangzhou-Guiyang, Taiyuan-Xian section of Datong-Xian, Hangzhou-Changsha section of Shanghai-Kunming, as well as Chengdu-Leshan-Emeishan high-speed lines all became reality. In 2015, Chengdu-Chongqing, west line of Haikou-Sanya, Hefei-Fuzhou, Jilin-Hunchun, and Nanjing-Anqing high-speed rails were all put into operation. In 2016, Zhengzhou-Xuzhou, Shanghai-Kunming, Guangzhou-Kunming high-speed rail lines will all be opened. China has attained the acme of high-speed railway development, for it has achieved the broadest, fastest, and most advanced high-speed rail network in the world. About 75,000 miles (120,000 km) tracks were in use and over 12,500 miles (20,000 km) were the high-speed type. In addition, China's advanced high-speed technology has come of age in the international arena. Plans of collaborative high-speed rail ventures with foreign regional governments have been made to project China's technical knowhow abroad, including the China-Pakistan Line, China-Thailand Line, China-Laos Line, China-Myanmar Line, and China-Nepal Line.

China's railway network has a total length of 75,000 miles (120,000 km), among which 12,500 miles (20,000 km) are high-speed railways. These railways shape a dense net covering almost every corner of China, even remote mountainous areas, Tibet on the "Roof of the World," and Hainan Island on the sea. By 2030, the railway network in China is expected to reach 93,200 miles (150,000 km). First of all, we will introduce several major normal-speed railways, including five vertical lines running in a north-south direction and three horizontal lines traversing in an east-west direction. As they were completed years ago, most of them can only accommodate normal-speed trains.

Three railway network methods are determined: high-speed railway network, ordinary-speed railway network, and comprehensive transportation terminal.

(1) High-speed railway network

Meet the increased passenger transportation requirement, to optimize and to expand the space, construction standard are determined. Eight column lines and eight row lines are designed together with local and intercity lines.

(2) Ordinary-speed railway network

Enlarge the mid-west railway network, and improve the network in the east together with the overall quality.

(3) Comprehensive transportation terminal

Reasonably arrange the network with the principle of passenger train inside and freight train outside. Terminals location should also be optimized and facilities should be improved.

3 High-Speed Railway Development Around the World

High-speed running is an important symbol of railway modernization. Since 1964 the world's first high-speed railway, Tokyo–Osaka high-speed railway, was built in Japan, the following 50 years witnessed rapid development of the high-speed railway. Coming into the 21st century, all-round development of high-speed railway has been seen, and a global period of high-speed rail network construction has arrived. The development of high-speed railway can be divided into three different stages as follows.

1) The first wave of high-speed railway construction (from the 1960s to the late 1980s)

Worldwide, the initial development period of high-speed railway is from 1964 to 1990. In addition to North America, some other countries with advanced economy and technology, Japan, France, Italy and Germany, jointly pushed forward the first wave of high-speed railway construction. As the adoption of new technology enhanced the competitiveness of the railway, market share of railway passenger transport began to rebound, economic efficiency increased, and the problem of limited transport capacity was solved. Railway construction also promotes construction of relevant industries and brought balanced development to regions along routes. New construction projects provided impetus to technical renovations of existing railway network and benefited existing facilities of these countries.

2) The second wave of high-speed railway construction (from the late 1980s to the mid-1990s)

The achievements of high-speed railway construction in Japan and France came to have impact on many other countries. The second wave of high-speed railway construction appeared in Europe in the 1990s. In this period, Japan, France, Germany and Italy made comprehensive plans for high-speed railway construction, and forged ahead into an era of system planning and construction. High-speed railway construction was not only needed by the railway department, but it was also a political demand of interconnection among regions. Energy saving and the environment protection call for development of pollution-free high-speed railway, and high-speed rail network within countries or among them came into being.

3) The third wave of high-speed railway construction (from the mid-1990s to now)

The third wave of high-speed railway construction and research appeared in the mid-1990s. Spreading to Asia, North America, Oceania, and Europe, it formed a revival movement in the field of railway transportation. Since 1992, 12 countries and regions have constructed high-speed railways, and new line lengths have added up to about 19,512 km. Among them, China has completed and put into operation about 20,000 km of high-speed passenger-dedicated lines.

Unlike the first and the second waves, countries who have taken part in the third wave of high-speed railway construction have shared some characteristics:

(1) Most countries, in the early stages of the high-speed railway construction, have formulated a national plan for it.

- (2) The governments of most countries shared the consensus that although the funds for the construction of high-speed railway is huge, from the perspective of social efficiency, energy saving, environmental pollution control, etc., construction of high-speed railway as a whole is very beneficial to society.
- (3) The high-speed railway has promoted regional interaction and balanced development. European countries have already taken the construction of high-speed railways as political a task, calling for hand-in-hand cooperation to break the bondage of boundary during construction.
- (4) Construction funds were raised through multiple financing methods, rather than national public investment only.
- (5) Technology innovation of high-speed railway has radiated to related areas.
- According to incomplete statistics, until December 2015, the world’s high-speed trains were operating on track totaling 29,890 km, covering 11 countries and regions.

Nationality	China	Japan	Germany	Spain	France	Korea	Italy
Mileage of high-speed railway (km)	20,000	2388	2311	2230	2024	420	254

4 Railway Location and Design

Railway construction is a kind of complicated and systematic engineering affecting many aspects, with lots of influencing factors and in high technology level. Linked by routes, it is a huge project containing relative majors and projects, such as economy, running performance, bridges, tunnels, rail, subgrade, and station, which needs combined and joint operation of multiple disciplines and work types, such as communication signals of station, motor vehicles, power, water supply and drainage, house building, construction organization, budget, etc. Therefore, railway location design is a systematic planning of a railway, whether constructing a new one or reconstructing an old one.

Guided by this planning, the whole railway design process must aim to achieve the best coordination, the shortest period, the lowest cost, and an optimal outcome. The work of the general designer (or the general engineer), apart from fixing lines and placing flags, is making general design plan, coordinating professional relationships, routes and station as the main body, conducting technology management, putting out operation requests, making sure jobs completed as plan, and finally, improving the quality of design outcomes.

Comprehensive railway location design, say, an overall design of railway, is an issue of underlying importance. It aims at providing quality-reliable design documents to guarantee economic benefit of railway construction investment. Since railway location design is a complex

technical job with broad affected areas, surveys should be done according to established procedures, and materials should be provided as required.

Railway location design needs two kinds of materials: economic materials (such as volume of passenger traffic, volume of freight traffic, the proportion of local traffic and direct traffic in whole traffic, freight handling capacity, etc.) and technical materials (such as terrain, geology, meteorology along railways, etc.). The economic materials and technical materials are obtained through economic survey and technology survey, respectively.

The basic tasks of railway location and design are as follows:

- (1) Plan the basic line strike and select the main technical standards for railway construction, according to the needs of national politics, economy and defense, basing on natural conditions, resource distribution, and industrial and agricultural development, etc. of regions along into consideration.

- (2) Determine spatial position of alignments according to the natural conditions of topography, geology, hydrology, and specific circumstances of villages and towns, traffic, farmland, water conservancy facilities, etc. On the premise of guaranteeing running safety, strive to improve the quality of line, reduce engineering costs, and save operating expenses.

- (3) Lay out various kinds of buildings, such as railway stations, bridges, tunnels, culverts, subgrades, retaining walls, etc., and determine their types or size to make them cooperate with each other on the whole, perform

economically, and provide the basis for the next single design.

Railway location and design must proceed by making overall plans and taking national benefit and all factors into consideration, and it must correctly handle the relationship between railway and industry and agriculture, and also the relationship between immediate and long-term development. Railway construction must match up the development of water conservancy, roads, shipping, and urban-rural construction. Sticking to the principle of frugality is also important: pay attention to standard setting, not too high and leaving space for future development as well; adopt new technology, new materials, new structures, and new equipment actively and deliberately.

Railway location must pay attention to economic benefit. It should not only consider the railway sector efficiency, and the social benefits; in the formulation of design decisions and the selection principle, it should focus on social benefits.

In railway location and design, design personnel should undertake research work seriously, earnestly complete economic surveys and other surveys on topography, geology, and hydrology, and practically select different plans and determine reasonable railway locations.

Chapter 1

Railway Transport Capacity and Construction Standards

Abstract

The chapter starts by looking at railway traffic volume. The type and availability of various categories of traffic largely determine the kinds and quantities of rolling stock and motive power, the level of track construction and maintenance, the system of operation, and, most importantly, the profitability of the system. Railway carrying capacity and railway traffic capacity are then explored, followed by high-speed railway transport capacity. Finally, railway classification and main technical standards are considered. Railway classification refers to class grade of a railway according to its role in railway network, properties, volume of long-term passenger and freight traffic, maximum allowable axle load and designed speed, etc. The railway main technical standards are basic standards, which influence the traffic capacity, construction cost, operation quality, and the selection of other equipment standards.

Keywords

Traffic volume; Railway carrying capacity; Traffic capacity; High-speed railways; Classification; Standards

1.1 Railway Traffic Volume and Design Period

The type and availability of various categories of traffic largely determine the kinds and quantities of rolling stock and motive power, the level of track construction and maintenance, the system of operation, and, most importantly, the profitability of the system.

1.1.1 The Significance of Traffic Volume

Before designing new railway or reconstruction of an existing railway, it is necessary to carry out the economic survey so that the political, defense, and economic significance of the design line is clear, and the status of the design line in the railway network is then determined as well. The economic survey can also provide overall design and various facilities design with information of passengers and freight volume. The significance of traffic volume is as follows:

(1) Designing of railway capacity largely base on the volume of passenger and freight which also has a significant impact on selecting the main technical standards. On the other hand, the capacities of passenger and freight transportation equipment are determined by the main technical standards, which should not be less than the investigated or forecasted

volume in order to meet the requirements of the national transportation.

(2) The evaluation of railway economic benefits is largely based on the volume of passenger and freight which also determines the railway operation income, transport costs, payback periods of economic efficiency, etc. Higher traffic volume means more income, lower cost, and shorter payback period. In order to achieve more railway economic benefits, it is necessary to attach great importance to the investigation and prediction of passenger and freight volume.

(3) The traffic volume is important for the selection of a route. In the location procedure, there are a lot of route schemes with different economic and technical conditions. If the traffic volume is large, it is much easier to select the route scheme with higher investment, as its operating expenses is lower than that with lower investment. If the volume is small, the possibility to select the scheme with large investment will decrease. Thus, the traffic volume is important for route selection.

Overall, passenger and freight volume plays an important role in the design of railway. If the investigated or predicted passenger and freight volume is larger than that of the actual situation, the design standard and the capacity of equipment will be unnecessarily higher than required, causing an increase of investment. Once it is put into use, due to the smaller actual volume, railway capacity is idle, investment wastes, operating income is less than expected, therefore the revenue is reduced. If the investigated or predicted volume is smaller than the reality, although the initial investment decreases, once being put into use, capacity will be saturated soon, causing the railway's premature reconstruction, the additional investment

increases. Neither of the inaccurate predictions are economical. That is why the railway design must attach great importance to the investigation and forecast of passenger and freight volume.

1.1.2 Economic Investigates and Traffic Forecasts

Railways need to forecast the type and volume of traffic that can be anticipated, the same as in many other business enterprises. It is necessary when planning a new line and when reconstructing an existing line. There must be sufficient traffic in view to give economic justification to the project (unless special reasons such as national defense arise), and it is required to assure a reasonable return based on the large investment likely to be involved. Traffic for the distant as well as for the near future should be considered.

To forecast the traffic volume, the first work is to delimit the attracting scope of the design line. Then, in the designated attracting scope, an investigation should be carried out to assure the short-term passenger and freight volume, and based on the construction plan and the economic statistics in the scope, the long-term volume can then be predicted.

1.1.2.1 Attracting Scope

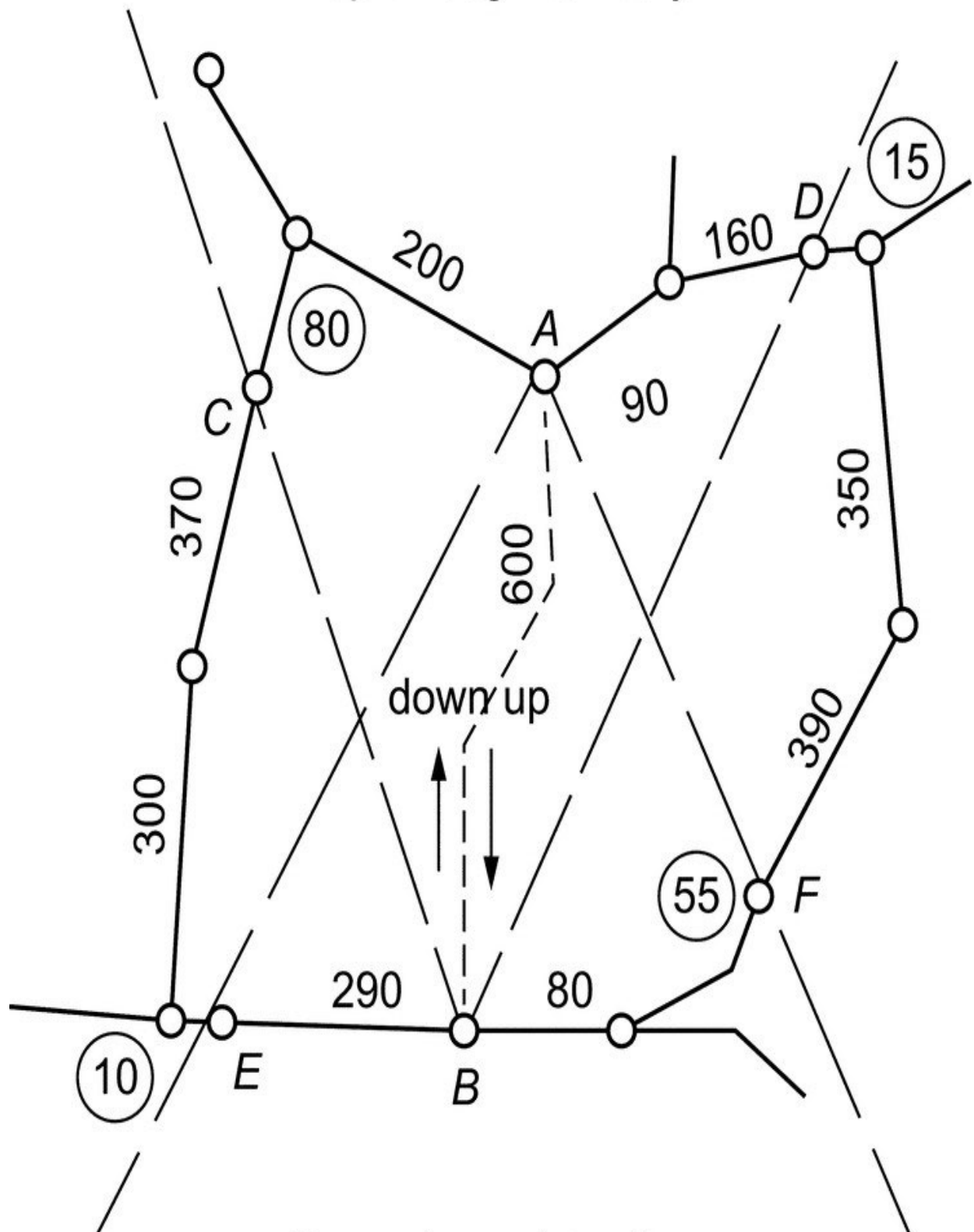
Attracting scope of the design line is the area that most traffic volume can be attracted. Traffic volume investigation and prediction are carried out in the attracting scope. According to the nature of traffic volume, the attracting scopes are divided into through attracting scope or through territory and regional attracting scope or regional territory.

(1) Through attracting scope

Through attracting scope is a favorable region to transport the passengers and freights through the design line among the railway network. As the railway traffic is calculated by kilometers, the through attracting scope can be decided in accordance with the equal-distance principle, which means the transportation distance through the design line is the shortest among all the transportation routes in the scope. The through attracting scope should be determined in the up-direction and down-direction, respectively, as shown in Fig. 1.1.

It is necessary to optimize the scope above on following considerations: make full use of lines with enough capacity to bypass restricted sections; make full use of the lines with good plane and profile condition to reduce transportation costs; make the through train with given tonnage rating to avoid changing weight of train in midway; make full use of the empty train to reduce emptying transportation, etc.

Up through territory



Down through territory

Fig. 1.1 Through attracting scope.

(2) Regional attracting scope

Regional attracting scope is the favorable area to transport the passengers and freights through the design line among the territory the line passing through. Traffic volume includes all the commodities shipped in and out, and the freights loading and unloading along the design line.

Regional attracting scope can be determined by principles of the minimum transport rate (or minimum transport distance) through the design line. Link the economic center of design line (cities, industrial and mining areas, etc.) to those of adjacent railway, and find the middle points of linked lines. The draft of regional attracting scope can then be delimited by connecting these middle points. Then, modify the draft on considering other transport conditions (such as highways and waterways), geographical conditions (mountains, rivers, etc.), and administrative divisions. When it is difficult to judge whether some economic centers near the boundary are included in the attracting scope, this can be determined by calculating the freight rate of various pathways (shipping costs of roads and railways and handling costs) in the direction of traffic flow, and the number of loading and unloading, shipping time, etc. should be taken into consideration as well. The dotted line in Fig. 1.2 shows the regional attracting scope of Line AB.

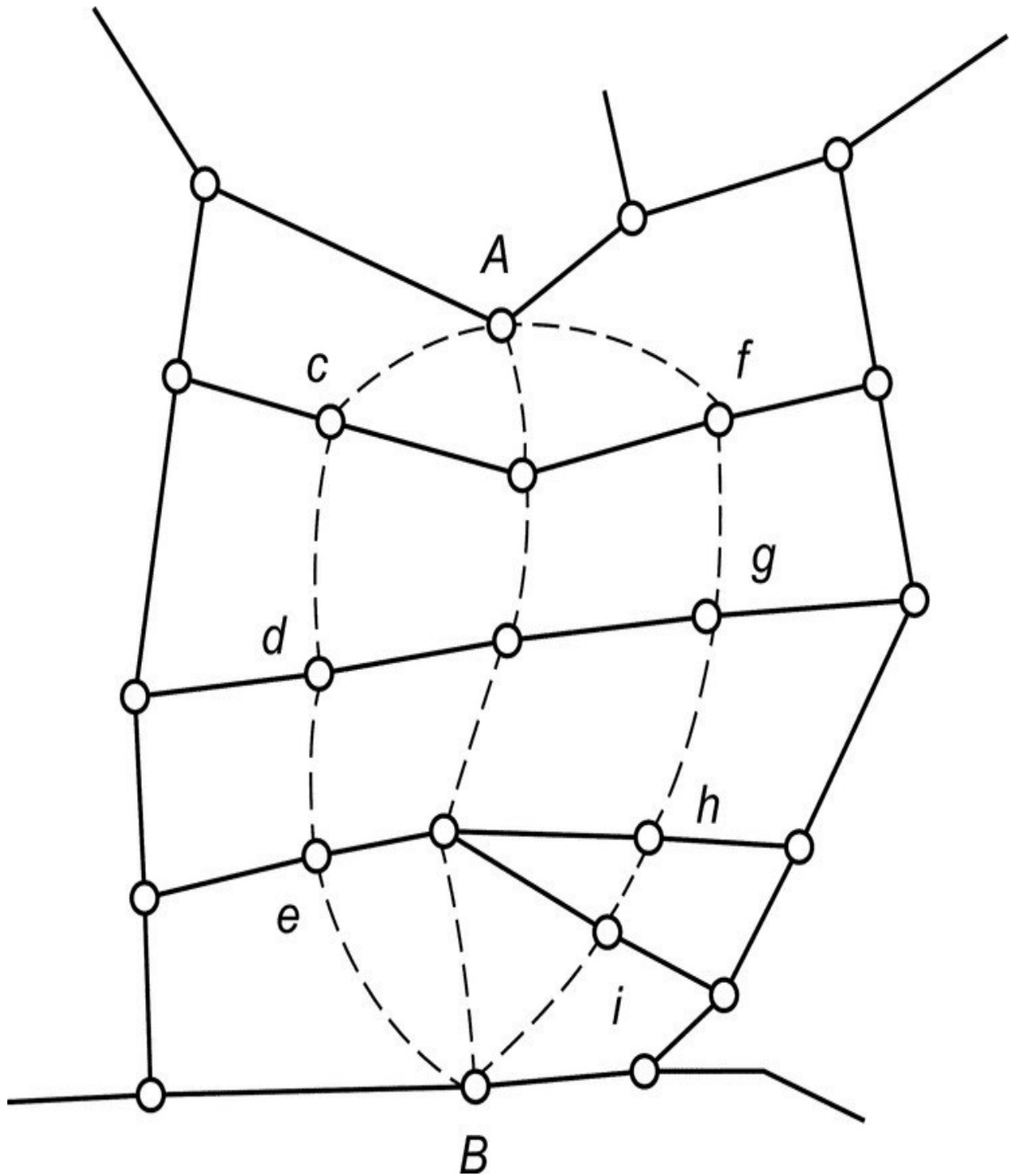


Fig. 1.2 Regional attracting scope.

(3) Influence of traffic flow

Certain well-defined transportation corridors have developed across the country. Such development, due in part to topographical features-valley routes, mountain passes, river crossings, and are also determined by the location of raw materials and of population and industrial distributions. Railway lines are frequently concentrated through certain points or gateways, partly because of geographical conditions but also because through rates are quoted via these points.

Fed by expanding urban populations, metropolitan centers have advanced toward each other in certain areas to form urban corridors, or continuums hundreds of kilometers in length. Such urban corridors demand rapid and extensive transportation services, both commuting and intercity. The problem is complicated by expensive and congested land uses.

1.1.2.2 Traffic Surveys

A traffic survey is often a necessary prerequisite for the construction of a line. Certain features of the survey are of interest to the locating engineer: the position of traffic sources helps to find the control points in order to determine the general location of the line; the potential volume of traffic is necessary in determining just what class of construction the foreseeable revenues justify. The engineer's design must include provisions for the estimated growth of traffic. It is significant to warn against overestimating future traffic or estimating too far into the future. Chinese railway suggests 5-10 years to be a reasonable estimation period, and has seen little in modern estimates and prophecies for

the future to give ones confidence in any estimate for a longer period. Nevertheless, the long-term forecast must still be made as a general guide.

However, there is a reason to build a new line. That is, the construction of additional mileage may permit entry into a thriving industrial area, or the new line may serve as a bridge to another line with which a profitable traffic interchange agreement has been completed. A newly opened mine or factory may be a sufficient motive.

Topography and terrain indicate the general territory from which traffic can be drawn. If the carrier is alone in the territory, all traffic adjacent to the line within reasonable hauling distance can be anticipated. The presence of roads at right angles to the route can widen the possible traffic area by providing feeder service. Natural barriers such as mountains and unbridged rivers will limit the possible sources of traffic.

The character of lands and communities must also be considered. Rich, fertile land can be counted on for a large volume of agricultural products. If it bears minerals or forests, traffic from these sources is a reasonable expectation. Communities dependent on forest and mineral wealth may have a rapid growth and expansion but may diminish quickly when their natural resources have been exhausted. Rural centers have a slow, steady growth, but year-to-year traffic will fluctuate with crop and market conditions. Seaports are dependent in part on the state of world business and trade. Large metropolitan centers offer a fairly constant traffic. The small community with only one industry rises and falls with the status of that particular business. Small towns with a diversity of business interests offer stable and developing traffic possibilities.

The presence or the possibility of a competing road or other types of carrier will lessen the potential traffic of a proposed area. Other things being equal, the first local carrier has advantage over other carriers with established clientele. However, if the first carrier has abused its privileges, its shippers may turn to an alternative service.

The location of station facilities with respect to the center of traffic cannot be ignored. Usually the carrier with the most conveniently located facilities will get the business. Store-to-door pickup and delivery may serve as a partial aid in overcoming the handicap of poor location.

It is helpful to examine the traffic history and experience of another road situated similarly to the proposed route.

There may be occasions when the survey data already enumerated do not give an accurate enough picture. A detailed traffic investigation should then be taken, including all the industries and their capacities, volumes of freight both in and out and the possible future growth of the industries and communities. The same information should be collected from farms, merchandise establishments, and all other agencies that can be possible sources of traffic.

1.1.2.3 Computation and Predictions of Freight Traffic Volume

The volume of through freight traffic can be predicted by analyzing the commodity supply and demand in up and down direction respectively in the attracting scope, in accordance with the national plan of commodity interflow.

The volume of local freight traffic can be estimated by the method of balance of production, marketing and transportation, and the traffic volume of each kind of goods should be estimated separately. For example, estimate the traffic volume of grains. The groupings of grains include food, feed grains, seed grain, brewing, grain for food processing, and grain reserves, etc. The total yield volume can be obtained by multiplying the sown area by the average output per unit. The total shipping volume is the difference between the yield and sales volume (positive value is shipped out amount, negative value is shipped into amount). To minus the volume transported by highways, waterways and other modes of transportation from the total, we get the railway-transported volume of grain. To summarize all volume of goods shipped, the traffic volume in up and down direction can be obtained.

The long-term prediction is lack of experience and is often carried out by comparing with the existing railway with similar conditions, using curve fitting or multiple regression analysis, and combining with the investigated results of short-term traffic volume.

By research and forecasting, summary the through freight traffic volume and local freight traffic volume can be summarized to draw the freight flow diagram, as shown in Fig. 1.3, from which the freight type, quantity and flow direction of each section are clear as well as the loading and unloading volume at each station.

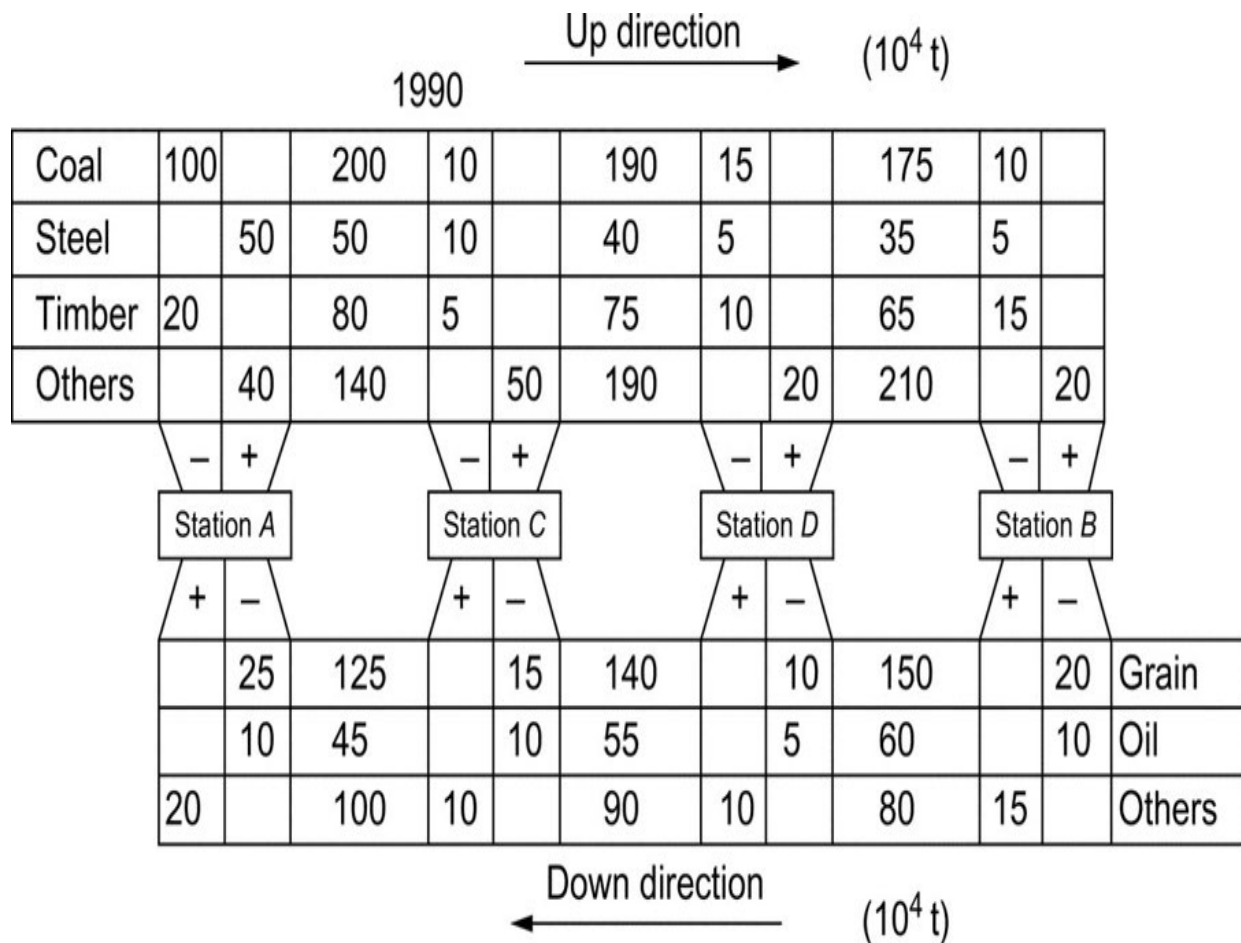


Fig. 1.3 Goods flow diagram.

1.1.2.4 Computation and Forecasting of Passenger Traffic

Generally, the proportion of through passenger traffic volume is not very large. Typical passenger flow investigation can be applied to find out the ratio of through traffic volume and local traffic volume in order to estimate through traffic volume by local traffic volume.

Local passenger traffic volume is related with the total population, the proportion of workers and miners, per capita income, number of migration factory, early settlers, as well as scenic spots in the attracting scope.

With the summary of the passenger traffic, the number of passenger trains can be estimated by the capacity of each train, or by taking the existing line with the similar conditions as a reference to proposed the passenger train number of design line.

1.1.3 Computation of Traffic Indices

Some traffic information is often a necessary prerequisite for the building of a line. Certain features of the traffic are of interest to the locating engineer, such as the traffic volume, traffic turnover, density of freight traffic, ratio of goods flow, fluctuation coefficient of traffic, and types of railway traffic. The potential volume of traffic is necessary in determining just what class of construction the foreseeable revenues justify. The engineer's design must include provision for an estimated growth of traffic.

1.1.3.1 The Traffic Volume

The railway traffic includes freight traffic and passenger traffic.

The volume of freight traffic (VFT) is the freight tonnage needed to transport by design line (or district) in a year on one direction. It is the sum of all types of goods, should be computed in up direction and down direction, respectively, shown as follows:

$$(1.1)$$

where VFT_i is the annual traffic volume of freight type i in 10^4 tons per year.

The volume of passenger traffic (VPT) is the number of passengers to be transported by design line (or district) in a year on one direction. It should be determined in up direction and down direction respectively using by means of passenger traffic prediction. For intercity rail, the statistics should be collected in peak season and ordinary days, respectively.

1.1.3.2 Traffic Turnover

Railway traffic turnover includes freight turnover and passenger turnover. It is an important indicator to measure the production capacity of rail transportation.

The freight turnover (FT) is amount of freight traffic volume completed by the design line (or district) in one year, it can be calculated using Eq. (1.2) with volume of various freights, the corresponding transport distance D_i (km) in one year in

up-direction and down-direction, Eq. (1.2) is shown as follows:

$$FT = \sum_{\text{up}} (VFT_i * D_i) + \sum_{\text{down}} (VFT_i * D_i) \quad (10^4 \text{ ton} \cdot \text{km}/\text{year})$$

(1.2)

The passenger turnover (PT) is amount of passenger traffic volume completed by the design line (or district) in one year, and can be calculated in the annual passenger traffic volume or in the number of trains. If in passenger traffic volume, it is the sum of passenger traffic volume in up and down direction times the corresponding transportation, as shown in Eq. (1.3):

$$PT = \sum (VPT_{\text{up}} + VPT_{\text{down}}) * D_i \quad (10^4 \text{ person km}/\text{year})$$

(1.3)

where VPT_{up}, VPT_{down} are annual passenger traffic volume of up direction and down direction, in 10⁴ person.

If calculated by the number of pairs of passenger trains, NP, Eq. (1.4) is applied:

$$PT = 2 \times 365 \sum (N_{PT} \times N_{PC} \times a_{SO} \times D_i) / 10^4 \quad (10^4 \text{ person} \cdot \text{km}/\text{year})$$

(1.4)

where NPT is the number of pairs of passenger trains per day; NPC is the fixed number of passengers of each passenger train, in persons; α SO is the seat occupancy coefficient, taking 0.85–0.90; D_i is the running distance of different passenger trains in the design line (km).

1.1.3.3 Density of Freight Traffic

The density of freight traffic (DFT) is the average freight turnover per kilometer of design line (or district), it can be calculated with Eq. (1.5).

$$DFT = \frac{FT}{D} \quad [10^4 \text{ ton} \cdot \text{km}/\text{km} \cdot \text{year}]$$

(1.5)

where FT is the freight turnover of design line or district (10^4 ton km/year); and D is the length of design line (or district) (km).

1.1.3.4 Density of Passenger Traffic

The density of passenger traffic (DPT) is the average passenger turnover per kilometer of railway line (or district):

$$DPT = \frac{PT}{D} \quad [10^4 \text{ person} \cdot \text{km} / \text{km} \cdot \text{year}]$$

(1.6)

where DPT is the passenger turnover of railway line or district (10^4 person km/year); D is the length of design line (or district) (km).

1.1.3.5 Ratio of Goods Flow

When the freight traffic volumes in up direction and down direction are not balanced, the traffic directions are distinguished as light goods flow direction and heavy goods flow direction. The ratio of goods flow (λ_{LH}) is the coefficient of unevenness of goods traffic in two direction, the ratio of the light traffic direction (GFLD) to that in heavier traffic direction (GFHD) as shown in Eq. (1.7)

(1.7)

1.1.3.6 Fluctuation Coefficient of Freight Traffic

The fluctuation coefficient of freight traffic is a coefficient of unevenness of freight traffic by seasons.

As the production and consumption have seasonal fluctuation, freight traffic volume of the design line is not equal in each month every year. Fluctuation coefficient of freight traffic (β) is the ratio of freight traffic volume in the busiest month to the annual average volume (Eq. (1.8)). The design line must complete the transportation task of the busiest month, so it is necessary to consider the influence of fluctuation coefficient in railway design.

$$\beta = \frac{\text{Maximum monthly freight volume in one year}}{\text{Annual average freight volume}}$$

(1.8)

1.1.3.7 Fluctuation Coefficient of Passenger Traffic

The fluctuation coefficient of passenger traffic reflects the seasonal fluctuation of passenger traffic.

As for the holidays or other reasons, the passenger traffic of railway lines not equal in each month of a year or in each day of a month, sometimes the passenger traffic volume fluctuates greatly in peak season and off season. Normally we use monthly passenger traffic fluctuation to measure the passenger traffic fluctuation of the design line. The ratio of peak day passenger traffic volume to the average daily passenger traffic volume in the month is called monthly passenger traffic fluctuation coefficient; it is shown as β_P in the equation. High-speed rail and intercity rail must complete peak-day passenger tasks, so monthly passenger traffic fluctuation coefficient should be considered in the calculation of the railway passenger capacity.

$$\beta_P = \frac{\text{Peak day largest passenger traffic}}{\text{Average week day passenger traffic}}$$

(1.9)

Based on daily passenger traffic volume, the passenger traffic fluctuation coefficient β_K is 1.0.

1.1.3.8 Types of Railway Traffic

The type of railway traffic largely depends on the type of traction power and rolling stock and motive power, the level of track construction and maintenance, the operation

system, and most importantly, the profitability of the system.

The types of railway traffic include the through freight train (FT), less-than-carload freight trains (LTL), pick-up and drop train (PUDT), fast freight train (FFT), and passenger trains.

Through train is a kind of car-load freight train. Carload (CL) freight train moves in sufficient quantities to require one or more fully loaded cars. Traffic volume specifies the minimum tonnage of a commodity that the shipper must offer to obtain the low carload rate. Most bulk commodities and large manufactured products move in carload or, when in great quantities, in trainload lots based on a minimum number of cars in the shipment (20, 30, 50, etc.).

The LTL train is the train which transports local bulk goods. It also loads and unloads goods in transshipment district, normally it runs in one section.

Less than carload (LCL) freight includes all freight in quantities smaller than that required for a carload minimum. Individual shipments must be brought to the freight house either in the shipper's own truck or in the railroad's pickup and delivery vehicle. Shipments to the same city or terminal destination are combined into cars billed to these points. Because of the costs of additional handling, railway are permitted to charge more money per ton for LCL freight than for CL freight. Independent agencies undertake to consolidate the goods of several shippers to like destinations into carloads, which then improves carload rates. The saving in freight charges achieved by the freight forwarder is then shared with the shipper.

PUDT is a train that can transport local carload freight. It can also do the drop and pull transportation and pick-up and

delivery service at transshipment station, it generally runs in one section.

Fast freight train is a train that delivers fresh or perishable goods. In order to shorten the journey time, this train rarely stops, other ordinary freight trains should stop to let this train pass without stop.

A passenger train is a train that transports passengers. The passenger train can be classified into: passenger express, through passenger express, direct passenger express, ordinary passenger trains and suburban trains according to different operational requirements, transportation organization mode, travel speed, and group situation.

The pairs of various trains should be determined based on the analysis and surveying of economic investigation.

1.1.4 Design Period

After the line is put into operation, the traffic volume of passenger and freight will grow year by year with the development of the national economy, the traffic capacity of railways should adapt to these growth. The design period of a railway is generally divided into short term and long term. Short term is 10 years since the railway line has been put into operation; long term is 20 years since it was put into operation. If necessary, may also add the initial term, it is five years since the railway line has been put into operation. Predicted volume through economic survey is applied to each term.

The design standards of the railway facilities should make the railway capacity adapting to the growth of traffic volume, and should also save the initial investment. The infrastructure of railway line, structures, and equipment which are difficult to reconstruct or expand should be designed according to long-term traffic volume and transport characteristics, and should adapt to the requirement of further development. The buildings and equipment which are easy to reconstruct or expand, should be designed according to short-term traffic volume and features, and conditions should be reserved for further development.

The equipment, such as locomotives, rolling stocks, the number of which will increase or decrease with the traffic demand, should be designed according to the traffic volume of the third or the fifth year after operation.

The operating equipment, which will increase or decrease with the traffic demand such as configuration number of EMU and installed capacity of the transformers, can be designed according to the traffic volume in the fifth year after operation.

1.2 Railway Carrying Capacity in the Section

The railway carrying capacity means, under certain operation organization conditions and certain type of rolling stock, the number of pairs of trains for single-track line or the number of trains for double-track line in one day-and-night. It can also be expressed with the number of vehicles or the tons of goods. For passenger dedicated railway, it can be expressed with number of passengers.

The railway carrying capacity is affected by the number of main lines, the length of section, plane and profile conditions, type of locomotive, signal, interlock, block equipment, maintenance facilities, and operation management, etc. The possible carrying capacity is determined by the weakest one of all facilities just mentioned. In railway design, the carrying capacity of various facilities is designed by the railway carrying capacity in section. In order to coordinate with each other, carrying capacity of the facilities should be no less than the carrying capacity in the section.

1.2.1 Train Working Diagram

Driving organizational method is embodied by the train working diagram.

The train working diagram is the technical documents to indicate the train operating in certain section and the arrival and departure time or passing through time. It rules the program required for occupation of the section by various trains, the time of starting from, passing through or arrival at each station, the operating time and dwell time at each station, etc., as shown in Fig. 1.4. The train working diagram take the advantage of coordinate theory to show the relationship of trains both in time and space, on which the abscissa presents time, a vertical line is drawn every 10 min; ordinate represents the distance, the horizontal line is drawn at each center of intermediate train distancing point. The schedule train paths with upward and downward oblique lines represent up and down trains respectively. The oblique line between two stations represents the locus of the train point, the slope represents train speed. The steeper of oblique line is, the higher of train speed will be. The intersection points between oblique and horizontal lines represent the time of starting from, passing through or arrival at each station; the period between the two intersecting points express running time of the train. For example, in Fig. 1.4, train 1248 pass C station at 0:06, and arrive at B station at 0:20, meaning the running time is 14 min. The train working diagram also shows the train dwell time in the station; as train 1248 reaches the station at 0:20 and departs at 0:27, the stopping time is 7 min.

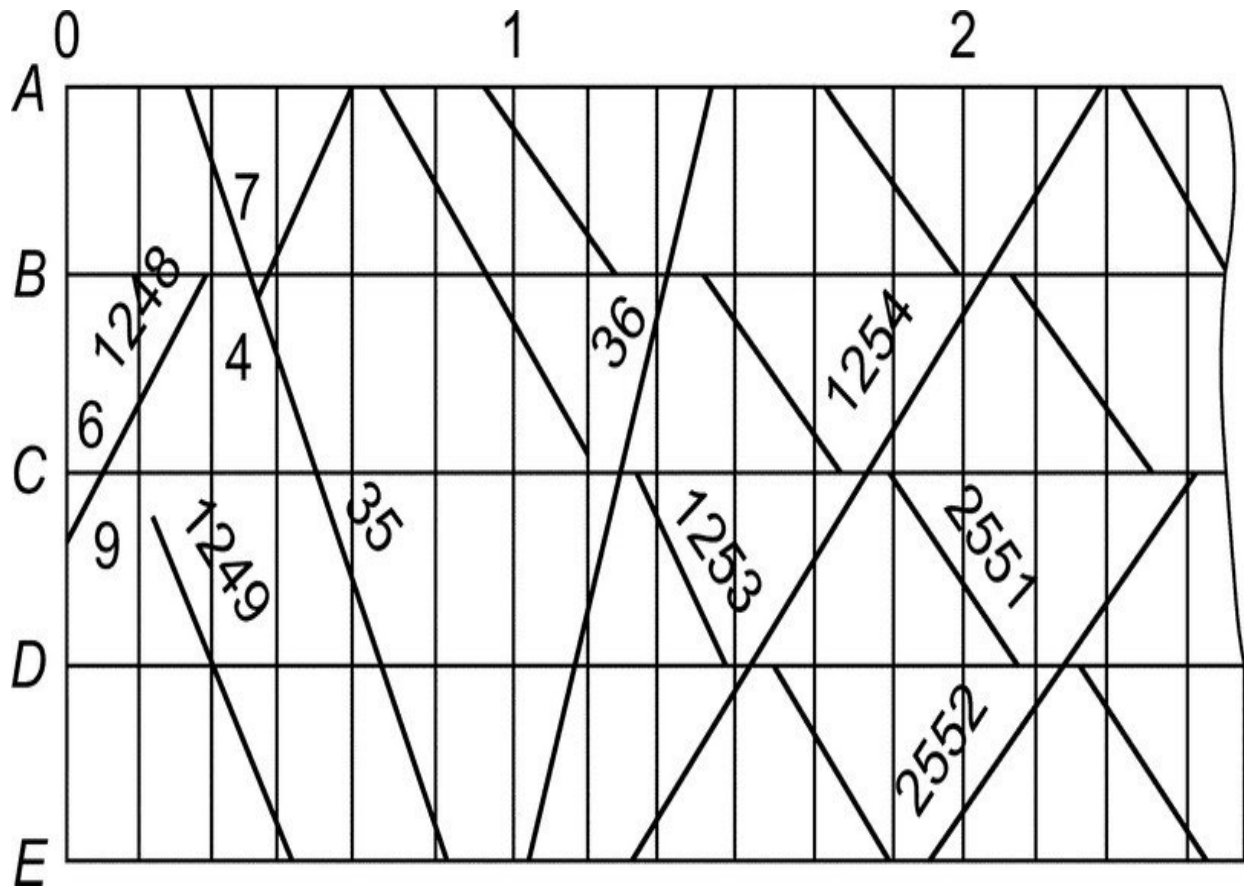


Fig. 1.4 Non-parallel train working diagram on single-line.

The up and down directions of trains in China are specified as: the direction of a railway line running away from Beijing is defined as down direction, and that running towards Beijing is defined as up direction. The numbering of up trains is arranged for even numbers, and that of down trains is arranged for odd numbers.

The railway operations use non-parallel train working diagram (shows in Fig. 1.4). As the running speed of various trains (passenger train, through freight train, pick-up and drop train, etc.) on the railway line is different, running lines of various trains in the same section are non-parallel. A non-

parallel train working diagram is only used in actual operation.

In railway design, an engineer uses the parallel train working diagram (see Fig. 1.5). In this graph, assuming all trains running on the railway line are through trains, up trains and down trains are arranged in pairs, and all trains run in the same direction and same section with the same speed, so that oblique lines (train speed lines) are parallel to each other. It is easily to calculate carrying capacity with the parallel and in pairs train working diagram.

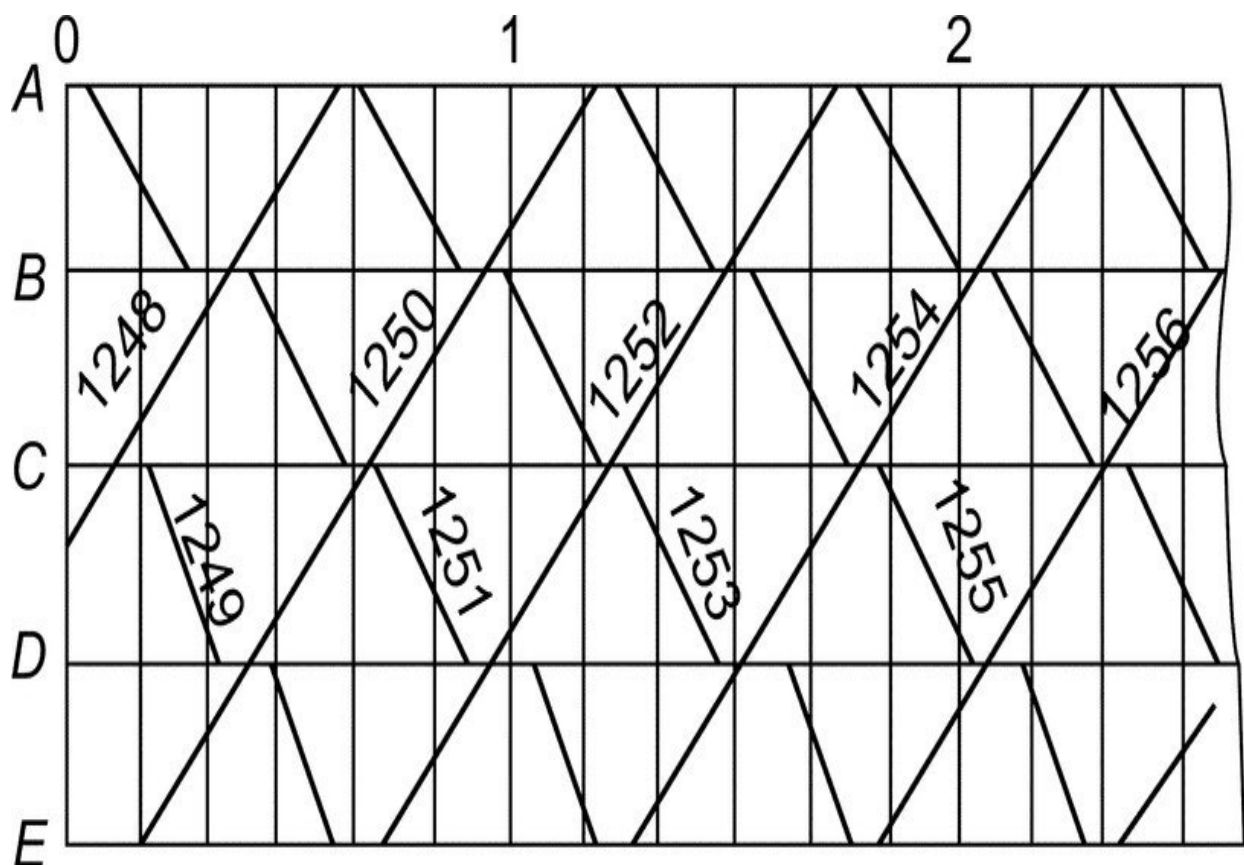


Fig. 1.5 Parallel and in pairs train working diagram on single line.

Studying the characteristic and regularity of various train working diagrams should base on parallel and in pairs train working diagram. To calculate the carrying capacity in section, the carrying capacity in the section of parallel train working diagram is calculated first. Then, the actual carrying capacity can be calculated based on that of the non-parallel train working diagram, on considering the given number of other various trains and the related removal coefficient.

1.2.2 Train Speed

Types of train speed involved in the railway line location and design are shown as follows:

(1) Design speed

The design speed is the maximum running speed of passenger train, which is determined on considering the transport demand, railway class, number of main lines, terrain conditions, type of locomotive, and plane and profile condition. It is the basic parameter for the design standards of various buildings and equipment related to the speed of passenger train. The maximum speed among all sections (for short, section-designed speed or section speed) in the design line is called design speed of the line, expressed in $V_{\max}$ (kilometers per hour).

(2) Running speed V_R

This refers to the average speed of freight train or passenger train with the assumption of non-stop in midway (excluding

dwel time at intermediate stations, and deceleration and acceleration time of train when entering and departing from stations). It can also be obtained via the traction calculation.

(3) Technical speed V_{TE}

This is the average speed of ordinary freight (or passengers) trains running in the section, excluding dwell time at intermediate stations, but on considering deceleration and acceleration time of train when entering and departing from stations. It can also be obtained of traction calculation.

(4) Travel (section) speed V_{TR}

It is the average speed of ordinary freight (or passengers) trains running in sections on considering the dwell time at intermediate stations and acceleration and deceleration time when entering and starting from the stations. It can be estimated by the travelling time of ordinary freight train (or passenger train) on non-parallel train working diagram for operational departments, or by the travel speed coefficient for design department.

The travel speed coefficient β_{TR} is the ratio of travel speed V_{TR} to running speed V_R , therefore $V_{TR} = \beta_{TR} \cdot V_R$. In railway location and design, β_{TR} can use empirical data: 0.7 for internal combustion and electric traction on single-track line; 0.8 and 0.85 for internal combustion and electric traction respectively on double-track railway.

1.2.3 Carrying Capacity in Section

The carrying capacity in section is computed on the basis of parallel train working diagram.

1.2.3.1 Period in Parallel Train Working Diagram

In a parallel train working diagram, as trains in the same direction and same section have the same speed, and the up and down trains have the same crossing and meeting mode in the same station, the running lines in the same direction are parallel. It can be seen from this parallel train working diagram that the train paths in each section are always scheduled at the same mode and periodically repeated set by set. The total occupancy time in the section by the train or by the set (up and down) is called a period in the train working diagram, expressed as TP, as shown in Fig. 1.6.

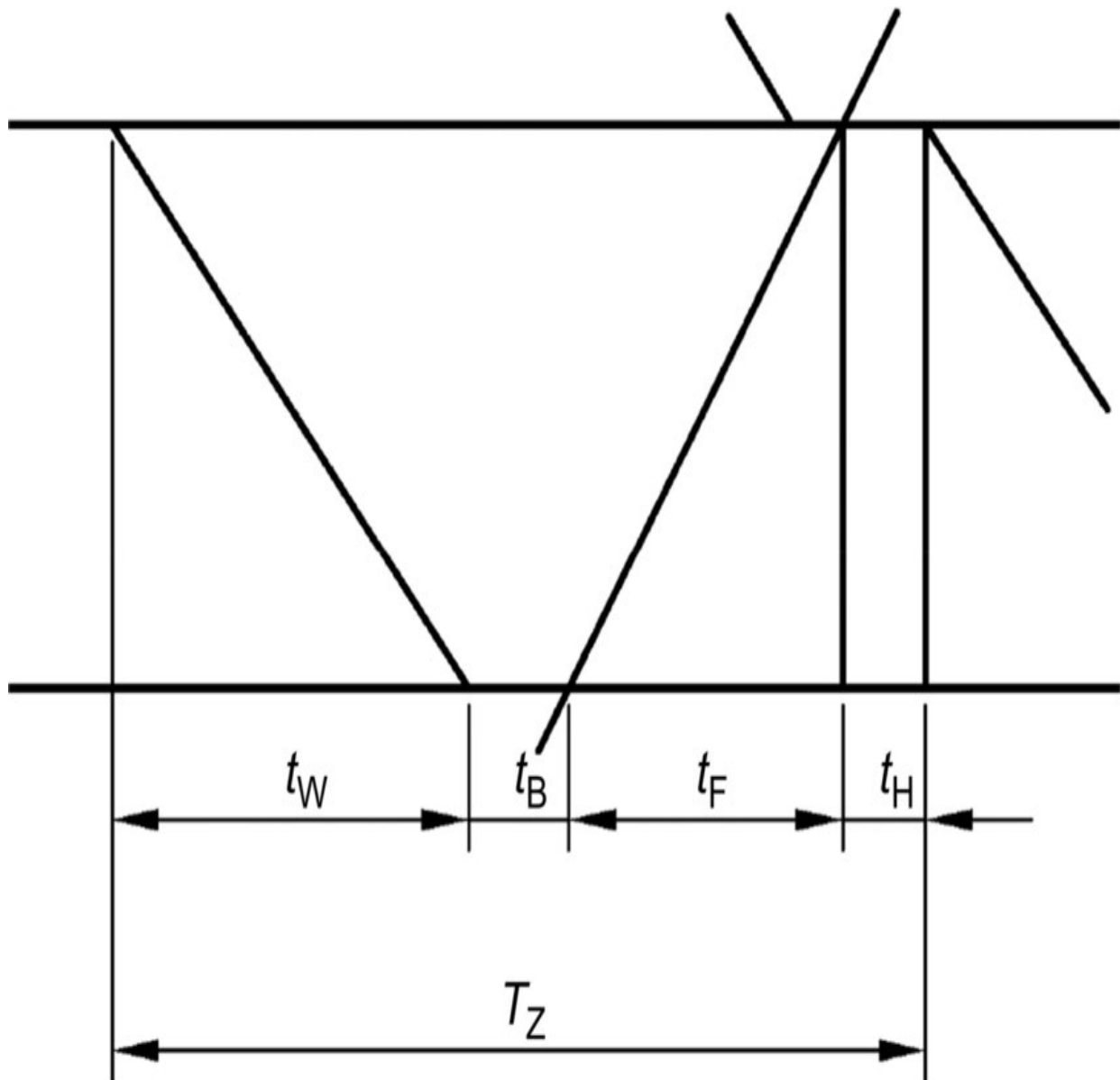


Fig. 1.6 Period in parallel train working diagram.

Due to the difference of distance between stations, running speeds, and travelling times of various sections of railway (or district), the interval time in each stations are different. Periods in the train working diagram of various sections are different, and carrying capacity of each section is also different. The section with the longest period has the

minimum carrying capacity, called the control section. It will restrict the carrying capacity of the whole line or district. The carrying capacity of the railway line (or district) should be calculated based on the period in the train working diagram of the limiting section.

1.2.3.2 Carrying Capacity of Parallel Train Working Diagram in Pairs on Single-Track Line

When the carrying capacity is on the basis of parallel train working diagram scheduled with trains in pairs on single-track line, it should be calculated with the total occupancy time in the section by a pair of trains (called the period in the train working diagram), as shown in Fig. 1.6. It includes the running time of up and down train in section (t_F , t_B), and time-interval between two trains dispatching from and arriving at stations t_A , t_C . The carrying capacity N can be calculated as follows:

$$N = \frac{1440 - T_{CMW}}{T_P} = \frac{1440 - T_{CMW}}{t_F + t_B + t_A + t_C} \quad (\text{number of pairs of trains per day})$$

(1.10)

where 1440 is the number of minutes one day and night; T_P is the period in parallel train working diagram on a single-track line; T_{CMW} is the comprehensive maintenance window

time, it is the possessive interval for comprehensive maintenance on the train working diagram as required for capital repair work, in minutes: 90 min for electric traction, 60 min for internal combustion traction; t_F , t_B are the time of train running forward and back in the section, in minutes, it is related with the distance between stations, plane and profile condition, traction mass, type of locomotive, and braking conditions. It can be calculated by the computation of train traction; t_A is the time interval between two opposite trains arriving at station not at the same time, in minutes; and t_C is the time interval for crossing of two opposite trains at station, in minutes.

t_A and t_C are related with type of signal, interlock and block, number of main lines and operation feature. In railway location design, t_A and t_C can take value in Table 1.1.

Table 1.1

Time Interval of Station Operation (min)

Block Mode	t_A	t_C
Electric staff system (brand)	5-6	3-4
Semi-automatic block	4-6	2-3

Automatic block	3-5	1-2
Automatic block and centralized traffic control	3-5	0.5-1.0

1.2.3.3 Carrying Capacity of Parallel Train Working Diagram on Double-Track Line

The carrying capacity on a double-track line should be considered on the basis of parallel train working diagram. As the up and down trains operate on different single line, the carrying capacity should be calculated by different direction, in number of trains per day.

(1) Computation with semi-automatic block

By using semi-automatic blocks, trains in the same direction can operate successively, as shown in Fig. 1.7A, the carrying capacity N is

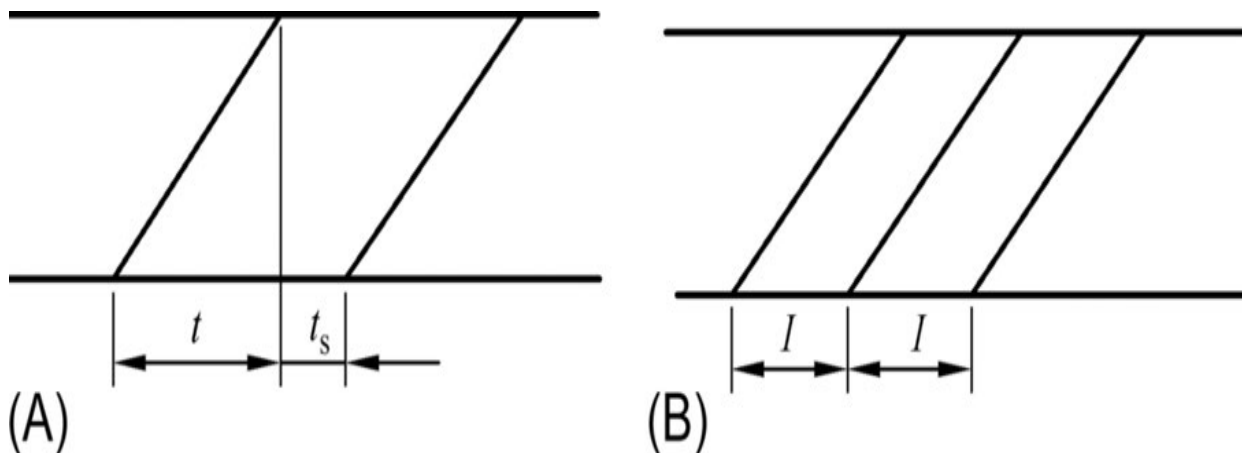


Fig. 1.7 Parallel operation diagram: (A) successive, (B) fleeting operation.

$$N = \frac{1440 - T_{CMW}}{T_P} = \frac{1440 - T_{CMW}}{t + t_S} \quad (\text{number of trains/day})$$

(1.11)

where T_P is the period in parallel train working diagram by dispatching trains in succession on double-track line (without automatic block signals); T_{CMW} is the comprehensive maintenance window time, it is the possessive interval for comprehensive maintenance on the train diagram as required for capital repair work, in minutes: 120 min for electric traction, 70 min for internal combustion traction; t is the running time of ordinary freight train in section between two stations on one direction, in minutes; t_S is the time interval for two trains dispatching in successive in the same direction, in minutes: if the previous and the following trains all pass through the front station, $t_S=4-6$ min; if the previous train passes through the station, the following one stops, $t_S=2-3$ min.

(2) Computation with automatic block

By using automatic blocks, trains run in fleeting operation in the same direction with a given time-interval, as shown in Fig. 1.7B. The carrying capacity N is

$$N = \frac{1440 - T_{CMW}}{T_P} = \frac{1440 - T_{CMW}}{I} \quad (\text{number of trains/day})$$

(1.12)

where TP is the period in parallel train working diagram with trains spaced by automatic block signals on double-track line; it equals to I; and I is called headway, it is the time-interval between trains spaced by automatic block signals in the same direction; it shall be calculated and determined according to traction and braking performance of train, train control mode, the number of arrival-departure tracks and turnout layout of stations, it generally takes 8–10 min. TCMW is the same definition and value with Eq. (1.11).

1.3 Railway Traffic Capacity

The railway traffic capacity (RTC) is the volume of freights (tons) transported by railway in one direction in a year. The traffic capacity of various periods of the design line should not be less than the investigated value.

The railway traffic capacity (RTC) can be calculated by Eq. (1.13)

$$RTC = \frac{365N_{CGFT} \times W_{net}}{10^6 \beta} \quad (\text{Million tons per year})$$

(1.13)

where W_{net} is the net loading weight of ordinary freight train; β is the fluctuation coefficient of freight traffic, it determined by the result of economic survey, normally 1.15; and N_{CGFT} is the converted number of pairs of ordinary freight trains, in pairs per day, calculated by Eq. (1.14).

The traction tonnage of fast freight trains, LTL trains, and pick-up and drop trains is usually smaller than that of ordinary freight trains, number of pairs of these trains should be converted into pairs of ordinary freight trains by the mass of loading goods. The number of pairs of converted ordinary freight trains N_{CGFT} is

$$N_{CGFT} = N_{GFT} + N_{FFT} \times \mu_{FFT} + N_{LTL} \times \mu_{LTL} + N_{PU} \times \mu_{PU} \quad (\text{pairs/day})$$

(1.14)

where N_{GFT} , N_{FFT} , N_{LTL} , N_{PU} are the number of pairs of ordinary freight trains, express freight trains, LTL, pick-up and drop trains (pairs/day); and μ_{FFT} , μ_{LTL} , μ_{PU} are the full carload coefficients, they are the ratios of tonnages of fast freight train, LTL and pick-up and drop train to that of ordinary freight train. The value can be determined by the specific conditions of design line, normally 0.75 for μ_{FFT} , 0.5 for μ_{LT} , 0.75 for μ_{PU} .

The number of pairs of ordinary freight trains (N_{GFT}) running on the design line in a day should be determined on the basis of the carrying capacity in section (N), on considering reserve carrying capacity, removing capacity occupied by passenger trains, fast freight trains, LTL, and pick-up and drop trains.

When there is no through passenger train scheduled, the number of pairs of ordinary freight trains can be calculated by the following equation:

$$N_{\text{GFT}} = \frac{N}{1+a} - (N_P \times \varepsilon_P + N_{\text{FFT}} \times \varepsilon_{\text{FFT}} + N_{\text{LTL}} \times \varepsilon_{\text{LTL}} + N_{\text{PU}} \times \varepsilon_{\text{PU}}) \quad (\text{pairs/day})$$

(1.15a)

When the design line has scheduled through passenger trains with number of NDP, the number of pairs of ordinary freight train should be calculated by equation

$$N_{\text{GFT}} = \frac{N}{1+a} - (N_P \times \varepsilon_P + N_{\text{FFT}} \times \varepsilon_{\text{FFT}} + N_{\text{LTL}} \times \varepsilon_{\text{LTL}} + N_{\text{PU}} \times \varepsilon_{\text{PU}}) - N_{\text{DP}} \varepsilon_{\text{DP}} \quad (\text{pairs/day})$$

(1.15b)

In general, the removal coefficient ε_{DP} for through passenger train is 1, the number of pairs of ordinary freight train can be calculated by formula

$$N_{\text{GFT}} = \frac{N}{1+a} - (N_P \times \varepsilon_P + N_{\text{FFT}} \times \varepsilon_{\text{FFT}} + N_{\text{LTL}} \times \varepsilon_{\text{LTL}} + N_{\text{PU}} \times \varepsilon_{\text{PU}}) - N_{\text{DP}} \quad (\text{pairs/day})$$

(1.15c)

where N is the carrying capacity (number of pairs of trains running per day); α is the coefficient of reserve carrying capacity; the reserve capacity is used to guarantee transportation requirement of military and national economy departments; to ensure the timely regulation of train working diagram in case of train delay to recover the operating order; to ensure the daily maintenance and overhaul of railway would not interfere the normal operation of the train; usually, $\alpha=0.20$ for single track, and $\alpha=0.15$ for double tracks; N_P , N_{DP} , N_{FFT} , N_{LTL} , N_{PU} are the number of pairs of passenger trains, through passenger trains, fast freight trains, LTL, and pick-up and drop trains (pairs per day); and ε_P , ε_{DP} , ε_{FFT} , ε_{LTL} , ε_{PU} are the removal coefficient for passenger train, through passenger train, fast freight train, LTL, pick-up and drop train. Removal coefficients are ratio of time for operating a pair of passenger train, fast freight train, LTL, pick-up and drop train to that of ordinary freight train. As passenger trains and fast freight trains run faster and stop less, the ordinary freight train should stop at stations to cross opposing passenger train and fast freight train, or to be overtaken by a passenger train or freight train. As LTLs and pick-up trains stop more often and with longer dwell time, the removal coefficients are greater than 1. Removal coefficient usually depends on the number of main lines, block mode, number of all type of trains, the schedule of the train working diagram, speed differences of various trains, and non-identity of various sections. Normally it uses the value shown in Tables 1.2A and 1.2B.

Table 1.2A

Removal Coefficient (min)

Number of Main Lines	Block Modes	Passenger Train	Express Freight Train	LTL	Detach
Single line	Automatic	1.0	1.0	1.5-2.0	1.3-1
Semi- automatic	1.1-1.3	1.2	1.5-2.0	1.3-1.5	The n
Double line	Automatic	Shown in Table 1.2B	2.0-2.3	3.0-4.5	2.5-3
Semi- automatic	1.3-1.5	1.4	2.0-3.0	1.5-2.0	

Note: Other block can refer to the deduction coefficient of semi-automatic block.

Table 1.2B

Removal Coefficient of Passenger Train in Three-Aspect Automatic Block Section (min)

I (min) NK (number of trains)	6	7	8	9	10
5-10			2.3-2.4	2.15-2.3	2.
11-20			2.3-2.35	2.15-2.2	2.
21-30		2.4-2.45	2.2-2.25	2.05-2.1	1.
31-40	2.5-2.55	2.3-2.35	2.1-2.15	1.95-2.0	1.
41-50	2.4-2.45	2.2-2.25	2.0-2.05	1.85-1.9	
51-60	2.3-2.35	2.1-2.15	1.9-1.95		
>61	Determined by graphical method				

Note: In four-aspect automatic block section, the values are determined by the graphical method referred to in the above table.

Substituting Eq. (1.15a) into Eq. (1.14), Eq. (1.16) is obtained:

$$N_{\text{GFT}} = \frac{N}{1+a} - [(N_P \varepsilon_P + N_{\text{FFT}}(\varepsilon_{\text{FFT}} - \mu_{\text{FFT}}) + N_{\text{LTL}}(\varepsilon_{\text{LTL}} - \mu_{\text{LTL}}) + N_{\text{PU}}(\varepsilon_{\text{PU}} - \mu_{\text{PU}})] \text{ (pairs/day)}$$

(1.16)

1.4 High-Speed Railway Transport Capacity

1.4.1 Carrying Capacity of High-Speed Railway

The carrying capacity of high-speed railway means, under certain operation organization conditions, the maximum capability of handling passing, arrival or departure of trains (or pair of trains) by all the available fixed equipment in the section in 24 hours. It is influenced by transport mode, running speed, type of train, number and dwell time of stops, schedule of train diagram, distance between stations, and skylight set.

The carrying capacity of high-speed railway can be calculated by removal coefficient method. The removal coefficient method succeeds from the traditional method of non-parallel train working diagram. It takes the occupancy capacity of a certain train as standards and to find out the equivalent relationship of occupancy capacity of other trains with the standard one. By this method, occupancy capacity of different type of trains is converted into number of standard train by normalization processing; the theoretical value of carrying capacity is then obtained.

There may be two removal coefficients of various trains in passenger districts. High-speed trains stopping at intermediate stations occupy additional time of train working diagram, resulting in removal coefficient of high-speed trains ϵ_{HST} ; between the high-speed trains and medium-speed trains, the difference of travelling speed will introduce removal coefficient of the medium-speed trains (ϵ_{MST}).

The carrying capacity of high-speed railway varies from sections, expressed with the number of pairs of highest speed-level trains. It can be calculated by the following steps:

- (1) To estimate the carrying capacity in section of parallel train working diagram; with entire high speed train;
- (2) To estimate carrying capacity in section of non-parallel train working diagram with entire high-speed trains and carrying capacity in section in peak hours; and
- (3) To estimate the carrying capacity in section with trains at different speed levels running on one line.

1.4.1.1 Section Carrying Capacity of High-Speed Railway in Parallel Train Working Diagram

$$N = \frac{1440 - T_{CMW}}{I} - \frac{60 \times L_{PTD}}{V \times I} = \frac{1}{I} \left(1440 - T_{CMW} - \frac{60 \times L_{PTD}}{V} \right) \text{ (pairs per day)}$$

(1.17)

or

$$N = \frac{1440 - T_{CMW} - T_{INE}}{I} \text{ (pairs per day)}$$

where N is the section carrying capacity of high-speed railway in parallel train working diagram (pairs per day); TCMW is the comprehensive maintenance window time; it is the possessive interval in the train working diagram. It refers to the time of stopping train from operation and cutting power in certain section and in certain period, time of which is used for maintenance of track, catenary, etc., generally takes 240–360 min; I is the headway, in minutes; LPTD is the length of passenger transport district, if the length of skylight is less than the passenger transport district, it shall take the length of skylight, in kilometer; V is the running speed (km/h); and TINE is the invalid time interval of train working diagram, in minutes, including non-passenger traffic time, time of triangle area, etc.

A passenger transport district is constituted by sections between two huge intermediate stations where there are a lot of starting and terminating passenger trains or a large number of transit trains from or to adjoining lines.

1.4.1.2 Section Carrying Capacity of High-Speed Railway in Non-Parallel Train Working Diagram, With Entire High Speed Passenger Train

As some high-speed passenger trains will stop at intermediate stations, the other will pass through, there is the difference of travelling speeds between stopping train (including various stops) and passing through trains. The difference is represented with the removal coefficient of high-speed passenger train.

The section carrying capacity of entire high speed trains can be estimate by the following equation:

$$N_{\text{HST}} = \frac{N}{\epsilon_{\text{HST}}} = \frac{1440 - T_{\text{CMW}} - T_{\text{INE}}}{I\epsilon_{\text{HST}}} \quad (\text{number of trains /day})$$

(1.18)

The maximum carrying capacity of entire high-speed trains per hour is

$$N_{\text{HST}}^h = \frac{60}{I\epsilon_{\text{HST}}} \quad (\text{number of trains/hour})$$

(1.19)

The utility carrying capacity of the section with entire high-speed trains is

$$N^u_{\text{HST}} = N_{\text{HST}} \times K_U \quad (\text{number of trains/day})$$

(1.20)

where N_{HST} is the maximum carrying capacity of the section with entire high-speed trains; ε_{HST} is the removal coefficient of high-speed trains, generally take 1.4–1.6; $\varepsilon'_{\text{GHST}}$ is the removal coefficient of high-speed train during computation time, $\varepsilon'_{\text{HST}} = 1 - \varepsilon_{\text{HST}}$; and K_U is the utility coefficient of carrying capacity in the section, generally take 0.9.

1.4.1.3 Prediction of Carrying Capacity in the Section With Trains at Different Speed Levels

The carrying capacity of high-speed railway running with high-speed trains and medium-speed trains can be calculated as follows:

$$N_m = N_{HST1} + N_{MST} = N_{HST} - N_{MST} \times \varepsilon_{MST} + N_{MST} = \frac{1440 - T_{CWM} - T_{INE}}{I\varepsilon_J}$$

(1.21)

where N_m is the maximum section carrying capacity with trains running at different speed level, which equals to the sum of high-speed trains and medium-speed trains (in number of trains per day); N_{MST} is the number of medium-speed trains scheduled in train working diagram (in number of trains per day); ε_{MST} is the removal coefficient of medium-speed trains; N_{HST1} is the number of high-speed trains can be scheduled after scheduling the specified medium-speed trains (in number of trains per day); ε_J is the average removal coefficient of high-speed train and medium-speed train, $\varepsilon_J = \varepsilon_{MST} \times \gamma_{MST} + \varepsilon_{HST} \times (1 - \gamma_{MST})$, the value can be taken from Table 1.3; and γ_{MST} is the proportion of medium-speed trains in train working diagram.

Table 1.3

The ϵ_{MST} and ϵ_J of Medium-Speed Train in Various Proportions

γ_{MST}	0.00	0.10	0.20	0.30	0.40	0.50	0.60	
ϵ_{MST}	$r_S=0$		4.57	3.89	3.28	2.98	2.79	2.47
	$r_S=0.2$		4.90	3.80	3.47	3.18	3.02	
ϵ_J	1.40	1.75	1.88	2.02	2.11	2.21	2.13	

Note: r_s in the table is the ratio of high-speed train stopping at intermediate stations.

The other symbols have the same meaning as mentioned before.

$$N_m^u = N_{HST}^u - N_{MST} \epsilon_{MST} + N_{MST} = N_{HST} K_U - N_{MST} \epsilon_{MST} + N_{MST}$$

(1.22)

where N_{mu} is the utility carrying capacity of the section running with different speed levels trains (in number of trains per day).

1.4.2 Traffic Capacity of High-Speed Railways

The traffic capacity of high speed railways refers to the number of passenger transported by the line in one year. The traffic capacity of the line with trains running with entire high speed and that with different speed levels shall be calculated respectively.

The annual volume of passengers transported by a train is

(1.23)

where β_P is the seasonal fluctuation coefficient of passenger volume; α_{TC} is the average train capacity, in number of persons per train; for 200 km/h, 300 km/h and above level trains, long EMU takes 1200 persons, short EMU takes 600 persons; and ϕ_Z is the average seat occupancy coefficient, referring to the utilization of seats; for 300 km/h and above level trains, it generally takes 0.8–0.85, 0.95 in peak hours; for 200 km/h level train, it is calculated according to the train capacity of long EMU.

The annual traffic capacity of high-speed railway ATC is obtained according to traffic capacity of all type of passenger trains.

1.4.2.1 Traffic Capacity of High-Speed Railway Running With Entire High Speed Trains

$$A_{TC} = N_{HST} \times K_U \times A_{P1}^{HST} \quad (\text{Ten thousand passengers/year})$$

where N_{HST} is the maximum section carrying capacity with entire high-speed trains (number of trains per day); K_U is the utility coefficient of carrying capacity in section, generally takes 0.9; and A_{P1}^{HST} is the annual volume of passengers transported by a high-speed train.

1.4.2.2 Traffic Capacity of Section Running With Different Speed Levels Trains

$$A_{TC} = N_{HST1} \times A_{PI}^{HST} + N_{MST} \times A_{PI}^{MST} + N_{NST} \times A_{PI}^{NST} \text{ (Ten thousand passengers/year)}$$

(1.24)

where N_{HST1} , N_{MST} , N_{NST} is the utility carrying capacity of high-speed trains, medium speed trains and normal speed trains in number of trains per day; and is the annual volume of passengers transported by a medium-speed train and a normal speed trains.

1.4.3 The Utilization of Carrying Capacity of High-Speed Railway

The utilization of carrying capacity of high-speed railway is very different from that of normal speed railway in following aspects:

(1) Because of the passenger travel characteristics, there are different periods, such as peak hours, flat peak and trough of passenger flow, so that the utilizations of carrying capacity at day and night are uneven. It is different with the normal railway as normal railway focus on balanced transportation and making full use of the section carrying capacity.

(2) Theoretically, the train working diagram of high-speed railway can be scheduled more train paths, but in practice, as the time

interval occupied by each train path is different, the actual traffic capacity completed by different lines is quite different.

(3) Comparing with the normal speed railway, the actual traffic capacity of high speed railway is much more different with the theoretical one. To complete the same volume of passenger traffic, a high-speed railway usually needs much more reserve capacity.

(4) As there are long-distance and short-distance capacity for high-speed railway, in passenger transport districts with longer journeys, especially in the district running with high-speed trains and medium-speed trains, the carrying capacity is not enough for long-distance transportation and spare capacity for the short-distance transportation. The carrying capacity for long distance can be sectioned into that for short distance, but the short-distance capacity cannot be combined with the long-distance capacity.

1.5 Railway Classification and Main Technical Standards

1.5.1 Railway Classification

Railway classification refers to class grade of a railway according to its role in railway network, properties, volume of long-term passenger and freight traffic, maximum allowable axle load and designed speed, etc.

Railway classification is the basic standard of a railway system, which determines the technical standards and equipment types. In railway design, it is necessary to determine the class of the line first, then other main technical standards and equipment types can be decided. The railway classification serves as a guide to the following stages.

Railway classification can be determined based on individual indicator or several indicators. These indicators include: railway technical characteristics and parameters, status and significance of the design line in the railway network, and volume of passenger and freight traffic of the design line, etc.

1.5.1.1 Significance of Railway Classification

As China has vast territory, complicated topography, unbalanced population and resources distribution, and the different economic conditions, railway's role in network, properties, traffic volume, safety and comfort level required are different. Therefore, railways should be classed as different grades in order to enhance the economic effectiveness and social effectiveness of railway construction.

1.5.1.2 Basis of Railway Classification

Basically, railway is classified according to axle load of rolling stock, maximum running speed, traffic volume of passenger and freight, designed speed, and significance of design line.

(1) Axle load of rolling stock

Axle load of rolling stock is important for railway construction. It is one of major basis to determine the designed load standard. The axle load of locomotive shall affect the power of locomotive, and train's axle load shall affect the train's load per meter. The bridge load and track type shall also be controlled by car's axle load.

Axle load of rolling stock in China are generally 21–23 ton. Axle loads with 25 ton, 28 ton, 30 ton are only applied for coal transportation lines such as Datong-Qinhuangdao railway line. Apart from a few of railways for coal traffic using fixed train set, most passenger and freight trains share the same railway network. As the axle load has the same impacts on each railway line, axle load is usually not used to classify the railway lines in China.

The axle loads of EMU in China are 14–16 t. In general, railway line for passenger traffic shall not be classified according to axle loads.

(2) The maximum running speed

The maximum running speed is one of the important indicators of railway transportation quality. It affects the traveling time of passenger and freight trains, traffic capacity and the using condition of rolling stock. It also affect construction cost, expenditure for buying rolling stock, locomotive energy consumption, transportation cost, investment effectiveness, etc. The running speed is limited by the power of locomotive, structure of rolling stocks, standards of alignment and track, level of signal facilities, traffic control and organization, etc. The maximum speed is a major technical parameter to determine the radius, the length of transition curve, the minimum length of straights and curves, and the radius of vertical curves. It is also important for determination of the type of track.

No matter what transportation mode a railway line shall take, the designed speed of passenger trains is one of the important factors for classifying railway grade.

With the development of economics, people's living standards are improved, the demand of improving train speed, saving traveling time of each person increases. Meanwhile, the railway faces the fierce competition from other transportation modes, so improving speed is also an requirement. In the past 10 years, the improvements of the technical level of railway equipment and rolling stock technology help the increasing of train speed. In 1994, Guangzhou-Shenzhen quasi-high-speed railway line was put into operation. Since 1996, China's main railway lines have been sped up several times and successively high speed trains were put into use; the maximum speed had reached 140–200 km/h in that time. With the completion of the Qinhuangdao-Shenyang Dedicated Passenger Railway Line and Beijing-Tianjin Intercity Railway Line, China has mastered the supporting technology of construction of 200–350 km/h high-speed railway, especially in the design of line, bridges and culverts, roadbed, track, etc. According to the plan of the Ministry of Railways, the total size of 30,000 km of fast transportation network should be completed by 2020, as well as the design speed of mixed passenger and freight railway (for short, line of mixed service) being anticipated to reach the highest speed of 160–200 km/h.

Improving the quality of rail transport is the main objective of the development of the railway. In the freight-traffic-majored railway, that is to improve its freight transport capacity; in the passenger major railway, that is to increase its operation speed; in mixed passenger and freight trains, that is both to improve the freight through capacity and to increase the operation speed. Therefore, no matter what mode of railway lines, the designed speed is the main factor of railway classification.

Britain, Japan and other railway developed countries set the maximum speed as the one of the main indicators of railway classification. Germany, France, Japan and other high-speed railway developed countries set the speed as the one of the main indicators of high-speed railway classification, railways whose speeds greater than 200 km/h is classified as high-speed railway. In recent years, China was gradually set the speed as one of the main indicators to classify railway.

(3) Annual Volume of Passenger and freight traffic

Annual volume of passenger and freight traffic is one of the major factors for classifying railway grade. Railways are built to satisfy the needs of local transportation first. Annual volume of passenger and freight traffic is the basis for designing railway, the basis for evaluation of economic effectiveness, and an important factors for determination of route alternative.

The annual volume of passenger and freight traffic shall affect the track-train interaction, track distortion, even the service life of facilities. In general railway investment, cost of railway traffic and traffic revenue are decided by annual volume of passenger and freight traffic.

Moreover, the annual volume of passenger and freight traffic is the crucial for the design of railway capacity, it has significant impact on the engineering investment, transportation costs and income of design line. Therefore, to ensure that the same service life, larger capacity is necessary when using high standard technical equipment.

For these reasons, under the same service life, equipment with high standards should be applied in the railway lines with large traffic volume.

(4) Significance of the design line and its role in the railway network

Railway plays a very important part in land transportation system. Railways can provide reliable, economical, and rapid movement for all types of commodities, especially bulk freight, or for any other stuff moving in large volumes. Passenger should move with comfort and reasonably high speed. Railways share in the efficient handling of mass commutation traffic. Even for short haul and merchandise traffic, the railway can provide a service that is prompt, reliable and economical.

Even in some under-developing regions where the traffic volume is very small, industrial development can be promoted and a prosperous economy created by building railways, so in these areas, railways also play an important role.

The railway has an important position in inland transport, in order to develop the economy, railway construction in undeveloped areas with small traffic volume is able to promote the economy. Once a railway has been built in these areas, traffic volume increasing will improve the economic benefit of railways. Therefore, the significance of railway line and the role of the line in railway network should be set as an important factor for railway level classification. The role and significance of railway should be related to the economic development of all regions. Normally, the main railway lines in railway network, are significant for connecting the national economic areas (include connecting and across national economic zone), and it promotes economic and cultural communication and development as well, especially for economically backward area. Railway lines that link the economically developed areas mainly point to those who link coastal economically developed areas or large cities with strong economic strength (such as municipalities, large industrial cities, etc.). In economically developed regions, passenger and freight traffic volume are large, so a double-track railway should be constructed or at least designed. Railways connecting important cities generally refers to railways connecting the capital city or the economically developed prefecture-level cities; if the traffic volume is large, such railways should be classified as high-level railways. However, in some capital city or prefecture-level city in western China, such as Qinghai, Tibet, etc., although the annual volume of passenger and freight traffic is relatively small, but on considering its role in the railway network, it can also be built as a high-level railway.

It can be seen that the railway significance as an important factor of China's railway classification is consistent with national conditions in China. The line significance can be

evaluated by developing planning, role in the railway network, and the impacts on the connected cities, the development of the local economy and regional culture, etc.

In summary, railway grades in China should be classified by passenger and freight traffic, and its characteristics (speed, transporting tasks, weight), etc.

1.5.1.3 Railway Classification Method

Railways could be classified to various grades according to a single factor or multiple factors synthetically. These indicators include the railway technical characteristics and parameters, status and significance of the design line in the railway network, and the volume of passenger and freight traffic, etc.

In some countries, such as Germany, France, the USA, Russia, and UIC, railways are classified in single factor methods. The other countries, railways are classified in multiple factors synthetically, such as Britain, Japan and China.

Germany, France and the International Union of Railways classified the railway into several grades by the axle load of trains. French railways are classified into three grades depending on maximum axle load (16 t, 18 t, 20 t), German railways are classified into ten grades depending on maximum axle load (16 to 22.5 t) and the maximum allowable weight of the train per meter (5.0 to 8.0 t/m), International Union of Railways are classified into three grades depending on maximum axle load (16–20 t).

In U.S.A., railways are classified into 4 grades depending on the density of freight traffic (1 Mt-km/km–20 Mt-km/km); In Russia, railways are classified into 4 grades according to annual volume of passenger and freight traffic (5–20 Mt).

Countries such as Britain and Japan classify railways into several grades by multiple indicators. UK classified railway into 16 grades according to train speed (80–200 km/h) and annual traffic volume (2–12 Mt).

In Japan, narrow gauge railway are classified into 4 grades by annual traffic volume (5 Mt–20 Mt), speed (85–110 km/h) and axle load (14–18 t); Japan Shinkansen railways are all high-speed railways.

In China, before 2000, apart from Guangzhou-Shenzhen quasi-high-speed railway, most of railways are classified into 3 grades depending on annual volume of passenger and freight traffic, its impact on railways network. After 2000, with the planning and construction of passenger dedicated line and high speed railway, the transportation nature of China's railway was developed from the only mode of mixed service for passenger and freight traffic to multiple modes with both mixed service for passenger and freight traffic and passenger dedicated line, etc. Railways should be classified according to annual volume of passenger and freight traffic, role in railways network, and maximum designed speed.

1.5.1.4 Railway Classification in China

Now, China's railways are mainly three types of lines for passenger dedicated traffic, lines of mixed service for passenger and freight traffic and lines of freight traffic, according to the impact that the lines have on railway networks, main transportation characteristics, main transportation work, designed speed of passenger train, and volume of passenger and goods traffic, etc. These three types shall be divided in eight grades, such as High-speed line, rapid-speed line, fast line of mixed service, Class I-IV, and heavy haul railway. The passenger train maximum design speed and (or) freight train maximum design speed for each class are limited as well.

(1) Passenger Dedicated Lines

A passenger dedicated line refers to the standard gauge railway in the railway network dedicated for passenger transportation, and the train can run with 200 km/h or the higher speed in the in sections. The class of a newly built passenger dedicated line (or district) can be classified into high-speed railway and fast-speed railway according to its role in network and design speed.

1) High-speed railway

A passenger dedicated railway with maximum designed speed of 250 km/h and above, which plays an important role in railway network, is classified as a high-speed railway.

A high-speed railway is usually built in developed regions which have dense populations and large volumes of passenger traffic. It links the political center and economic center, which has particularly important political and economic significance. On high-speed lines, passenger trains could run in the speed of 250 km/h and above in main section, and the minimum headway time reaches 3 min. The seating capacity could be up to 1600 persons per train, the maximum traffic-carrying capacity could be 2×32,000 persons or over.

The transport organization of high-speed railway can employ the mode on the matching principle of high speed trains and crossing-line trains, and should consider the compatibility of mixed operation of different speeds on the same track. As for the new 300–350 km/h high-speed passenger line, in line passenger train should use the MU with the speed of 300 km/h or over, crossing-line trains should use the MU with the speed of 200 km/h or over.

2) Fast-speed railway

Fast-speed railways serves as auxiliary and connecting lines for local regions with the designed speed lower than 250 km/h.

In China, fast-speed lines can be also classified into fast-speed trunk line for passenger traffic and inter-city line according to different impact on fast railway network, transport demand, and servicing area.

(i) Fast-speed trunk line

A fast-speed trunk line shall be built in a developed economy, densely populated region where there is a heavy volume. It generally links provincial capital cities, big or medium-sized cities; play an important political and economic part. The designed speed is 200 km/h or above. The major task of express passenger railway is transfer passenger, the train can running at 200 km/h or above in the main section, minimum running interval of the train decrease to 3 min, the train density will up to 20 per hour, train seating capacity can reach to 1600 people/per train, maximum transport capacity an hour will reach 2×22,000 people, it can use for large, fast, and high-density transport.

The transport organization can employ the mode of trains in this line and over-line trains from other lines running on the same line. For a newly designed railway line with speed of 200–250 km/h, an crossing-line train's speed cannot be lower than 160 km/h.

(ii) Inter-city railway

Inter-city railway is generally built in some developed economy zone, linking main cities in the zone. Trains can run with speed of 160 km/h, 200 km/h or over on main sections.

Intercity rail lines still operate commuter trains and provide suburban services in the zone.

The intercity railways can be classified into single intercity railway and duplex intercity railway. For single intercity railway, only two terminations have the economy passenger traffic demand; a duplex intercity railway connects several cities and there is the demand of economy passenger traffic between each two cities.

The ministry of railways, P.R.C., has planned several rapid-speed regional networks, such as Bohai sea zone, YangZi river delta zone, Zhujiang river delta zone, Jing-jin zone, etc. Industrial integration of urban agglomeration in the region is greatly accelerated, so cities in the region will have a large demand of passenger and freight transportation. In order to use the land resources in the area more efficiently, to protect the ecological environment, and to share the pressure of road transportation and urban hub, it is necessary to construct public transportation system with fast speed and large capacity, that is, intercity rail system.

(2) Railway of mixed service for passenger and freight traffic

A railway carrying both passenger and freight traffic is classified as railway for mixed passenger and freight traffic, for short, is called a railway of mixed service.

Railways of mixed service are also divided into fast line of mixed service and ordinary line of mixed service.

1) The fast line of mixed service

A fast line of mixed service shall be built in a developed economy region with large volume of passenger traffic and freight traffic. It is mainly for passenger transportation and also some fast freight trains. The maximum designed speed of passenger trains is 200 km/h, and the maximum designed speed of freight trains is 120 km/h.

2) The ordinary line of mixed service

Railways of mixed service for both passenger and freight traffic with 160 km/h or lower designed speed of passenger train, 120 km/h or lower of freight train are called the ordinary line of mixed service. Ordinary railways of mixed service for passenger and freight traffic can be classified as 4 grades of Class I, Class II, Class III, and Class IV.

The class of a new line or reconstructed railway should be determined according to its role in railway network, properties, designed speed of passenger train, and volume of passenger and freight traffic.

Class I Railway: Play a trunk part in railway network, and the volume of short-term traffic is no less than 20 million tons.

Class II Railway: Play a linking and auxiliary part in railway network, and the volume of short-term traffic is less than 20 million tons and larger than 10 million tons.

Class III Railway: Serve for a local zone, and the volume of short-term traffic is less than 10 million tons and larger than 5 million tons.

Class IV Railway: Serve for a local zone, and the volume of short-term traffic is less than 5 million tons.

The annual volume above is the summation of freight traffic in heavy direction and converted volume of passenger traffic. A pair of passenger train per day is converted as 1 million ton of freight.

The railway classification of mixed service lines can be no difference on the whole line, or varies in districts. For a very long line, if the natural conditions, economic conditions, and traffic volume varies in districts, it can be classified as different grade in different districts. But neither too many grades nor short districts is preferred.

(3) Freight railway

The railways dedicated for freight transport in railway network, whose axle load is 25 tons or above, train tonnage rating is 10,000 tons or above, and annual transportation capacity about 100 million or above, are always operated with heavy haul traffic.

Railways for freight traffic have usually been built in zones of raw materials – forests, coal deposits, oil fields, and ranges of iron and copper ore. These railways are applied for mass goods transportation, bulk goods transportation. The traffic volume of a single ride can be above 5000 tons, total mass can reach 10,000–20,000 tons, and axle load is usually 30 tons.

In most countries, such as the USA, Germany, Russia, and Japan, freight railways are generally classified by volume of freight traffic, and take the volume of freight traffic as an important factor for railway classification.

Based on the practical experience of railway heavy haul traffic, heavy haul railway is classified into three grades according to the total goods traffic density and total passing weight in one direction:

Class I heavy haul railway—annual volume passing one km should be no less than 8 million tons·km/km.

Class II heavy haul railway—annual volume passing one km should be 6–8 million tons·km/km.

Class III heavy haul railway—annual volume passing one km should be 4–5 million tons·km/km.

1.5.2 The Main Technical Standards

Railway main technical standards are basic standards types of railway facilities, which shall have obviously influence on the traffic capacity, construction cost, operation quality, and the selection of other equipment standards.

1.5.2.1 Items of Main Technical Standards

The main technical standards shall be determined after economic comparisons which figure out the project role in railway network, transport demand, engineering specification to meet the demand of travel time target.

The main technical standards of railway of mixed service for passenger and freight traffic shall include the followings: numbers of main lines, ruling grade, minimum radius of curvature, available length of arrival and departure line, traction types, types of locomotives (freight, passenger, and for future), tonnage rating, locomotive routing, and type of blocking.

The main technical standards of railway for passenger traffic shall include followings: designed speed, distance between centers of main line tracks, minimum plane curve radius, maximum gradient, available length of arrival and departure line, EMU type, train operation control mode, train operation command mode, and minimum headway.

Among these standards, numbers of main tracks, maximum grade (or ruling grade), minimum radius of curvature, available length of arrival and departure line belong to engineering standards, that are very difficult to reconstruct them; others belong to facility standards, that can be changed easily with the increasing of traffic. The decisions for selection of main standards should be made or suggested.

All standards shall be systematically designed and coordinated. The main technical standards of railway shall be selected according to design principle of system optimization based on the role that the design line plays in the railway network, topography along the railway, geological condition, traffic capacity and transport demand.

1.5.2.2 Selection of Main Technical Standards

The selection of main technical standards should be done by means of social/economic comparison of alternatives.

(1) Designed speed

The designed speed refers to the maximum operating speed among all sections, expressed with V_{max} (km/h), which is also a basic parameter for the design of related buildings and facilities. The designed speed of high-speed railway and intercity railway should be determined based on its significance, traffic demand, project condition, etc. Designed speed of mixed service railway for both passenger and freight traffic should be determined based on traffic demand, railway grade, number of main lines, topographic condition, locomotive type, and alignment condition. In general, designed speed of passenger train, for high-speed line, is 250 km/h and over, for fast-speed line, is 200 km/h and over; for mixed service of passenger and freight traffic, is 160 km/h and lower.

(2) Number of main lines

The main line refers to the line linking and passing through all stations. In terms of the number of main lines, railways can be divided into single line railway, double line railway,

or multiple line railway. In a single line railway, there is only one main line. Only one train shall be allowed to enter a section or a block section at the same time. Only at a station can two trains meet or pass each other.

In a double line railway, there are two main lines: up direction line and down direction line. In ordinary conditions, trains run on the up direction line or down direction line separately. But at the same section or block section of the same direction line, only one train can be allowed to enter at the same time. Only at a station can two trains meet or pass each.

The high-speed railway or rapid-speed railway shall be designed as one-time-constructed double-track electrified lines. The main line shall be designed as a bidirectional operation line.

In an ordinary line of mixed service, there is a great disparity in carrying capacity between single line railway and double line railway, such as the capacity in single line is 42–48 pair per day, but it is 144–180 pair per day of double line. In general, the capacity of a double line railway is about 3–4 times that of a single-track line, and the investment cost of the former is 30% less than that of two single-track lines. The travel speed of double line is 30% higher than that of single line, and 20% lower transportation cost of double line compared to single line. From this point of view, it seems that to construct a double line is more economical than constructing two or three single track, and to add a second track to a single track is more profitable than to build another single track line. It is true for a private enterprise. But from a wider scope of the national railway, especially in developing countries where railway networks are not well established, it may not always be superior. Because, once a railway is constructed, it often attracts many industrial establishments along the line. When the additional track is laid, the factories will even more largely accumulate in the advantageous belt. Then, it may take shape of an abnormal development of the country, co-existence of prosperous zones along the railway and lands of poverty with deserted resource. Therefore, in less developed countries, especially in China, where lives the world largest population, railway network establishment is of the first importance. Before a country-wide network with adequate grid is formed, excessive double-track roads should undergo careful consideration.

(3) Minimum curve radius

Minimum plane curve radius is the minimum one to be used in a projected railway. It not only influences some operating indicators, such as traffic safety, riding comfortableness, running quality, but also some engineering economy indicators, such as running speed, running time, investment, income of operation, and expenditure of operation.

Minimum plane curve radius shall be determined according to railway classification, designed operation speed, traffic organization mode, and safety and ride comfort level and engineering working conditions, etc.

(4) Maximum gradient

The maximum gradient is the steepest grade allowed to be used on a railway line. In some special natural conditions, the maximum gradient not only affects the alignments, line length and distribution of stations, but also directly affects traffic safety, running speed, traffic capacity, the project investment, operating expenses and the profitability of the system. It is one of overall technical standards affect the whole railway engineering. The maximum gradient shall be determined according to designed operation speed, locomotive power, traffic organization mode, safety and ride comfort level, and annual volume of traffic, etc.

In an ordinary railway line for mixed passenger and freight traffic, the maximum gradient is determined to meet the requirements of freight operation. The maximum gradient of single locomotive hauling is defined as the ruling grade, over which a tonnage train can be hauled at a given speed by a given locomotive consist or horsepower. The tonnage capability varies from each class of locomotive, but in every case, the maximum tonnage that can be pulled over the engine district by each locomotive at a given speed is set by the ruling grade. All lesser grades offer no obstacle to the movement of a train of that size. The ruling grade does not necessarily have the maximum gradient of the division. Momentum grades, pusher grades, or those that must regularly be doubled by tonnage train may be heavier. The ruling gradient (maximum gradient) of design line (or district) should be determined by the railway class, terrain category, type of traction and transport demands, and coordination with the tonnage rating of adjacent railway.

A passenger dedicated railway, using high-power, lightweight MU, has excellent traction and braking performance; high-speed trains can adapt to a large gradient operation. The mass of high-speed trains is not the major factor limiting the maximum gradient. The maximum gradient should be determined by mode of transport organizations and topographic conditions. Passenger railways in China generally employ mixed operation of high-speed trains and crossing-line medium-speed trains on the same line. The power of high-speed MU is relatively high; it can reach the maximum allowable speed in a steep slope, and it can select an appropriate power configuration basis on the speed target, so the maximum gradient of high-speed railway is mainly influenced by traction characteristics and train formation conditions of crossing-line passenger trains.

(5) Available length of arrival and departure line

Arrival-departure lines are built at stations especially for train reception and departure. In order to assure the traffic safety, a train can only be allowed to stop in a limited safe area of an arrival-departure line. The available length of arrival and departure line is the maximum length that can be used for train stopping without influencing the operation on adjacent lines.

1) Railway of mixed service

In ordinary lines of mixed services, the available length of arrival and departure line will limit the length of freight trains (traction tonnage), moreover influence the carrying capacity, construction investment, cost of railway traffic, etc. The selection of available length of arrival-departure line should meet the freight traffic demand, and be coordinate with that of adjacent railway lines. It generally takes the series value as 1050 m, 850 m, 750 m, and 650 m.

The available length of arrival-departure line shall not be shorter than the length of freight train in long term design period.

For reconstruction of existing line or building a second line, if the values mentioned above lead to huge project, the available length can be determined and calculated by the actual requirement.

As the length of short-term freight train is generally shorter than that of long-term trains, if the arrival and departure track length of short term period set as the same of long-term, it will increase the initial investment, the shunting operation distance, and the operation cost, so the available length of short-term train should be set by the actual requirement.

2) Passenger dedicated railway

At present, China's passenger dedicated railway employ the transport organization mode of high-speed trains and crossing line trains operating on the same track, high-speed trains use EMU. The available length of arrival and departure track must meet requirement of the longest train stopping. The available length of arrival-departure line is composed of length of passenger platform, safety distance, distance between fouling post and insulated joint.

According to the requirements of the longest passenger train formation, the platform length shall be 450 m; on considering the errors to check speed and distance, the protection distance of driver to confirm parking point, etc., the safety protection distance should be no less than 95 m; according to maximum distance 4.85 m from the first wheel set to the head of EMU, the distance from warning mark to track section insulator is 5 m, so the available length of arrival and departure track is $2 \times (5 + 95) + 450 = 650$ m.

The available length of arrival and departure track of passenger dedicated line should not be less than 650 m.

If reserving 125 m of security walking distance at both ends of station, the available length of arrival and departure track of passenger dedicated line is: $450 + 2 \times 125 = 700$ m.

(6) Traction type

Traction type refers to the category of locomotive traction power or MU power. There are three traction types applied for railway: electric traction, diesel traction, and steam traction. The different characteristics of different traction type greatly influence the railway with respect to carrying capacity, running speed, operating conditions, and engineering and transport economy. The steam locomotive has faded out for many years, and can only been used in less important lines.

The development direction of traction will focus on the high-power electric and diesel locomotives in the future. Now, the selection of power supply for projected line is not difficult in some countries as in China and European countries. In district, where can be reached by high-tension wire, especially from hydro-power plant, electric energy is almost undoubtedly superior to any other energy supply.

1) Electric traction

Electric traction is not only the develop direction of the railway, the requirement for building environmentally friendly, resource-saving transportation, but also the power demand for high-speed train running. Electric locomotives have high thermal efficiency, thermal power is 14–18%, hydroelectric can reach to 60%. One setup can supply for longer distance without fuel supply and split water supply, and a high locomotive utilization is achieved. High locomotive power, high speed, large traction, can significantly increase the rail capacity. Without noise and pollution, cabin crew have a good working condition. Compared with diesel locomotives, locomotive cost is lower, but the electric locomotives need the catenary to receive power, have less independence, and higher investment.

To railway of mixed service, China's electric locomotive has constituted different axes and axis style of Shao-Shan locomotive series, these can be selected based on the different operating conditions.

For passenger line, high-speed railway abroad all use electric traction, in China, currently used and developed MU are all electric traction MU.

2) Diesel traction

The thermal efficiency of diesel locomotive is 22–28%. Locomotives do not need power supply equipment, and have good independence. But they consume expensive liquid fuel, locomotive structure is complicated, and the cost is higher. The traction power and efficiency in high temperature, high altitude area decrease.

For railway of mixed service, diesel locomotive such as several Dong-Feng locomotive series with different axes number and axis style, can be selected by different operating conditions.

3) Steam traction

Structure, manufacture, and maintenance technology of steam locomotive is simple with lower cost, but the thermal efficiency is lower, only 6% to 8%, and it requires water supply every 40–60 km. locomotive service time is longer, utilization efficiency is low, locomotive power is low, capacity is low, and crew working conditions is poor. China stopped producing steam locomotive in 1988, steam locomotive on the main lines have been replaced by electric and diesel locomotives, for newly built railway, except a very few low-grade lines use steam traction for transition, most in use lines use electricity or internal traction.

4) Rules for selection

Type of traction should be selected according to traction power planning, railway characteristics and natural conditions along the railway and the distribution of power resources. The main lines with large traffic volume, or lines on large slope, lines on or adjacent long tunnels should be given priority for electric traction. A high-speed railway should be designed as an electrified railway.

In regions where traffic volume is not very heavy, the cost of electrification can be postponed until the traffic amount requests. In the first period, diesel engines may be used. In many cases, the delay may be 5–10 years. The early opening to traffic will give considerable compensation to pay expense of electrification.

Economic, environmental, and energy supply factors play increasingly vital roles in the viability of systems using straight electric propulsion. The application of electric propulsion to rail technology finds utility both in the electrification of existing railroads (now diesel powered) and in the construction of rapid transit and light rail lines for urban passenger service. Electric locomotives must be considered both in terms of their traction motor characteristics and of the system of power supply and transmission to those motors.

The foregoing characteristics are of great interest to the locating engineer. The hauling capacity of electric locomotives is based not upon the maximum grade encountered but upon the profile as a whole. A grade that would require pusher engines in steam service might be overcome by an electric locomotive making additional current demands if the grade can be negotiated before the motors become too warm. Thus length of grade is an important consideration. It should not be longer than can be traversed in 1 h or less at the speed and loading for the locomotive hourly rating. It should also be followed by much easier gradients or preferably descending gradients to permit the cooling of the motors. A profile with many short, heavy grades permits a heavier tonnage per locomotive unit than one that contains a few very long grades. Electrification may well be considered as a possible alternative to grade reductions. It should not be considered as an alternative to good, careful location design. An electric locomotive turning in a good performance on a poorly located line will give a far better performance on a line with properly designed gradients.

The selection of type of locomotives should consider the requirement of traffic service with its growing needs the natural conditions to be faced. The type of locomotive should be selected to meet the traffic demand development.

In railway line of passenger traffic, a frequently used and useful system of motive power classification is by type of motor. So that it should be design straight as electrified railway. EMU (electric multiple unit) type shall comply with passenger train operation speed.

The selection of tractive energy supply is rather a matter of available energy resources. Owing to the superiority of electricity, in the countries with enough electric power supply, electric traction is almost unquestionably the best selection for major railways. Only in petroleum producing countries diesel engines may be preferable. But there still is a selection between direct diesel engine driving and electric engine supplied by power plants using oil as fuel.

In these countries or area where there is plentiful power resources, in a long run, the perspective of adopting electric traction as the dominant measure of railway tractive power is doubtless. In these areas, railway lines shall be designed for electric driven as far as possible.

This condition does not eliminate the use of diesel traction. For light traffic lines in easy topographic districts and industrial railways where the investment of electrification is not worthwhile, in some districts having enough oil supply but being remote from the reach of electricity and for shunting service, the diesel locomotives are indispensable. Furthermore, in the first period of electric railway operation, when the traffic is not so heavy, diesel locomotives may be used as a transition measure to postpone the investment of electrification. Of course, the cost of replacing the facilities in the locomotive terminals has to be considered. At any rate, the diesel locomotives are still very important.

Nevertheless, there are still places in these countries where the comparison and selection of kind of energy supply have to be made.

In the comparison, when the difference of economic and social effectiveness between alternatives is not obvious, further analyses with various matching of locomotive patterns and alignment standards should be done until the doubtless scheme of energy supply is certified.

(7) Type of locomotive (EMU)

Type of locomotives or multiple units (MU) means locomotive or MU models in the same kind of traction. It has an important influence on traffic capacity, running speed, operating conditions and the economics of engineering and transport. Since the steam locomotives stopped producing in 1980, large power electricity, diesel locomotives developed rapidly, formed 4,6,8,12 axis number series and BB, Bo-Bo, Bo-Bo -Bo, Co-Co, 2 (Bo-Bo), 2 (Co-Co) axis series (here, B and C, represent two- and three-axis bogie, respectively, and o means electricity transmission); axis of passenger and freight train are up to 900 kilowatt and 800 kilowatt, respectively; diesel is up to 613 kilowatt and 532 kilowatt, respectively. The traction performance and braking performance of locomotive has been greatly improved. The main technical parameters of China's electric power and diesel locomotives in part are shown in Table 1.4.

In order to achieve high-speed operation, the power device are mounted in each carriage to make it not only have traction, but also able to carry passengers; these passenger vehicles become motor cars. A multiple unit (MU) is composed of several powered vehicles (called motor cars) and several vehicles without power (called trailers). MU can be

classified by different methods. It is divided into electric multiple unit (EMU) and diesel multiple unit (DMU) in terms of the type of traction; it can be divided into power centralized MU and power distributed MU in terms of power distributing form; it can be divided into electric transmission and hydraulic transmission in terms of driving mode. Both ends of a DMU are usually motor cars, some with passenger compartments. EMUs are divided into centralized power and decentralized power.

Since 2003, China has produced CHR series MU with 200–350 speeds level based on the advanced technology imported from Japan, France, Germany, Canada, and other developed countries. These MUs are all electric dispersed (EMU). The main technical parameters of main type of EMUs in China are shown in Table 1.5.

The locomotive (EMU) type should be determined based on the type of tractions, transport demands, coordination with the technical standards of plane and profile, the distribution of stations and adjacent line traction quality and economic comparison. MU should be chosen for trains with speed of 200 km/h.

The selection of locomotive characteristics for railway designs is met in three phases: the wheel (axle) arrangement, braking system, and the motive power.

It is common sense that the mountain railways require suitable wheel arrangement to fit the sharp curves. On Chinese railways, for example, several types of electric engine are used and to be used. The twin-unit freight service SS4 and SS4b with Bo-Bo (2×2 bogies, each carries 2 axles) arrangement are satisfactory for mountain lines will soon be put into serial production. By using different gear transmissions, the same type of engine may be used to drive a passenger train with higher speed and lower tractive effort than it is in freight service. The locomotive is equipped with a laterally flexible middle bogie, so that it can pass the sharp curves with minimum wear on the wheel rails.

The bogies carrying three axles each cause considerable trouble to the maintenance engineers on the difficult section, such as widening of track gauge, sidewise displacement, excessive wear, and rail creeping. In addition to the inadequate bogie construction of the locomotive, the weak track structure is another important factor of the track troubles. The complaining of the steep grade even led to objection to the grade standards of the famous section from the Baoji-Qinling range of the Baoji-Chengdu railway. Actually, the expenses of changing the locomotives and straightening the track structure will only be 1/15–1/20 of the excessive investment of the flatter grade line. It is also liable to bring about landslide and environmental trouble due to the lengthened railway line in the extremely rugged mountains.

The new passenger electric locomotive SS5 is an advanced type used on lines of plain districts. The wheel arrangement is Bo-Bo and maximum speed is 140 km/h. The engine may also be used on mountain lines, but the match of tractive effort and maximum speed is not so adequate, as it is used in plain districts.

The regenerative braking technology has long been studied, but it was started only recently to apply in the SS5 engines. Actually, it is more necessary for the freight locomotives on mountain lines. Regeneration of electric power will give considerable benefit to the operating expenses.

The new high-speed electric multiple units CRH1–CRH5, CRH380, are advanced type motor cars used on high speed lines for passenger traffic. The wheel arrangement is Bo-Bo and maximum speed is 200–350 km/h.

Table 1.4

The Main Technical Parameters of China’s Electric and Diesel Locomotives in Part

Type of Traction	Locomotive Type	Application	Axis Type	Wheelbase (M)	Power (kW)
Electric	SS1	Passenger, Freight	Co-Co	4.60	3780
SS3	Passenger, Freight	Co-Co	2.3+2.0	4350	48
SS4	Freight	2(Bo-Bo)	3.00	6400	51.5
SS4B	Freight	2(Bo-Bo)	2.90	6400	50
SS6B	Passenger, Freight	Co-Co	2.3+2.0	4800	50
SS7	Passenger, Freight	Bo-Bo-Bo	2.88	4800	48
SS7D	Passenger	Bo-Bo-Bo	2.88	4800	96
SS8	Passenger	Bo-Bo	2.90	3600	99.0
SS9	Passenger	Co-Co	2.88	4800	105
HXD1	Freight	2(Bo-Bo)	2.90	9600	70/65
HXD2	Freight	2(Bo-Bo)	2.90	10,000	70/65
HXD3	Freight	Co-Co	2.88	7200	70/65
Diesel	DF4	Passenger, Freight	Co-Co	1.8+1.8	2426
DF4B	Passenger, Freight	Co-Co	1.8+1.8	2426	29.0 21.8
DF4E	Freight	2(Co-Co)	1.8+1.8	4860	22
DF6	Freight	Co-Co	1.8+1.8	2941	22.2
DF8	Freight	Co-Co	1.8+1.8	3309	31.2
DF10D	Freight	2(Bo-Bo)	1.8+1.8	4260	27.7
DF11	Freight	Co-Co	2.0+2.0	3680	65.6

HXN3	Freight	Co-Co	2.0+2.0	4660	20.0

Table 1.5

The Main Technical Parameters of EMU in China

Items	Type of EMU			
CRH1	CRH2	CRH3	CRH5	CRH380
Marshallled form	2×[2M+1T]+[1M+1T]	[4M+4T]/[6M+2T]	2[2M+1T]+2T	[3M+1T]
Seating capacity (person)	668	610	610	620+2
Marshalling quality (t)	420.4	359.7	380.0	451.0
Marshalling length (m)	213.5	201.4	200.0	451.0
Operating speed (km/h)	200	200/300	350	200
Length of the vehicle front (mm)	26,950	25,700	25,675	27,600
Length of the middle vehicle (mm)	26,600	25,000	24,775	25,000
Vehicle width (mm)	3328	3380	2950	3200
Vehicle height (mm)	4040	3700	3890	4270
Axle type of MU	Bo´-Bo´	Bo´-Bo´	Bo´-Bo´	Bo´-Bo´
Bogie wheelbase (mm)	2700	2500	2500	2700
Bogie center distance (m)	17.500	17.500	17.375	17.500
Bogie wheel diameter (mm)	915-835	860-790	860-790	890-810
Axle/Kerb weight (t)	≤16	≤14	≤14	≤17/16
Total traction power (kW)	5500	4800/7200	2400	5500
Single motor power (kW)	275	300	500	550
Tonnes-average power (kW/t)	13.08	13.34	21.05	12.19

Starting tractive effort (kN)	325	237	300	300
Starting acceleration (m/s ²)	0.5	0.406	0.406	0.6
Emergency braking distance (m)	≤2000	≤1800	≤1800	≤2000

(8) Tonnage ratings

Tonnage ratings tell us how many tons a given locomotive or locomotive consist can haul over a particular engine district. Comparative tonnage ratings over alternative routes can be a major factor in route location. In building trains, yardmasters need to know how many tons can be placed behind a given locomotive consist or what horsepower is needed to move a proposed tonnage.

Tonnage ratings are influenced by a large number of operational, technical and economic factors, such as volume of traffic, locomotive traction, available length of arrival and departure line, and strength of track structure etc.

1) Freight flow: The tonnage rating is closely related to the freight flow conditions. The railway transported mainly for large bulk goods should take a higher standard of tonnage rating. The tonnage rating should be determined by comprehensively analyzing of freights category, amount of freight, production and marketing relations, and handling and storage equipment, etc.

The more important measure of adopting the traffic demand from the speedy economic development is the important and expansion of railway network. It serves to disperse the freight and passenger flow of the existing lines and makes the industrial development evenly. The smooth success of this motion-wide project can only be obtained when the satisfactory circulation is formed.

2) Locomotive hauling capacity: When the maximum grade of design line is given, locomotive hauling capacity and loading capacity of car are the major technical factors to determine tonnage rating of freight train. To improve the tonnage rating needs the locomotives with corresponding power and sufficient braking force. There are two ways to improve the locomotive power: using high-power locomotives; and using multiple-traction of several medium-power locomotives.

The tonnage rating of a locomotive or locomotive consist is that tonnage which can be hauled at a specified minimum speed over a given territory.

For heavy freight traffic line, higher tonnage rating shall be taken. Standards of tonnage rating shall meet the requirement of goods transportation. When the maximum gradient is determined, locomotive traction and carrying capacity are main influenced factors for determining tonnage rating. In order to raise the tonnage rating, a locomotive should have enough tractive power and braking force. In order to raise the locomotive traction, there are two ways: employ high power locomotive, or multiple medium locomotives hauling.

3) Available length of arrival and departure track: Under the given carload per meter of track, the traction tonnage will limited by the available length of arrival and departure track. To improve the traction tonnage, it should set an appropriate available length of arrival and departure track. The available length of arrival and departure track of China's main railway was basically 850 m, and the corresponding tonnage rating of normal freight train is 3000–4000 tons. If the tonnage rating is larger than 4000 tons, the available length of arrival and departure track should be lengthened. For heavy hauling of 5000 tons, it is necessary to set the available length of arrival and departure track at 1050 m.

The standards as locomotive hauling capacity, the available length of arrival and departure track, and the ruling grade are the main factors affecting traction tonnage, which should be

determined with synthetic optimization method in terms of transport tasks and terrain conditions.

For a given arrival and departure line, tonnage rating can be raised by employing high power locomotive. But employing high power will increase axle load and load per meter of track. For this reason, it is necessary to use heavy track and increase live load of bridge, so that the cost of construction operation will be increased.

4) Strength of track structure: When the available length of arrival and departure track is given, for the purpose to improve tonnage rating, the heavy cars can be used to increase the carload per meter track. Using heavy cars will increase the axle load, it is necessary to use heavy track structure and increase the bridge live load grade, and affect the maintenance and handling conditions of moving and fix equipment, the project operating costs by these changes.

5) Ruling grade: Because the limiting factor on a territory is usually the ruling grade, a rating is the tonnage that can be hauled up that grade at a given minimum speed. Foregoing chapters have demonstrated that the hauling capacity of a locomotive is a function of its horsepower and tractive effort (or drawbar pull), speed, weight, and gearing, as well as a function of gradient, curvature, and weather. This suggests that a tonnage rating must be established separately for each class of motive power or consist and for each type of traffic and desired minimum speed. It will vary from district to district, depending on the ruling grade of a district. and may be modified to meet severe weather conditions.

6) Rolling stock: With the growth of traffic and the increasing locomotive power and train length in many important lines, the physical characters of rolling stock, especially of the freight cars have revealed their weakness, such as, low speed of transmitting braking force, insufficient strength of coupling devices and lack of automatic control of long freight trains. These weak points are constraining the practice of heavy train operation as well as new trunk line designs and the strengthening projects of existing lines.

Railways of several big countries operate super-long freight trains and obtain considerable economy and efficiency. However the condition in China does not demand the increment of 1500-2500 ton each train on major lines will significantly release the congested lines without much reconstruction work.

The selection of tonnage ratings should be also selected on considering the harmonization and match with the adjacent line.

In short, the conditions of automation and vehicles are limiting the railway progress and should be considered for the first stage of operation of designed lines. But the imperfection should not be the constraining factor of the long-term designs.

Even the above factors limit the increase of train weight; it is quite a task of innovation of railway facilities. Together with the weakness of automatic traffic and train control, these insufficient facilities form the major hindrance of the advancement of Chinese railway capacity. But in comparison with the achievement of economic development and technical advancement of the past years, the railway technical problem is a minor one. It is very likely that the vicious cycle will turn into a satisfactory circulation in the nearest future.

(9) Type of block

A railway line is divided into many sections or block sections by train spacing points. In a single-track railway line, the dividing points are center of home signals at the adjacent two

stations. In a double-track railway line, section is divided from station by home signals or station limit sign. In order to increase the carrying capacity of section, a station section is also divided into several block sections by the automatic through signals (Fig. 1.8), taking pillars of through signals in the same direction as demarcation points.

The method to manage trains operating in section by using of signals is called blocking mode, or blocking for short. Facilities for blocking are called block instruments.

Train operation block should be completed by station operators on duty. Train drivers can only occupy the section after they get the travel permitting certification from the station operator. The certificate that a train occupies a section is normally the permitting display of starting signal at station and through signal in section. To ensure the safety of train running in the section and increase the carrying capacity in section, drivers can only obtain the travel permitting certificate by ensuring the section free to avoid the possible conflict accidents. On the other hand, it is necessary to handle block procedures and give the offer quickly to reduce the train interval time. When using the signal displayed as permitting certificate, the certificate will be automatically canceled after the train enters the section by turning off permission display automatically. The permission displays can only open again after the train is totally out of the section and handling the next block.

There are three ways to realize blocking. They are manual block, semi-automatic block, and automatic block.

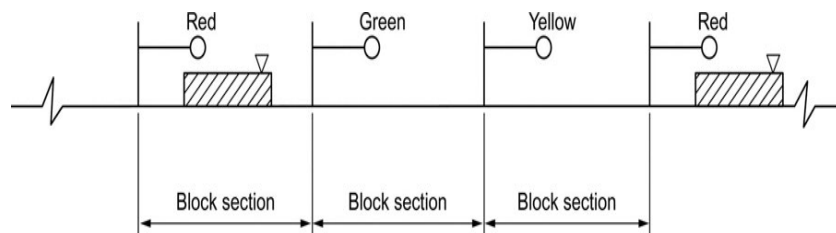


Fig. 1.8 Dividing sections with automatic block.

1) Manual block

This is a block mode using electric staff or tablet as the certificate to permit the train occupying section, and station operator checks whether section free or not.

The electric-staff block works by setting a staff instrument at each end of the station, and the two staff instruments have electrical locking relationship with each other. The certificate of train entering the section is the staff belonging to the section. If the station at either end of the section wants to get out the staff, it is necessary to make sure the section is free and get permit of the other station. When one staff has been got out, neither station can get staff out from the staff instrument so that it can make sure there is only one train running in the section. This mode is rarely used in main lines of China now.

2) Semi-automatic block

Semi-automatic block is the block mode, in which the block machine interlocks with signal. In this system, block procedures is handled by operator and driver, train depart from station by starting signal display, and the starting signal turn off automatically. Because

this mode need manipulation by station operators and also need train operation automatically, it is called semi-automatic block. The certificate of train entering the section is the starting signal shows green. As the starting signal is controlled by block machine, only the section is free and both stations have go through the block formalities, the starting signal can shows green again.

In semi-automatic block, the credentials of train entering section is signal display, it eliminate the time of drivers submit staff, thereby the operation time of train arrival and departure at station reduces, and the carrying capacity increases.

3) Automatic block

Automatic block can exchange the through signals displaying in terms of status of train running and block sections; drivers control the train running by the signal display. By automatic block, the section between two stations will be divided into several block sub-sections (shown in Fig. 1.9), so that the interval time among trains in the same direction become decreasing further. Because the signal change is totally controlled by the train with the track circuit, it is an automatic block system.

There are two automatic block modes in ordinary railway section: one is three-aspect automatic block with red, yellow, and green signals display. The red light means that the block section in the front is occupied, and train must stop; yellow light means that there is only one block section forward is free and train must decelerate; green light means there are at least two block sections are free, and trains can run in designated speed. The second one is four-aspect automatic block. It is formed based on the three-aspect by adding another yellow-green display (or yellow flash). Yellow-green display means that after the train passes through the green signal at full speed, drivers begin to decelerate the train in normal braking mode to the designated speed and pass the yellow-green signal and yellow signal, and make sure the train stops at the next red signal. Or after a train passes the yellow-green signal at full speed, the over-speed protection system decelerates the train using emergency braking, to make the train pass the yellow signal at a limited speed, and then stop at the next red signal. Therefore, the braking distance of four-aspect automatic block is the next block section. The high-speed railway reconstructed by an existing line normally uses the existing signal equipment, just adding some ancillary equipment to meet the needs of high-speed operation.

A single-track railway using an automatic block can improve the carrying capacity, but not so obviously; a double-track railway using an automatic block can reduce the interval time between two trains in the same direction to 8-10 min, while the carrying capacity will increase to 100 per day or more.

A single-track railway should use semi-automatic block in long term; a double-track railway should use an automatic block. When the passenger train design speed is higher than 120 m/h, double-track railway should use speed differential automatic blocking, single-track railway should use automatic block or automatic station block. One district can only use one type of block.

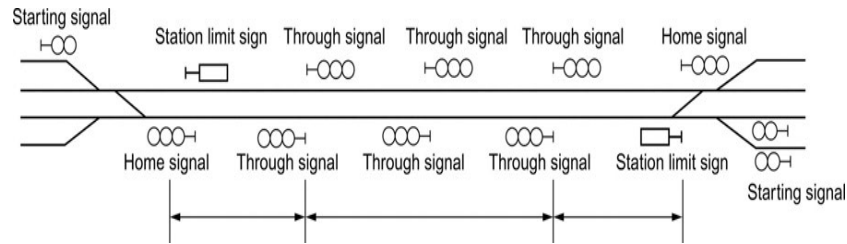


Fig. 1.9 Automatic block partitions.

(10) Train operation control mode

With the speed increasing and the traffic interval decreasing of the main line railways, it cannot meet the requirement of railway development to block by light signals. It is necessary to develop the automatic train operation control system.

To guarantee the high safety and efficiency of high speed railway, it is necessary to employ modern highly automatic signal equipment to keep the interval of the trains by fixing block sub-section. For the high speed passenger railway with speed of 200 km/h and above, signal systems should employ self-closing automatic control system, and traffic control mode should employ automatic control.

Automatic operation control system uses advanced technology as computer control, computer networks, communications and information processing to connect with trains, traction system, tracks, turnouts and other equipment or systems in order to achieve train operation control, safety protection, automatic operation, dispatching management and other tasks. So, the operation control system is crucial for the train operation control and safety protection in the whole railway system.

At present, China's railways employ the Chinese Railway Train Control System (CTCS system) which combine the common locomotive signal and the major locomotive signal with monitoring and recording devices.

High-speed dedicated passenger lines should employ operation control system (CTCS), on-board signal as the certificate for train operation. In China's railway, CTCS-2 is a train control system with track-based transmitting information, which delivering train control information by track circuit combined with balise. CTCS-3 is a train control system used to examine the track occupation condition by using track circuit method based on radio transmission information.

Based on China's current railway development, passenger railway usually employ CTCS-2 "goal - distance" continuous speed control mode. The operation control mode of a high speed trains shall use CTCS-2 train control system based on track circuit or CTCS-3 train control system based on GSM-R wireless communication transmission. CTCS-2 train control system serves as backup when CTCS-3 system is employed.

The operation control mode of 250 km/h high-speed trains uses CTCS-2 train control system.

(11) Transportation scheduling (traffic control) mode

The production activities carried out in railway transport sectors in order to control transportation and production status, to organize daily work, and to direct and to monitor

daily transportation, are referred as railway traffic control. To make sure the daily transportation and production can offer unity of command and effective monitoring, the railway transport system must implement centralized leadership and unified command. Dispatch center is the management command center of daily railway transport and producing; traffic control is the core work of a schedule agency.

To improve the passenger dedicated line transport command efficiency and automation level, an operation scheduling system should share information, reduce the labor intensity of production staff transport. A passenger dedicated line should use centralized dispatching system (CTC).

CTC is the technology equipment of dispatch center (dispatcher) which takes centralized control of the signal equipment in one section and direct control of the train. The relay interlocking of the intermediate station in the section and the automatic blocking devices in the section are combined to establish a signal communication and remote integrated system directly controlled by train dispatcher, which is called a CTC system.

CTC refers to both advanced technology equipment, and a newly organized transportation. CTC improves traffic control automation by centralized control, which guarantees the safety and efficiency of railway transportation. With the full use of through capacity of the railway, productivity and working conditions are improved.

Automatic blocking combined with centralized scheduling realizes all turnouts and signals remote control by dispatcher, strengthening the traffic organization plan and flexibility, achieving safer operation and higher through capacity.

The centralized traffic train control system has long been a mature technique in many industrial countries. Thirty years ago, computer technique came into railways as an aid to the CTC system and strongly promoted the railway operation. On Chinese railway, centralized traffic control has been successfully used in major railways. That is one of the reasons why the train frequency and efficiency in this country is among the best of the world.

If the computer aided automation was timely applied in railway operation, the train frequency and traffic capacity would further be promoted.

The wide adoption of centralized traffic control and development of computer aided automation will yield effectiveness of railway operation in many respects, such as automatic demonstration of exact train position, signal condition, record of traffic diagram, automatic warning in case of disordered condition and regulation, automatic traffic statistics etc. The timely development of advanced automatic control facilities is one of the urgent problem of Chinese railway.

The expenses of signal and communication, both investment of facilities and maintenance work are much lower in comparison with those of the permanent way and rolling stock. So that, the economic way of increasing the railway capacity and releasing tightened condition of railway network is the improvement of control system and rolling stock facilities. From the viewpoint of safety, the most reliable and advanced devices should undoubtedly be used.

(12) Minimum headway

In an automatic block district, when two or more trains are scheduled to run on the same section and in the same direction by the intervals of block district, the operation mode is called a tracking operation. The minimum headway is the time interval between trains

spaced automatically. The minimum headway should be 3–4 min, according to transport demand.

Track train intervals are determined by the automatic block signal system, train length, train speed, block section length, etc.

By the requirements of safe driving, the train tracking time interval includes the following situations:

- ① The minimum time interval for train track;
- ② The time interval of the train tracks when the main line train stop in station;
- ③ The time interval of the train tracks when the lateral line train stop in station; and
- ④ Outbound train track time interval.

The train track time intervals should meet all the above requirements of time intervals in actual operation.

Minimum headway has significant impact on a railway's carrying capacity. On a double-track railway, if the track train interval time is 8 min, the carrying capacity may be 168 trains per day; if the track train interval time is 4 min, the carrying capacity may be up to 340 trains per day.

In recent times, China's railway running for both passenger and freight trains has employed a three-aspect automatic block system, the block section and signals are designed by means of the minimum interval time as 6–10 min of track train. For high speed passenger railway, the minimum headway shall be determined according to the transport requirements, generally 3–4 min.

(13) Locomotive routing or EMU routing

A locomotive (EMU) always runs forth and back on the same line section. The regular section is called locomotive (EMU) routing, or just routing for short. The length of routing is called routing distance. Stations at the end of routing are district stations for railway line of mixed service, and depots (running depot). There are locomotive facilities at district station or EMU maintenance facilities at depot (running depot). Routing distance will affect the journey time and through speed of trains.

The district stations on railway line of mixed service are divided into locomotive depot (basic depot) and locomotive turnaround depot by operating characteristics and equipment size. The locomotive depot shall be equipped a certain number of locomotives in order to complete transfer work between adjacent routes. Here is also equipment for locomotive running preparation, inspection and repair so that locomotives attached to this depot can be prepared and repaired here, and the crew belong to this district can live and shift at this depot. Turnaround depot is located at the locomotive return station and do not equip locomotives. Turnaround depots can take over locomotive running preparation, inspection and repair, crew rest or resides.

On passenger dedicated railway, in order to take on tasks of EMU maintenance, storage, and repairing, it is necessary to lay out EMU workshops (or depot, yard). Maintenance facilities are divided into three types, EMU workshop, EMU depot, and EMU yard. EMU depot and workshops, which is allocated EMU, undertakes the repair of for level I, II, III and above, temporary repair and service (including passenger traffic service) and stabling and night parking task. EMU depot undertakes passenger traffic service, the repair of level I, II,

temporary repair and stabling for departure and arrival EMU at the passenger station where the EMU depot is located. EMU yard undertakes EMU stabling, can be equipped with service facilities (including passenger traffic service) if required.

Routing may be divided into different modes depending on type, operation mode, and crew working system, such as arm short routing, arm long routing, loop short routing, semi-loop short routing, over-long routing (over long routing living at the two end district stations, over long routing living at the middle district station, over-long routing with caboose crew system Fig. 1.10).

The distance of routing is determined by routing type and crew working time without rest. In rules, crew working time cannot be longer than 9 hours and less than 6 hours. In terms of transport conditions, distance of routing is 70–120 km for short routing, 150–250 km for long routing, and 300–500 km for over-long routing in crew pooling system.

The passenger locomotive routing is generally 500–1000 km.

EMU employs a semi-crew-looping system, and is repaired at the depot until running up to running kilometers between predetermined repairs.

The routing mode can be divided into long routing, short routing, and over-long routing. Long routing is a single routing committing by one group of crew. Short routing is a turnaround routing committing by one group of crew. Over-long routing is a single routing committing by two group of crew.

In terms of locomotive (MU) operation mode, routings can be divided into arm mode, loop mode, and semi-loop mode. Arm mode means that locomotive (MU) returned to section station should be maintained in the depot. Under loop mode, locomotive (MU) take round-trip in two adjacent routing, and is maintained on the arrival and departure track of the section station without pick the hook. Using semi-loop mode, a locomotive (MU) takes a round-trip in two adjacent routings, and is maintained in a depot on each loop.

From the crew working system, routing is divided into fixed crew system and crew pooling system. By the fixed crew system, a locomotive (MU) is driven by the fixed crew group by the principle of three fix groups (the crew system in Fig. 1.10 needs four groups). If a crew group exceeds its working time in one month, it should be changed to three and a half groups in regulation.

By the crew pooling system, locomotive (MU) does not use a fixed crew group, staging drive by different crew, corresponding with over-long routing. This mode is suit for electricity and internal combustion traction. To use over-long routing and crew pooling system can reduce non-productive residence time of locomotive (MU) in the district station, accelerated turnover of locomotive and vehicle kilometers. The daily passenger transport of locomotives (MU) can increase by 40% or more, freight transport can increase more than 8%. At present, China is actively promoting this crew system.

Routing distance is mainly determined by the routing type, and related with continuous working time and train travel speed of locomotive (MU) crew group. Actual crew working time of driving locomotives (EMU) should generally not be less than six hours, and not more than nine hours. Crew continuous working time is included in operating residence time in original section and other section, and attendance time.

Locomotive routing should be determined by traction type, locomotive type, traffic characteristics, crew systems, line conditions, combined with the railway network planning, maintenance equipment layout, and use technical and economic ratio. China's railway

locomotive should vigorously pursue long routing, implement long routing, crew pooling system, while passenger locomotive routing is generally 500–1000 km, freight locomotive routing is generally 350–500 km.

High-speed MU routing uses cyclic operation system. EMU should be inspected until its running distance reaches the standard of inspection.

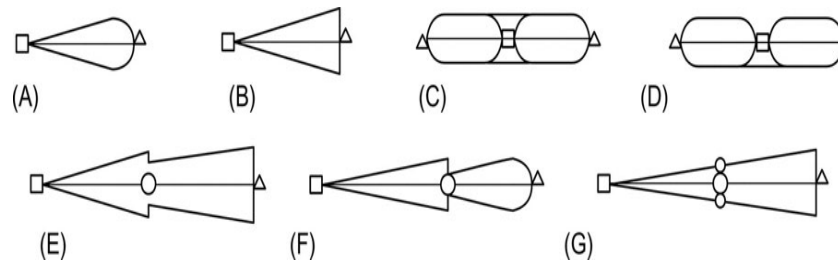


Fig. 1.10 Locomotive routing: (A) arm short routing, (B) arm long routing, (C) loop short routing, (D) semi-loop short routing, (E) over-long routing living at the two end district stations, (F) over-long routing living at the middle district station, (G) over-long routing with caboose crew system.

1.5.3 Comparison and Selection of Railway Main Technical Standards

Railway main technical standard option covers a wide range, will affect for a long time, and usually be roughly determined in the pre-feasibility study, finalized by comparison and selection in the feasibility study.

Comparison and selection of main technical standards is a complex task. With the requirement of completing the transporting task, according to condition as the function of design line in the railway network, the size and nature of transport, topography and geology and other natural conditions along the railway, resource distribution conditions, economic development and population density, the main technical of adjacent railway, the main technical standards of all possible solutions are proposed. Then, choose the best option from all the possible solutions by demonstrated the layout of railway network, regional economic development, reasonableness of technical and economic, the coordination between the main technical standards, environmental protection, and other aspects. The chosen main technical standards should comply with the following principles.

1.5.3.1 The Main Technical Standards Should Mutual Coordination

Each major technical standard should mutually coordinate with other standards, making the train quality, running speed, and the number of the train match well with each other.

Matching and coordination should consider the technical and economic feasibility. With the development of science and technology, the upgrade of equipment and improvement of traffic organization, the way of matching and coordination is also developed.

In terms of operation investment, cost of civil works is much greater than the equipment investment. According to China's railway investment analysis, the percentage of civil engineering fixed assets investment is about 85%; equipment category is only 15%, with 12% rolling stock and 3% signal system.

Therefore, under the premise of meeting the transport requirements, advanced communication and signal equipment and locomotive should be applied to make the railway engineering standards suitable for a region's natural conditions. It can also reduce the civil works, saving infrastructure investment, and improving economic efficiency.

1.5.3.2 The Main Technical Standards Should Combination by the Long and Short Term

A design line through capacity should adapt with the freight traffic volume growth. The choice of the main technical standards is necessary to meet the requirement of short term traffic volume, and adapt to the growth of traffic volume. It is required to save the initial investment and future reconstruction work.

In railway construction, the railway line engineering investment is very large, maximum gradient (ruling gradient) of railway line, the minimum curve radius and the effect length of arrival and departure track are hard to change after being completed. An improper selection can cause amounts of abandoned work, so those parameters should be selected depending on the long-term transportation needs. Locomotive (MU) is the phased investment in operation period, the cost of changing locomotive and changing the type of traction is relatively lower, the impact is small, so they should be considered to be gradually strengthened. Initial train weight is small, the train length is short, the arrival and departure track length can be shortened. In addition, the initial transport volume is small, through capacity requirement is low, the station can be spread open, block mode can be updated later. With these measurements, the initial investment decreases and economic efficiency increases.

1.5.3.3 The Choice of Main Technical Standard Should Consider the Combination of Point and Line

New line design should consider the railway network development, should solve the problem of railway network capacity coordination, point-line coordination, and the smooth transition of the design line and existing line.

The design line through capacity is generally controlled by the through capacity of railway section. Capability of other devices should adapt to the section capacity. Thus, the station capacity, electric traction support equipment capacity, locomotive maintenance capability in depot, the grouping station ungrouped capacity should coordinated with the railway section through capacity, otherwise, the small capacity equipment will limit the capacity of other equipment, the excessive capacity equipment will be idle and backlog investment.

1.5.3.4 Attention to the Role and Traffic in the Railway Network

The main technical standard selection should consider the railway network planning. For main railway lines that focus on direct transportation, main technical standard selection should consider the mass, maximum speed and the through capacity coordinating with adjacent railway, in order to reduce the frequency of train regrouping, and to keep railway network smooth.

The railway lines with large volume of passenger and freight traffic, high-level main technical standards is suggested to be applied. Therefore, the train running on it has large weight, high running speed, and large through capacity, in order to improve the operational indicators, improved operating conditions, and reduce transportation costs.

If the line is mainly for passenger traffic, large minimum curve radius, locomotive with a greater power and better braking ability should be applied to increase the running speed of passenger train, and to reduce the speed difference between passenger train and freight train, to guarantee the passenger comfort and to lessen the wheel and rail wear.

For railway lines mainly for regional economic services with small volume of passenger and freight traffic, the maximum gradient (ruling gradient) and the minimum curve radius should be suitable for the region natural conditions, to reduce the engineering investment. Distribution of stations should meet the requirement of transport capacity and the requirement of regional economic development.

1.5.3.5 Combined With the Natural Conditions Along Line

The size of maximum gradient (ruling gradient) can affect lines whether adapt to the terrain and overcome leveling obstacles. The maximum gradient (ruling gradient) should be selected to adapt the terrain, geology and other natural conditions. In difficult terrain region, small maximum gradient (ruling gradient) will increase the railway length and the number of projects; it will also destroy the natural conditions along the railway, leaving safety problems for operation in future, or even requiring a lot of money for alterations, maintenance and repair.

If the design line is a bit longer, natural conditions vary from each section, and different main technical standards can be selected for different sections.

1.5.3.6 Attention to the New Technology and New Equipment Application

Science and technology are primary for production, building railways, expanding transport capacity, reducing costs, improving economic efficiency, mainly rely on science and technology. New types of building materials and construction, advanced construction machinery and construction methods, make the construction of high bridge and long tunnels become possible. They are favorable to shorten line length, reduce the maximum gradient (ruling gradient). Advanced communication and signal equipment can improve the through capacity, also can keep the train running in a safer condition. Locomotive improving, power increasing, braking capability increasing, can elevate railway running speed and through capacity. As the development of science and technology, main technical standards can be selected based on different aspects, the design of the lines is promoted as well.

1.5.4 Synthetic Optimization Method for Railway Main Technical Standards

1.5.4.1 The Characteristics of Synthetic Optimization Method for Main Technical Standards

In order to eliminate the possible engineering deficiencies from the unreasonableness such as: (1) subjective and dictatorial decisions, (2) discordance of energy supply, rolling stock and permanent way engineering and (3) insufficient attention to technical innovation and environment protection, the “synthetic optimization” process is suggested.

The software part of the (railway) engineering project governs the hardware of detailed design and influences the construction and operation.

The idea of synthetic optimization involves: collecting the governing factors of major railway elements, for instance, type of traction energy, locomotive characteristics and alignment standards together as design variables and treat them simultaneously. The method of solution may be qualitative or quantitative. In case of selecting traction energy and number of main tracks, the traditional alternative selection or qualitative method is still useful. For the locomotive characteristics and alignment standards which can be expressed numerically, quantitative method with mathematics models and computer aided optimization will be applied.

The feature of synthetic optimization is that the solution of all the design variables of the different related specializations is accomplished in a single process. So that the resultant selected alternatives of functional element are automatically in coordination.

Any optimization design without the coordination of related functional elements, no matter how complicated its mathematical model is, should not be regarded as a synthetic one.

That is, mathematics modeling is one of the characters of quantitative synthetic optimization, but it is not the sufficient condition. On the contrary, if an engineering project is analyzed and selected from alternatives composed of different combinations of related element parts but without mathematics modeling, it is also a coordinate or synthetic optimal decision.

In the traditional process, the selection of alternatives is made among several possible schemes or machinery or even a part of certain structure. For example, in selection of railway gradient from some scheme independent from other factors, the scheme applied is only comparative better, but not necessarily the best.

Actually, many standards are interrelated, such as ruling grade, locomotive type, effective length of arrival and departure track, distance between stations (or time), block modes, etc. They all directly affect the transport capacity, so that these standards are interconnected, comprehensive affect the engineering, operation cost, and transportation capabilities. Consolidated optimization method aims to get the maximum output (transport capacity) by the minimum capital investment (construction costs, operating expenses), in order to get the best comprehensive economic benefits. This method can select several standards matching with each other in one time. By using a computer, one can automatically select optimal standards with the best techniques to increase the decision-making efficiency.

1.5.4.2 The Basic Principles of Main Technical Standards Synthetic Optimization

Some of the main technical standards are fixed equipment (civil engineering) standards, such as number of main lines, ruling grade, minimum curve radius, available length of arrival and departure track, station distance (or time), etc.; some are transportation facilities standards, such as locomotive type, block modes, etc. Fixed equipment standards need huge investment, transportation facilities standards investment is cheap, their influence extent to transport capacity have a lot of difference, which means their input-output ratio is different, coordination of the two type of standards is the most important factor to improving economic efficiency.

The development of China's mobile devices fell behind in the past, steam locomotives were applied most, the number of electricity, diesel locomotives is small, with single type, so it is the only choice to raise the fixed equipment standards (such as use small ruling gradient, etc.) in complex terrain conditions to accommodate these old equipment to meet the transport capacity needs. This design concept led more line built in difficult mountainous areas, increasing the project investment and operating expenditures, the economic efficiency is bad.

Now, China was discontinued the steam locomotive in 1988. Electricity, diesel locomotives are divided into different series by axes number and power, which gradually replace the steam locomotives. Vehicle performance has been improved then, and the advanced block modes are becoming more widely used. Design ideas should be changed into: "Line standards adapt to terrain, fixed equipment and mobile devices should coordinate with each other."

The synthetic optimization method is the new way to achieve the “fixed and mobile equipment coordinated with each other.”

(1) Variable selection

First, according to the system engineering approach and based on the systematic analysis, the factors (standard, etc.) which have a great impact on project costs, operating costs and transport capacity are determined as the design variable, such as railway grade, number of main lines, locomotive type, the number of locomotives, the effective length, the distance between stations (or time), block mode. Terrain category have a significant impact on project costs, it also can be treated as variables. The standard that can only get values in small range, such as railway grade, number of main lines, blocking mode and terrain categories can be used as reference variables.

(2) Establishment of the project costs, operating costs mathematical model

1) Civil engineering expenses mathematical model: civil engineering expenses are closely related to the variables, it can use multivariate statistical analysis to establish digital-analog. Civil engineering expenses AT should include a number of civil engineering and variables associated additional engineering fees; such as evacuation line engineering cost, steep slopes track strengthen cost; the strengthen cost of tracks related to radius and additional electric traction catenaries engineering cost, etc.

2) Locomotive, vehicle purchase costs, and freight delay loss cost: locomotive, vehicle purchase expenses AJ and AC are the function of running time, related with the relevant standards, it can be modeling by traction computational. Freight delay loss cost Ay is not only related to running time, but also related to the varieties of goods. It can be modeling by traction computation, according to the specific situation to determine whether it need to be included in the cost project.

3) Operating costs: operating costs E includes traveling expenses, start-stop related cost and line standards-related additional operating costs (such as the shoe consumption of the slope, track additional maintenance costs, limited speed time loss costs, accident loss and train assembly cost); radius related cost include wheel and rail consumption cost, limited speed cost, additional resistance cost, additional railway maintenance cost and accident loss, and fixed equipment maintenance cost etc. The mathematical model can be established by traction calculation method and operating statistics.

4) Exhibition line coefficient: exhibition line coefficient I is related with curves slope reduction, small radius sticky down slope reduction, tunnel slope reduction and station slope reduction, also related with the adaptation of slope limit and terrain, which is the function of several standards. It can be established by analyzing calculation and statistical methods.

(3) Establish mathematical model of objective function

Objective function is the indicator of economic benefit evaluation, it refers to the function of the design variables and transport capacity. The simplest objective function is to treat the engineering operating costs as economic evaluation indicator, combining one-time investment and annual expenditure

In the equation above, Δ is investment effect coefficient.

(4) Establish the mathematical model of constraint conditions

Constraint conditions refer to the restricted condition that technology and actual operation requirement have on the variables. They restrict the feasible region of variables.

1) Technology constraint: this refers to the feasible region restricted by technology, such as the bounds of effective length of arrival and departure track (L), minimum radius (R), ruling grade (I) and distance between stations (S), which can be determined depending on topographic condition, operation requirements, safety and comfort requirements, and regulations.

2) Function constraint: this refers to the transportation requirements, which is related with type and number of locomotives, ruling grade and distance between stations and signal block modes, etc. It requires the possible capability of the line (C_{xy}) larger than the required capability (CKN).

1.5.4.3 Optimization Method Selection

Optimization methods should be selected by the nature of mathematics model, the number of variables, and the stability of solutions. Because the optimization model mentioned before is extremely complex, which is an optimization problem of nonlinear mix discrete variables. Derivation of the function is difficult, as the number of variables is small, so a direct solution can be applied. In order to obtain a global optimal solution, a computer can be used for exhaustive search.

Chapter 2

Traction Calculation

Abstract

Traction calculation of train work studies the practical problems related to the train operation under various external forces, including the calculation or resolving of running speed and time, traction mass, locomotive or motor energy consumption, braking distance, etc. The first section of this chapter analyzes the formation of locomotive or EMU tractive effort, train running resistance, and braking pressure. The second section discusses the mathematical relations between acceleration (deceleration) and resultant force while three different forces are acting on a train; this is the train motion equation. We then employ the motion equation to solve some practical operating problems, such as traction mass, running speed, running time, braking, etc. Tractive tonnage is then discussed. The last section explains how to draw unit resultant force curves; then, based on this, the methods of calculating speed and running time are introduced.

Keywords

tractive effort; forces; braking pressure; train motion; tractive tonnage

Traction calculation of train work (or traction calculation for short) studies the practical problems related to the train operation under various external forces, including the calculation or resolving of running speed and time, traction mass, locomotive or motor energy consumption, braking distance, etc. In the design of a new line or reconstruction of an existing railway, these parameters are the basic data to determine the carrying capacity, traffic capacity, station distribution, grade of profile, locomotive routing, operating expenses, etc., and are important for the comparison of design schemes.

Traction calculation is based on mechanics, by combining scientific experiments and operational practice. Many calculation formulas and parameters are derived based on empirical formulas and test datum. As the actual forces exerted on the train are very complex during the movement, traction calculation only studies the external forces that affect the movement, considering the train as a mass point, which shall be concentrated at the center point of the train.

2.1 Forces Acting on the Train

The forces acting on a train include tractive force or tractive effort, train running resistance, and braking force.

2.1.1 Tractive Effort

Train resistance and other resistive forces must be overcome by a pulling force known as tractive force or tractive effort. This is a function of the locomotive horsepower. Tractive effort is an external force in the same direction as that of the train's movement, the value of which can be adjusted by the driver according to different conditions. Characteristics and problems arising from this relation will be explained primarily in terms of the electric or diesel locomotive, and the electric motor car will also be considered.

2.1.1.1 Formation of the Tractive Effort

Fig. 2.1 shows the formation of tractive effort in the transmission part of electric locomotive (or diesel-electric locomotive). The locomotive traction motor mounted on the shaft transfers the turning torque to the driving shaft through gears. The figure shows that the torque M on the shaft is the internal force for a locomotive, and it cannot make the locomotive move forward. Substituting couple F_1F_2 for torque M , we get $F_1 = F_2 = M/R$, R is the radius of the driving wheel. F_2 acts on the center of the driving wheel (i.e., wheel spindle bearings), and the force F_1 acts on the rail, attempting to push rail moving. As the rail is fixed and remains stationary, at the center O of a wheel and wheel/rail contact point A , a counter moment must be produced; its size shall be the same with M , but the direction is opposite. Force F_3 is a reactive force exerted by the bearing to the shaft, and F is a reactive force exerted by the rail to the wheel. As for the whole locomotive, F_3 is an internal force and acts on the traction wheel shaft through the bearing, while the wheel shaft, by applying force F_2 in the same value, but in a reversed direction, counter acts on the bearing, and the two forces reach a balance. Obviously, F is the only external force acting on the locomotive, which is the tractive force moving it forward. F is a counteractive force, which is produced by the adhesive effect between wheel and rail, and exerted by the rail to the circumference of the traction wheel. The integral sum of the external forces, which was exerted by the rail to the rim of driving wheel along a tangential direction, is referred to as the tractive effort at wheel rim, or tractive effort for short.

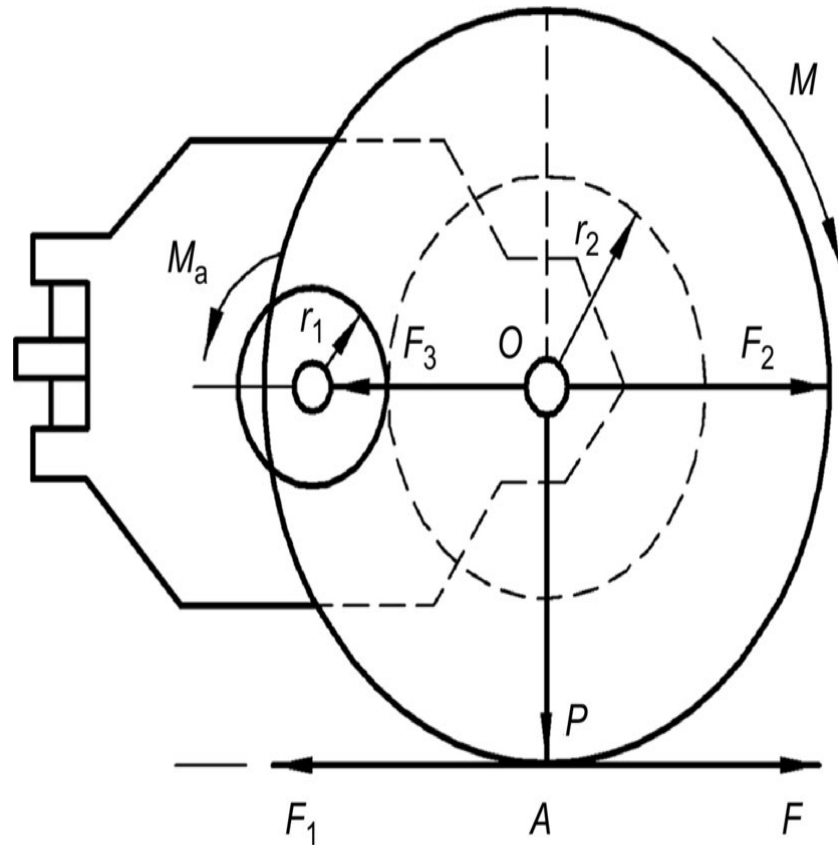


Fig. 2.1 Formation of tractive effort.

It is stipulated in the Regulations on Railway Train Traction Calculation (RRTTC) of China that the tractive effort at wheel rim is the calculation standard, meaning that the magnitude of train tractive effort is measured and represented with the tractive effort at wheel rim. Tractive effort at coupler, or holding hook traction, is the tractive force used to haul the train by locomotive (motor vehicle). Its value is equal to the wheel traction minus all running resistance of the locomotive (motor vehicle).

Sometimes, the tractive effort can be expressed as power.

Power is defined as the rate of working; work is the product of force times the distance through which that force is exerted:

$$p = \frac{\text{Force} \times \text{distance}}{\text{Unit rate of doing work}} = \frac{F \times v}{1000}$$

(2.1)

where p is the power, in kilowatt; F is the force in newtons; v is the speed in meters per second; and 1000 is the accepted unit rate of doing work, in 1000 m newtons of work per

second.

The equation is converted to kilometers per hour by converting kilometers per hour to meters per second:

$$(2.2)$$

where V is the speed in kilometers per hours; also,

$$(2.3)$$

The first form of Eq. (2.2) gives the power required to overcome a given resistance force F , the sum of train and all other resistances. The second form, Eq. (2.3), supplies the force available from a given power to overcome resistance; this is the tractive effort.

2.1.1.2 Adhesion and Adhesive Tractive Effort

(1) Adhesion Between Wheel and Rail

According to the analysis of the rigid body plane motion, when a wheel is rolling along the rail, there is no relative motion between contact points of wheel and rail at the moment they touch. The longitudinal effect between wheel and rail is static friction force in physics; its maximum value, or the “maximum static friction force” is a constant which has nothing to do with the motion. It is the product of the static friction coefficient times the vertical supporting force exerted by rail to the wheel. However, this is an ideal state, which is difficult to realize.

In fact, as there are wheel and rail deformations under the action of massive pressure, wheel and rail are not contacted at a point, there is no ideal instantaneous rotation center, and wheel tread is conical or worn profiled, combined with inevitably impact and various vibrations during the operation process. Therefore, while the wheel is rolling on the rail, there is inevitably a longitudinal and transverse sliding at the same time. That actually means it is not in a pure static friction, but in a state of “moving slightly while keeping static” or “sliding while keeping rolling,” and the maximum longitudinal horizontal force between the wheel/rail is much smaller than the physical “maximum static friction force.”

Therefore, railway traction and braking theory use the term “adhesion” instead of “static friction” when analyzing the wheel/rail longitudinal force. Accordingly, the maximum longitudinal force between the wheel and rail at adhesive state is called adhesive force, and the ratio of adhesive force to vertical load between the wheel-rail is called adhesion coefficient.

When the longitudinal force between wheel and rail exceeds the limit of maintaining adhesive state—adhesive force—a relative slip will occur between wheel and rail. The wheel will rapidly rotate under the powerful torque, but the speed of train is not high. The longitudinal force between the wheel and rail changes into the sliding friction force; its value is much smaller than adhesive force. This state is called “wheel slipping.” In a “wheel slipping” state, not only will the tractive effort be reduced sharply, but the rail and wheel will be seriously worn, so this state should be avoided.

(2) Adhesive Tractive Effort Restriction

Effective utilization of available tractive effort depends on the adhesion between wheel and rail. Adhesion is a function of the friction at the contact point of wheel/rail—that is, effective tractive effort is the production of the total weight on the drivers multiplied by the coefficient of friction between wheel and rail. The friction or adhesion factor represents the percentage of locomotive weight on the drivers that is available as effective tractive effort. In some locomotive design work, the reciprocal of the friction factor, called the factor of adhesion, is used. For $f=0.25$, the factor of adhesion would be 1.00. Adhesive tractive effort F_{μ} can be expressed as

$$(2.4)$$

where P_{μ} is the locomotive (EMU) adhesive mass (t) (adhesive mass of locomotive commonly used are shown in Tables 2.1 and 2.2; the masses of EMUs are shown in Table 2.5); g is the acceleration of gravity (m/s^2); and μ_j is the computational adhesion coefficient between wheel and rail.

Table 2.1

Electric Locomotive Characteristics

Type	Parameters					
Vcmin (km/h)	Tcmax (kN)	Ts (kN)	P, Pμ (t)	Vst (km/h)	Lloc (m)	
SS1	43.0	301.2	487.3	138	95	20.4

SS3	48.0	317.8	470	138	100	21.7
SS4	51.5	431.6	649.8	2×92	100	32.8
SS7	48.0	353.3	487.3	138	100	22.0
SS8	99.7	127.0	230.0	88	177	17.5
SS9	99.0	169.0	286.0	126	170	21.0
HXD1	70/65	494.0/532.0	760.0	2×92/2×100	120	2×17.616
HXD2	70/65	510.0/550.0	700.0/765.0	2×92/2×100	120	2×18.975
HXD3	70/65	370.0/380.0	485.0/520.0	138/150	120	20.846

Table 2.2

Tractive Performance Parameters of Diesel Locomotive

Machine Type	Items					
Vcmin (km/h)	Tcmax (kN)	Ts (kN)	P, P μ (t)	Vst (km/h)	Lloc (m)	
DF4(F)	20.0	302.1	401.7	135	100	21.1
DF4(P)	24.0	251.6	346.3	135	120	21.1
DF4B(F)	21.8	313.0	442.2	138	100	21.1
DF4B(P)	29.0	235.2	325.3	138	120	21.1
DF4C(F)	24.5	301.5	442.2	138	100	21.1
DF8	31.2	307.3	432.6	135	100	22.0
DF11	65.6	160.0	253.0	135	170	21.3

Note: Ts of DF4B(F), DF4C(F) or DF8 is limited by adhesion, the others is limited by starting current. All parameters are as before.

As the adhesion restriction, the tractive effort at wheel rim of locomotive (EMU) shall not exceed the adhesive traction which the locomotive (EMU) can produce.

A locomotive having excessive engine tractive effort capability for its weight is overdesigned and wastes engine capacity. The drivers will slip at speeds above the limiting adhesion speed and when starting. This can be overcome by adding ballast to the locomotive with an overweight frame or blocks of concrete. Idler wheels in a power truck will reduce the weight on the drivers by the amount of weight carried by the idlers.

(3) Computational Adhesion Coefficient

The coefficient of adhesion μ_j is not constant, but varies with the composition of the rail and wheel treads and the condition of the rail surface (dry or wet, clean, oily, or frosty). Values range from 0.30 for a clean, dry rail to 0.0–0.15 for a moist, greasy, or frosty rail surface. A slightly moist rail has a low adhesion value (the film of grease usually found on a rail head is spread over the tread surface by the moisture). A rail washed clean by a heavy rain has a high value. Sanding from a locomotive sandbox will increase μ_j to higher values, as will washing the rail with chemical cleaners. The latter is not presently a viable procedure, except, perhaps, on certain steep grades; increases of 17%–22% in adhesion have thus been obtained.

The adhesion coefficient μ_j between wheel and rail is difficult to calculate by using a theoretical method, which can only be expressed through an experimental formula originated from a special test. The experimental formula shows the relationship between the computational adhesion coefficient and the operating speed of train under normal adhesive condition.

Experimental formulae for computational adhesion coefficient μ_j of all kinds of locomotive are listed as follows:

Chinese electric locomotive

(2.5)

Chinese diesel-electric locomotive

(2.6)

where V is the running speed, in kilometers per hour.

Recent locomotive models, through better control of wheel slip, offer adhesion potentials of 22%–24% or more. Some slip always occurs between the wheel and rail. The difference between wheel circumference speed and rail speed is thought to lie between 0 and km/h to avoid excessive slip and loss of traction.

Slip reduction is accomplished by any one of several methods that monitor individual axle-motor speeds: apply sand automatically and adjust the generator or alternator output momentarily to bring the axle speed to a nonslip condition. One system measures ground speed with a small Doppler radar unit for comparison with motor speed by use of electronic solid-state sensors.

An aid in slip reduction is continuous welded rail (CWR), which gives a smoother, uninterrupted support to wheel treads. Trucks designed to maintain a more nearly equal weight on each axle also help. Series-parallel-connected DC motors, now in extended use, adjust current demand more readily to conform to traction availability for more uniform wheel rotation. A possible future use of AC motors may also improve adhesion under conventional wheel tread conditions. Higher adhesion permits more tonnage per locomotive unit.

A certain amount of slip can be expected as normal. Speed tapes derived from driving wheel revolutions have shown a taped distance of 1%–10% or more greater than the actual kilometer post distance traveled by the train.

At the present time, the series of CRH EMUs which are put into use in China are developed on the basis of the introduction of foreign advanced technology; The traction characteristics of EMUs refer to relevant foreign technical standards. The experimental formulas which are used to calculate the adhesion coefficient of high-speed train EMUs in foreign countries are listed as follows.

(2.7)

(2.8)

$$\text{Germany (dry rail)} : \mu_j = 0.116 + \frac{9}{42 + V}$$

(2.9)

$$\text{Germany (wet rail)} : \mu_j = 0.7 \times \left(0.116 + \frac{9}{42 + V} \right)$$

(2.10)

where V is the running speed in kilometers per hour.

2.1.1.3 Traction Characteristic Curve

Traction characteristic curves show the relationship between tractive effort at wheel rim (vertical axle) and the running speed (horizontal axis), usually obtained by test. Traction characteristic curve varies with traction type; if the traction type is the same, traction characteristic curves of various locomotive-hauled train (EMU train) has few differences. Traction characteristic curves for each type of motor are decided by the manufacturer. The following section will analyze the features of classification with examples of electric locomotive, diesel locomotive, and high-speed EMUs.

(1) Electric Locomotive

1) Motor Types

Economic, environmental, and energy supply factors play increasingly vital roles in the viability of systems using straight electric propulsion. This electric propulsion is applied both to the electrification of existing railways (now diesel-powered) and in the construction of rapid railway lines, and transit and intercity rail lines for urban passenger service. Electric locomotives must be considered in terms of both their traction motor characteristics and the system of power supply and transmission to those motors.

The electric locomotive obtains electric power from overhead lines. For traction purpose, the electrified railway adopts a single-phase AC power supply system in China. The high-voltage alternating current from overhead lines, via a pantograph installed on the locomotive, enters the transformer set on the locomotive, and then the current is transformed into low voltage alternating current, and furthermore, with the rectification of converter, the AC current will be converted into DC current. In order to let the current flow to traction motors, gear engagement between traction motor and the locomotive traction wheel was applied to supply the required torque to produce the tractive force. Finally, through the adhesion effect between wheel and rail, the locomotive traction force is generated.

Motive power is usually classified by type of motor, including single-phase series-wound DC motor and single-phase series-wound AC motor.

Single-phase series-wound DC motor has had extensive use from early days for street railway and rapid transit trains. It is the conventional propulsive unit for diesel-electric locomotives. The advent of thyristor solid-state silicon controlled rectifier systems has made this motor available to modern heavy-duty electric locomotives. Plant costs are reduced through the direct use of commercial (60-cycle) frequencies. Smoother operation and greater reliability are possible with stepless electronic control of motor current and voltage.

The characteristics of single-phase series-wound AC motors are essentially similar to those of the DC type (including the added advantages of the direct use of AC current with no commutator to maintain). Its performance is best at high speeds, but it lacks the DC low-speed capabilities and is bulky and less compact, which is an important consideration in the design of modern motive power.

On China's railways, traction motor on electric locomotive, currently adopts the DC series motor. This is because this kind of motor's mechanical characteristic curve is similar to a hyperbola, which is suitable for locomotive traction.

2) Motor-Generator Systems

DC motors applied for the long-line freight locomotives have many shortcomings, including the arcing of high voltage across the commutator and the transmission of high DC voltage with high line loss, expensive transmission equipment, or both.

One way to overcome these disadvantages is the application of a motor-generator combination. A high-voltage AC transmission line current, with its lower costs, energizes a generator in the locomotive. The generator drives DC motors with relatively low voltage. The electric locomotive becomes essentially a constant-horsepower machine with a transmission line power factor close to unity and with performance independent of the transmission-line voltage. The flexibility and smoothness of DC motor controls are available in conjunction with the cheaper transmission of high-voltage alternating current. The Great Northern and the Virginian railways use this type of power. Motor-generator units are weighty, bulky, and require large cabs and heavy running gear. The power loss is rather high.

An SS4 modern electric locomotive is shown in Fig. 2.2.



Fig. 2.2 SS4 modern electric locomotive.

3) The Induction Motor (Poly Phase and Split Phase)

The poly-phase induction motor differs in its characteristics from the motors mentioned before. A poly-phase current is applied to the stationary or stator windings, setting up a rotating magnetic field in which the rotor coils are placed. A current is induced in the rotor, which has a tendency to resist the rotation of the field. Since the field cannot stop, the rotor is pulled along, creating a certain amount of torque.

When no load is applied, the rotor revolves at a theoretically synchronous speed, i.e., at the same speed as the rotating field. (Practically, on account of wind age and bearing friction, it cannot revolve at a true synchronous speed.) There is no induced voltage in the rotor, hence no torque producing current flows. The speed in revolutions per minute is equal to twice the frequency of the field in revolutions per minute divided by the number of poles.

When a load is applied to the rotor, its speed slips below that of the field (synchronization speed), and the rotor conductors begin cutting magnetic lines of force of the rotating field. A voltage is induced in the rotor coils that is proportional to the relative speeds of the rotor and rotating field. Thus torque may be said to vary with the slip from synchronous speed to the speed of maximum load. The insertion of resistance in the rotor circuit determines the point of maximum torque, but since the resistance is inefficient (consuming the current), it should be kept at a minimum and only a small range of slip permitted between no-load (synchronous) and full-load or maximum torque speed. The poly-phase induction motor thus becomes a fairly constant-speed machine, regardless of the applied load.

For starting speeds, efficiency is not of prime importance. Resistance, therefore, can safely be introduced into the rotor circuit. It is then cut out step by step, keeping maximum torque and tractive effort in line with the actual speed.

Three-phase motors and transmission systems are frequently used in Europe, but have proved to be too cumbersome and inflexible in terms of application in China. A three-phase line current requires two trolley wires, with the rails constituting the third side of the circuit. The Norfolk and Western Railroad in the USA made use of a so-called split-phase system. A single-phase alternating current taken from a single overhead wire was changed to a three-phase current through a converter in the locomotive and fed to a three-phase motor. Two speeds of 14 and 28 mph were available by connecting the stator windings in series and in parallel, so as to have a four-pole and an eight-pole machine. The effective number of poles could be varied from the control panel. Thus, with four poles effective, twice the speed was obtained than with eight poles. One of the chief advantages of the split-phase induction motor is its ability to regenerate power automatically on descending grades.

(2) Electric Tractive Effort

There is a definite relation between torque, current, voltage, and speed, available in a series of characteristic curves furnished for each type of motor by the manufacturer, as shown in Fig. 2.3. The manufacturer's curves are often plotted on the basis of substation voltage. It is safer in estimation work to take the trolley voltage as 90% of the substation voltage. Thus only 90% of the torque from a manufacturer's curve based on substation voltage should be used in the equation for tractive effort. Single-phase DC motor voltages in successive steps may be applied to the motors to give variations in speed control. Since every tap or point on the controller for an AC motor is a running position, it is desirable to

have a series of curves showing AC motor performance under the several applied voltages. These curves are usually plotted with current as the abscissa and with torque (or tractive effort), speed, voltage, and horsepower shown as ordinates. Characteristic curves for varying speeds are shown in Fig. 2.3. Again, note that with silicon solid-state controlled rectifiers, the stepless electronic control of DC series-wound motors is available for smoother and more reliable operation.

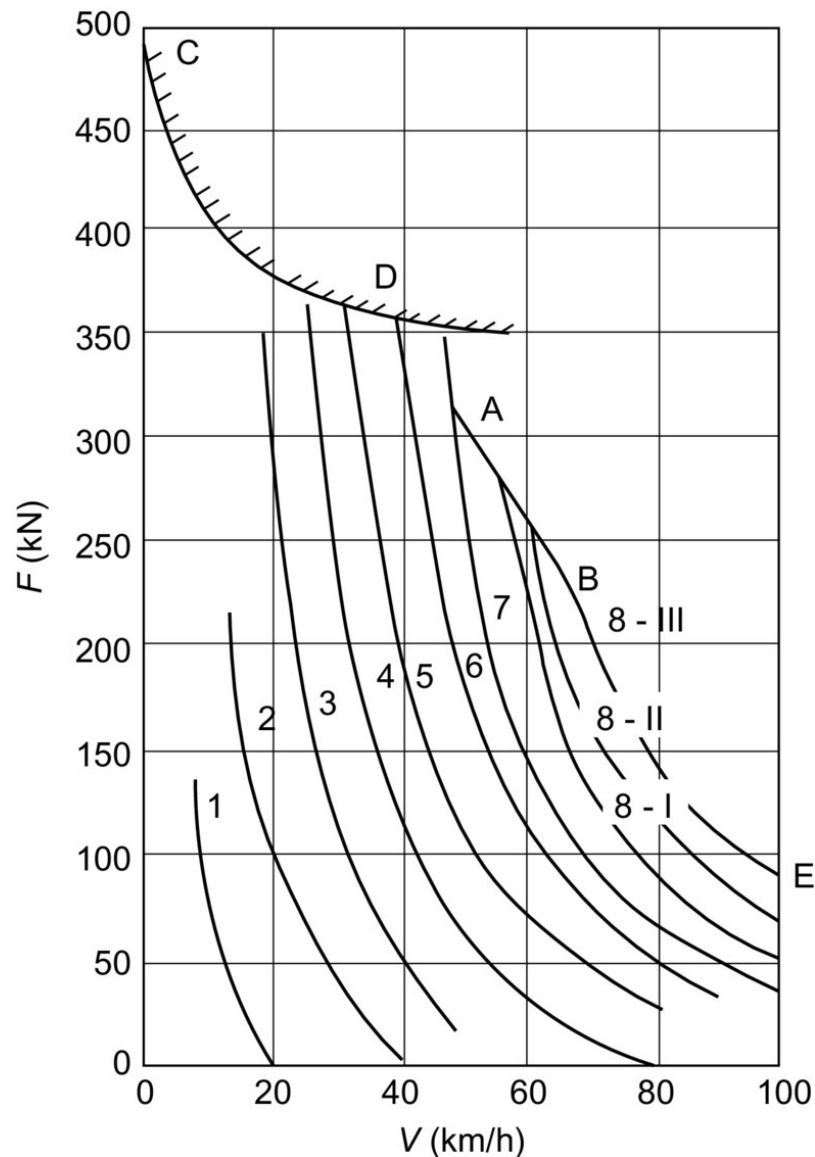


Fig. 2.3 Characteristic curve of an SS3 locomotive.

Fig. 2.3 shows the traction characteristic curve of an SS3 electric locomotive. Power of electric locomotive is supplied by power plants, so for each locomotive there is no limitation in terms of the capacity of power supply. Therefore, traction of electric

locomotive is mainly restricted by the power of traction motor and adhesion between wheel and rail.

The group of similar hyperbolic curves, which are numbered 1, 2,...,8-III, is the tractive force determined by the hauling power of the electric locomotive. It can be calculated after converting the electrical mechanical properties of the motor to wheel traction by the traction motor.

In the operation of the locomotive, according to the requirements of the operation, it is expected that the locomotive traction and speed can vary in a wide range. Only one curve, $F=F(V)$, is not enough. The speed of a mainline train is regulated by changing the input voltage of the motor and magnetic flux (by weakening magnetic field). SS3 locomotives have eight regulation levels; therefore, there are eight curves $F=F(V)$. On the eighth gear there are three weakening magnetic field levels, 8-I, 8-II, and 8-III, respectively called I, II, and III weakening magnetic fields.

In the absence of complete motor performance data, tractive effort may be estimated by the following approximation as given by the area in their manual (railroad engineering). For DC locomotives, tractive effort is inversely proportional to the cube of the speed and to the square roots of the horsepower:

$$\frac{T_1}{T_2} = \left(\frac{V_2}{V_1}\right)^3 \quad \text{or} \quad \frac{V_2}{V_1} = \left(\frac{T_1}{T_2}\right)^{1/3} \quad \text{or} \quad \frac{V_1}{V_2} = \left(\frac{p_2}{p_1}\right)^{1/2}$$

For single-phase motors:

$$\frac{T_1}{T_2} = \left(\frac{V_2}{V_1}\right)^{5/3} \quad \text{or} \quad \frac{V_2}{V_1} = \left(\frac{T_1}{T_2}\right)^{3/5} \quad \text{or} \quad \frac{V_1}{V_2} = \left(\frac{p_2}{p_1}\right)^{3/2}$$

If the tractive effort for a given speed is known, the tractive effort of any other speed can be determined.

(3) Electric Locomotive Ratings

Adhesive traction: Torque and tractive effort increase with the current. Tractive effort is unlimited, theoretically, since the power supply from the central stations is, for practical purposes, unlimited but a limitation is the point at which the drivers begin to slip, as determined by the factor of adhesion. The hatched line in Fig. 2.3 is the tractive effort curve limited by the adhesive force between wheel and rail, and it is calculated according to Eqs. (2.1), (2.2).

Traction force is limited by permitted current of motor: a second practical limitation is enforced by the heating of the motors at full load and high current value. As the heating does not occur at once, it is permissible to utilize the overload possibilities of the motors

for a limited period. At least two ratings are usually specified: the continuous and the hourly.

The continuous rating as prescribed by the Chinese Institute of Electrical Engineers is that maximum tractive effort which the locomotive can exert continuously without harm to the motors. It is not the maximum load the locomotive can handle, but it is the heaviest load that can be handled continuously with safety. The continuous rating is based on that continuous current and corresponding tractive effort which keeps motor temperature under 60°C (160°C with silicon windings), starting with a cool (25°C) motor.

The hourly rated tractive effort is based on that current and tractive effort which can be exerted for 1 h without harm to the motor; that is, the motor temperature is elevated by 60°C in 1 h, provided that the motors are cool when the overload is applied.

Much higher currents may be taken for shorter periods of time (such as 1 min), especially in the beginning and temperatures of 100°C may occasionally be reached without harm to the windings. When this operation occurs, measurements such as stops, coasting grades, or light pull below continuous current ratings must be applied immediately to permit the motors to cool.

The oblique line AB in Fig. 2.3 represents the continuous rating.

1) Traction force under different speeds

“Chinese traction calculation procedures” (TCP) stipulate that tractive effort of electric locomotive is to be taken via a continuous rating system. For example, in the SS3 locomotive, if the tractive effort for a given speed is known, the tractive effort of any other speed can be determined as follows: in the acceleration process (accelerate from 0 to locomotive construction speed), the tractive force takes adhesive traction (CD), and motor traction (DA, BE section), respectively, and the tractive effort determined by continuous rating (AB).

2) Calculated speed and calculated tractive force

Calculated speed is important for the calculation of the tractive mass of train, its corresponding tractive force is called calculated tractive effort. TCP take the speed and traction determined by the sustained current of the full-field traction characteristics at the highest step as the lowest calculated speed and maximum calculated traction. The corresponding speed and tractive force at point A in Fig. 2.3 are the lowest calculated speed ($v_{j\min}$) and maximum calculated tractive force ($F_{j\max}$) of SS3 electric locomotive, respectively.

3) Starting tractive effort

Starting tractive effort is the maximum tractive effort which is provided by locomotive under the starting status. A locomotive's starting traction stipulated by TCP is determined by calculating or specially testing based on certain restrictions, and is called calculated starting traction effort (TEs). The calculated traction effort of most freight locomotives is restricted by adhesion conditions. Calculated traction of passenger locomotives is restricted by starting current. In the calculation of SS3 locomotives under starting condition, starting calculated traction effort (TEs) is equal to adhesion traction effort when speed is zero as. A few locomotives use limited current traction effort as calculated starting traction effort.

4) Electric locomotive characteristics

The value parameters of frequently used Chinese electric locomotives are given in Table 2.1.

In Table 2.1, $v_{\min}$ is the minimum calculated speed, $T_{\max}$ is the maximum tractive effort, T_s is the starting tractive force, P and P_{μ} is the locomotive axle load and the locomotive adhesion axle load, and L_{loc} is the length of the locomotive.

(4) Effects on Location

The foregoing characteristics are of great interest to the locating engineer. The hauling capacity of electric locomotives is based not upon the maximum grade encountered but upon the profile as a whole. A grade that would require pusher engines in steam service might be overcome by an electric locomotive making additional current demands if the grade can be negotiated before the motors become too warm. Thus length of grade is an important consideration. It should not be longer than which can be traversed in 1 h or less at the speed and loading for the locomotive's hourly rating. It should also be followed by much easier gradients or preferably descending gradients to permit the cooling of the motors. A profile with many short, heavy grades permits a heavier tonnage per locomotive unit than one that contains a few very long grades. Electrification may well be considered as a possible alternative to grade reductions. Electrification should not be considered as an alternative to good, careful location design. An electric locomotive turning in a good performance on a poorly located line will give a far better performance on a line with properly designed gradients.

2.1.1.4 Diesel Locomotive

Unlike the electric locomotive with a practically "unlimited" power supply, the power of a diesel-electric is limited by the power of the diesel prime mover.

On the diesel locomotive, the power is provided by internal combustion engine (diesel). Because the wheel rotation curve $F=F(v)$ driven directly by internal combustion engine is not the ideal constant hyperbolic form, it cannot meet the requirements of locomotive traction characteristics, so power is produced by internal combustion engine transfer to locomotive tractive wheel through transmission device, and through the adhesive effect between wheel and rail producing locomotive traction. Therefore, diesel locomotive traction is restricted by the power of an internal combustion engine, transmission device, and the wheel/rail adhesion. Transmission devices are divided into mechanical driven, electrical, and hydraulic driven types.

(1) Diesel Engine

A diesel locomotive produces the power in an internal combustion engine, and drives wheels through the transmission device. In a diesel locomotive, between driving wheels and internal combustion engine is a transmission device, which is equally important to the generator and adapts to the tractive characteristics. There are three kinds of transmission devices: mechanical transmission device, hydraulic transmission device, and electricity device. The diesel locomotive equipped with an electric transmission device is referred to as a diesel-electric locomotive. According to the types of internal combustion engine used, diesel locomotives can be divided into diesel engine and gas turbine engine, and diesel engine locomotives are most widely used. In China, the term diesel locomotive generally refers to the diesel engine locomotive. The diesel-electric locomotives are mostly adopted by the main lines of Chinese railways.

Of all Chinese locomotives, 40% are diesel-electrics, a locomotive with characteristics making it peculiarly adaptable to railway requirements. A diesel-electric locomotive is essentially an electric locomotive with a self-contained power plant: the diesel engine-generator-motor combination (Fig. 2.4).



(A)



(B)

Fig. 2.4 (A) DF8 Diesel-electric locomotive (ac-dc). (B) HXN3 Diesel-electric locomotive (ac-dc-ac).

A diesel engine is a form of internal-combustion engine using the heat of compression instead of an electric spark, as in the more common gasoline motor, to fire the fuel mixture. In addition to the cylinders and pistons connected by cranks to the main shaft or drive shaft, there must be a means of injecting the fuel into the cylinders for ignition at the time of maximum compression. For the modern method of “solid” or direct injection, an atomizing injector nozzle and individual plunger pump must be included among the essentials. This combination then functions as a 4-cycle engine, the stages of operation being: (1) compression, (2) ignition and expansion (the power stroke), (3) an exhaust stroke forcing the burned gases out through valves in the head of the cylinder, and (4) a return stroke drawing in fresh air through the same valves in the cylinder head.

A 4-cycle engine locomotive using this operating sequence placed in switching service. Its size was useful in giving the additional weight on drivers necessary for the maximum adhesion and tractive effort so desirable in switching service, but it was too heavy, 43 kg/kw (kilogram/kilowatt), which was inefficient for road freight and passenger service. Successful development of a 2-cycle engine brought the diesel into general use. The method of introducing fresh air into the cylinders and exhausting the burned gases is essential to a 2-cycle engine. These functions are performed by a so-called scavenging pump with ports in the cylinder walls serving both as air intake and burned gases exhaust. (Some designs have exhaust ports in the cylinder head) The 2-stroke cycle is made up of (1) an intake-compression stroke and (2) a power-exhaust stroke giving approximately twice the power of a 4-cycle engine for the same weight. The scavenging pump also overcomes power losses that result from lowered atmospheric pressure at high altitude, thus performing a supercharging function. A lighter, more efficient 4-stroke engine has since been developed and finds current use.

The most important part of the diesel mechanism is the fuel-injector unit. The development of such a unit was necessary to eliminate the heavy piping required for the fuel system of stationary diesels. An injector unit is set in the head of each cylinder. Fuel is delivered to the injector by a constant-stroke plunger pump operated from a cam shaft. The pump may be built in multistage construction, with a fuel line leading to each cylinder. On modern 2-cycle engines, it is usually combined in the same assembly with the injection nozzle, forming a separate complete unit for each cylinder. The pump must measure the fuel with precise accuracy and deliver it at a definite moment and for a definite period of time to the ignition nozzle. About 0.71 mm are thus measured per compression stroke. Ignition takes place when the cylinder pressure reaches 410 N/cm² at a temperature of 30°C. The ignited fuel burns, raising the cylinder pressure an additional 135–210 N/cm². The pump must be able to inject fuel against the cylinder pressures. However, to force the oil through the small orifice openings of the injector tip in an atomized spray, pressures of 10,000–14,000 N/cm² are used.

The injector nozzle delivers the fuel pressurized by the pump into the cylinder in atomized form through an orifice or a pintle bottom in the nozzle. Clearances as low as 0.000065 cm are observed in manufacture, yet the injector must be rugged enough to retain a line adjustment. Any incorrect adjustment or dripping will lead to a marked loss in efficiency.

An adequate supply of air, especially at high altitudes, must be in the cylinders for complete combustion and maximum power. A multibladed compressor or turbocharger forces additional air into the cylinders under pressure to combine with heavy fuel loads.

Engines generally have eight speed settings or “notches” for the throttle. The “eighth notch” represents engine output capability, usually at 900–1050 rpm (revolutions per minute).

1) Electric coupling

The diesel engine is a constant-torque, constant-speed machine with little or no overload capacity. Some form of transmission is necessary to reduce the high engine speeds to those suitable for locomotive drive wheels and to obtain flexibility of control. Mechanical transmission has not possessed the strength or flexibility necessary for road and heavy, high-speed switching service. Maintenance costs are high. Hydraulic coupling, using a torque converter, has had successful use in heavy road freight service, but it lacks flexibility and is also difficult to maintain.

Electric coupling provides the requisite ease in speed control combined with ruggedness and flexibility. An electric generator or alternator is mounted on the diesel engine shaft and

furnishes current to drive the electric motors geared to the driving axles.

2) Generators

The self-excited, shunt-wound DC generator has been most commonly used in diesel-electrics. By varying the field current, the generator is able to operate at full diesel engine capacity without overloading or underloading. In a self-excited generator, residual magnetism permits initial operation. A portion of the current thus produced is shunted through the field coils, increasing both the magnetizing current and the current output. The current for separate excitation is taken from a storage battery or mechanically driven exciter unit. The generator output and load imposed on the prime mover can be regulated by controlling the excitation current. Excitation current is automatically increased or decreased with shaft speed. Generator speed can also be varied by changing the throttle setting or notch. Generator characteristics are shown in Figs. 2.5 and 2.6.

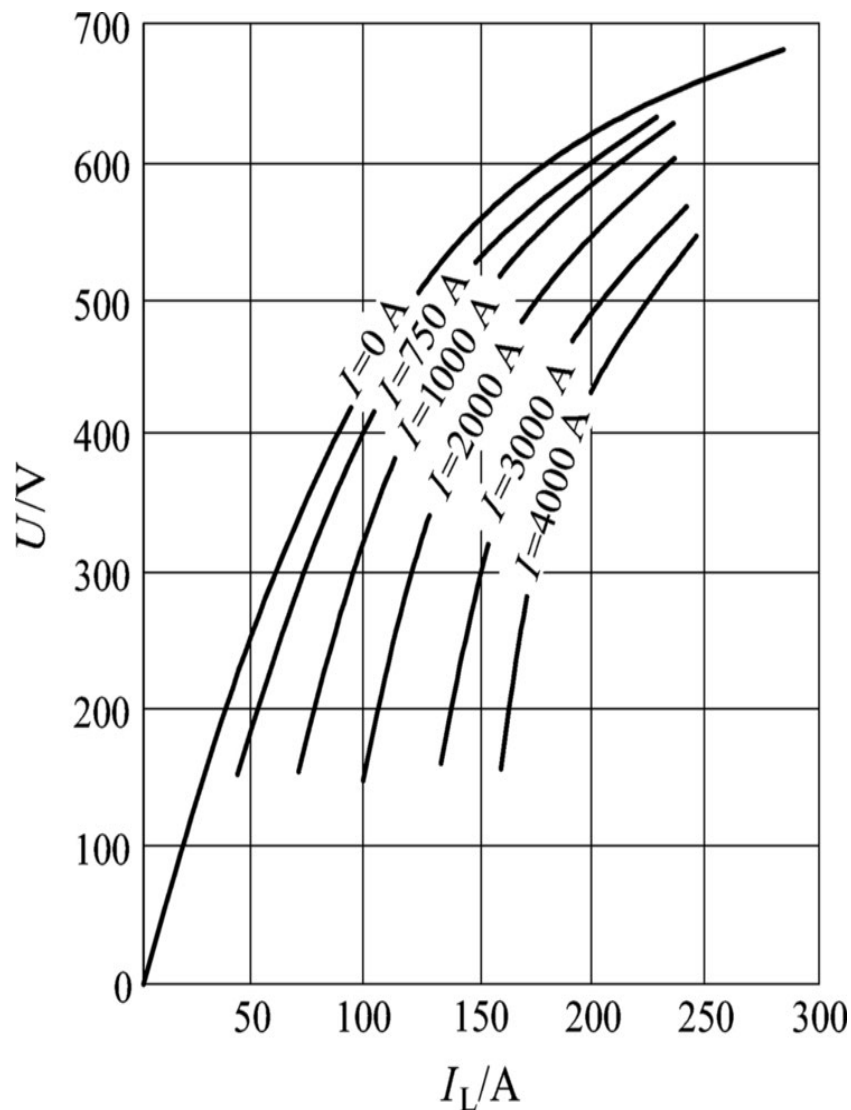


Fig. 2.5 TQFR-3000 generator load characteristics.

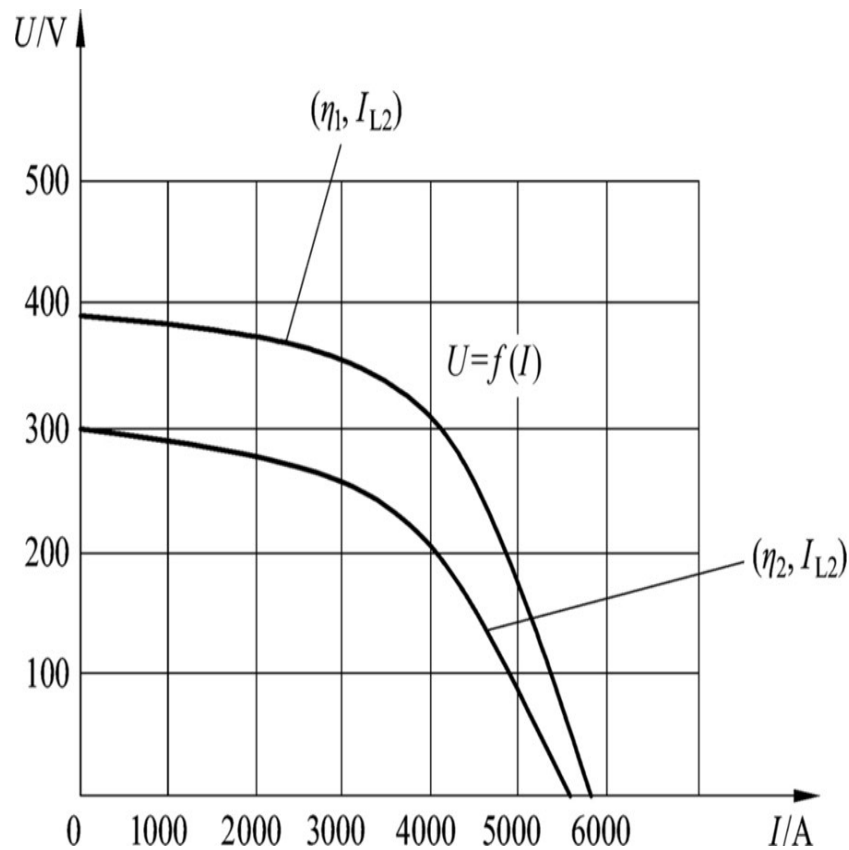


Fig. 2.6 TQFR-3000 generator external characteristics.

3) Starting systems

An external starting torque must be provided, since the diesel engine at zero speed has zero torque. A gasoline engine may be geared to the shaft. Most modern road engines, using a storage battery as current source, operate the generator as a motor to turn the shaft and provide initial compression. Because of difficulty in starting, locomotive engines have been permitted to idle for long periods. With high fuel costs and scarcity, there is a trend toward shutting down the engines for idle times that exceed 30 min. This practice may be combined with remote starting control for locomotives housed at outlying points when ambient temperatures fall below a predetermined level. The need for a hostler to be on duty for starting purposes is thereby eliminated. Less idling time and greater fuel savings would follow from an improved starting system permitting more frequent engine shutdowns.

4) Motors

Traction motors fed by the generator are geared to the driving axles. Different gear ratios provide high torque and tractive effort at low speeds for freight service and low torque at high speeds for passenger and expedited service. Motors are usually hung on the driving axle, with further suspension being attached to the power truck frame. The motor in almost

universal use is the 600 VDC, series-wound motor. Input or terminal current passes through each coil of the winding in turn (hence series-wound), thereby producing more torque for a given current input than with other winding patterns. It has the disadvantage compared to an AC motor of having a commutator and brushes to be maintained.

This motor has been used extensively from early days for elevated subways, and surface trains. Its characteristics make it especially suitable for railway use: simplicity of construction is combined with the ability to produce high starting torques. It may be loaded temporarily to the point where there is no immediate armature rotation without harm to the motor, an especially useful feature in starting heavy trains. As speed drops, there is a rapid increase in torque that tends to impose a relatively constant load on the line. Torque depends on the field strength, the current, and the number of turns in the armature. The product of the number of turns and the current is known as ampere turns and varies directly with the current. Torque, in turn, varies as the square of the current, since the field strength also depends on armature current.

The motor's speed of rotation depends upon the applied voltage for a given field strength. A counter electromotive force (EMF) is generated in the motor, which is equal to the applied voltage less the voltage drop in the motor itself. This back EMF increases as the current increases, tending to reduce the motor speed. Since in a series motor, the field current and strength vary directly with the load, torque increases as the field strength increases. But with increased field strength, more EMF is generated per revolution, leading to decreasing speed with increasing load and current. Motor characteristics are indicated by the typical curves in Fig. 2.7.

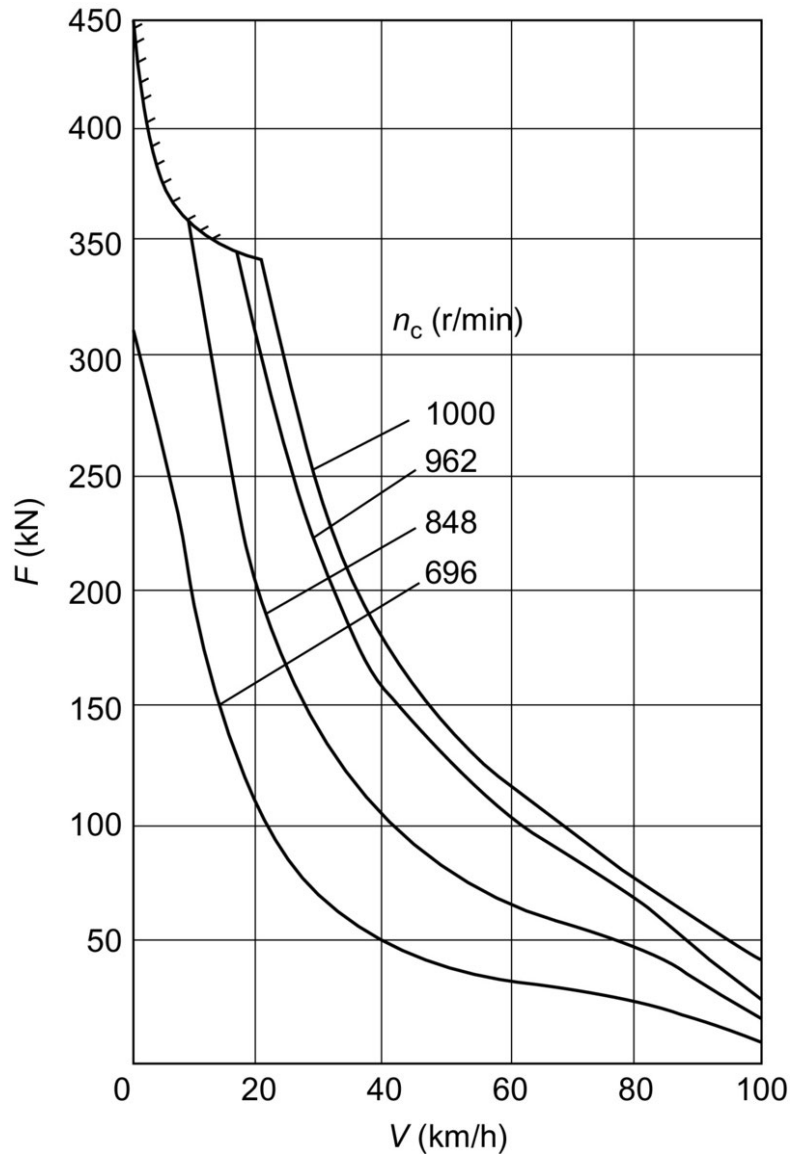


Fig. 2.7 Tractive characteristics curves for a DF 4B diesel-electric locomotive.

(2) Tractive Characteristics

Through electric coupling, tractive characteristics of the diesel-electric locomotive become largely those of its DC, series-wound motors.

1) Tractive effort

Tractive effort can be computed by equating the work done at the rim of the driving wheel, WD, with that performed by the torque or turning effort of the motor, W_m . This becomes

$$W_D = W_m$$

and

$$(2.11)$$

where TE is the tractive effort in newtons; D is the driving wheel diameter in centimeters; T is the motor torque in newton centimeters, taken at a distance of 12 cm from the shaft center (24-cm-diameter “torque circle”), available from the manufacturer; n is the number of motors; and e is the efficiency of the locomotive, 0.80–0.85, often taken as 82%.

The locating engineer would not be called upon to compute a tractive effort based on electrical characteristics of motors and generators. The curves furnished by the manufacturers are sufficiently accurate. Performance can be approximated by using the following equation:

$$(2.12)$$

where TE is the tractive effort in newtons; p_e is the engine shaft power; p_a is the power to auxiliaries; V is the speed in kilometers per hour; and e is the efficiency, taken as 0.80–0.85.

The common interpretation of the foregoing, taking an 0.82 efficiency into account, is

$$TE = 308p/V$$

where TE and v are as before and p is the manufacturer’s rated power for the locomotive. Using this equation, a tractive effort curve for a locomotive of any power can be calculated. Fig. 2.7 shows the characteristics curve for a DF4B type electric driven diesel locomotive, based on full or varying power from the engine. A series of lesser curves could be drawn with lower engine outputs. Not all the tractive force developed by the engine and shown on the curve can be utilized effectively. Certain limitations must be observed as follows.

2) Analysis tractive characteristic curve of electric drive diesel locomotive or electric power driven diesel locomotive, the internal combustion engine on the train drive a main generator, the current produced by the main generator drive the traction motor mounted on driving wheel shaft, traction motor then is engaged with shaft gear making driving wheel getting necessary rotary torque which produce tractive force. Main generator can take DC or AC type, but the traction motors are mostly in DC type now. Fig. 2.7 shows traction characteristic curve of the DF4B (cargo) type electric driven diesel locomotive. Its type belongs to AC-DC power transmission group, and it is used to explain basic concepts of electric drive in diesel locomotive traction characteristic curve.

Adhesion: Traction effort in the curve segment with hatched lines are adhesive tractive effort which can be calculated by Eqs. (2.4), (2.6).

Traction effort of diesel engine and transmission device: The power of the diesel engine is changed with the amount of fuel. Diesel engine power (speed) determines the generator power. A rotational speed has a tractive force curve $F=F(V)$. DF4B (cargo) locomotive diesel engine has four kinds of rotational speed; accordingly there are four curves $F=F(V)$.

The traction effort of a motor on an electric drive internal combustion engine vehicle is DC contact motor, like electric locomotive. It can also adjust the weakening magnetic field method. In Fig. 2.7, each curve $F=F(V)$ is composed of three segments: low speed range is filled with magnetic field; medium speed range is one level of weak magnetic field; and higher speed range is secondary weak magnetic field. Instead of showing a magnetic conversion process, in the figure, will be within the scope of the conversion process speed of traction average painting into a smooth curve.

Locomotive ratings: The gear ratio limitations of the preceding section apply for continuous or cruising operation. These ratings can be exceeded for short periods of time without seriously overheating the motors. This is a useful attribute in starting a train or ascending a short but steep grade. An overload sufficient to start a train may be permissible for a 5-10-min period or, at a lesser rate, for a 20-30-min period while ascending a grade that can be surmounted within that time limit. Locomotive ammeter scales are sometimes subdivided to show the permissible times for various ammeter readings. Straight electrics usually have, in addition, a I-h rating, which is useful on long grades. If the overload period is exceeded, the train must be stopped to cool the motors, which is undesirable. To permit motor cooling in motion, the locating engineer should endeavor to have lesser or even descending grades following a grade that makes maximum demand on the motors.

Traction effort limited by starting current: Train began to move is transformation process from the static to the dynamic, the train is starting from one car to the next car. When the caboose starts, the locomotive speed is about 2.5 km/h, which is used to calculate the starting traction of diesel locomotive. Some models are limited by adhesive force; some models are limited by the starting current.

Acceleration: Since the diesel engine is not directly coupled to the drivers, its full horsepower is available over all locomotive speed ranges; accelerating capacity is high throughout the low and medium speed ranges. The diesel-electric is thus especially suitable for switching and yard operations, where many starts and stops are made throughout the day. Rapid acceleration is also a desirable characteristic in road service such as commuter or way freight, where frequent stops require maximum acceleration in a minimum time to ensure a fast scheduled road time.

The minimum calculated speed $v_{\min}$ corresponding to the maximum calculated traction effort $TE_{\max}$ take continuous speed and continuous traction effort. Tractive performance parameters of diesel locomotive commonly used in China are shown in Table 2.2.

A diesel engine's effective power of the diesel locomotive is related to the amount of air which enters into the cylinder. Using the internal combustion engine car at plateau with low atmospheric pressure or at high temperature region, locomotive power will be reduced. At this point, modifications should be made for locomotive traction; the correction coefficient is determined by experiment.

The revised locomotive traction F_x is calculated according to the following formula:

$$(2.13)$$

where λ_h is the correction coefficient of ambient air temperature (see Table 2.3); λ_p is the correction coefficient of altitude (see Table 2.4); and λ_s is the tractive correction factor influenced by tunnel: For DF4B type passenger and freight locomotives, if the length of tunnel is more than 1000 m, it is 0.88 for the first locomotive of single or double machine and 0.85 for the second.

Table 2.3

Correction Coefficient of Ambient Air Temperature λ_h

Machine Type		Surrounding air temperature (°C)					
30	32	34	36	38	40		
DF4	1	0.985	0.958	0.930	0.904	0.877	
DF4B	1	0.982	0.952	0.921	0.892	0.864	
DF4C	1	0.987	0.954	0.920	0.886	0.853	
DF8, DF11	1	0.984	0.950	0.913	0.877	0.841	

Table 2.4

Altitude Correction Coefficient λp

Altitude (m)	500	1000	1500	2000	2500	3000	3
Atmospheric pressure (kPa)	95.23	89.64	84.32	79.40	74.61	70.22	6
DF4	1	0.933	0.855	0.780	0.707	0.638	0
DF4B	45GP802-A supercharge	1	0.940	0.880	—	—	—
ZN310 supercharge	—	—	0.885	0.823	0.758	0.697	0

Table 2.5

Traction Performance Parameters of CRH Series High-Speed EMU

Type	Parameters						
vs (km/h)	Ts (kN)	Ts (kN)	P (Mt)	vmax (km/h)	Length of car (m)	Head	Middle
CRH1	200	87	325	≤16	≤16	250	26.96
CRH2	200/300	132/83	237	≤14	≤14	250/330	25.70
CRH3	200/350	160/92	300	≤14	≤14	250/380	25.70
CRH5	200	95	300	≤17	≤16	250	27.60
CRH380AL	380	193	300	≤15	≤15	400	26.5
CRH6	200	99	230	15.5	15.5	220	25.45

Note: v_s is the highest operating speed, T_s is the traction corresponding to the highest operating speed. v_{max} is the maximum designed speed.

2.1.1.5 Tractive Characteristic Curves of High-Speed EMU

(1) EMU trainset

It is a development tendency to adopt the EMU in high-speed railways with speed of 200 km/h and over. Traction mode is basically divided into two categories: power distributed EMU and power concentrated EMU.

A power distributed EMU consists of motor vehicles and trailer vehicles. A motor car is a kind of passenger car with motor bogie and passenger compartment. A trailer is just a passenger car without power service. This kind of EMU is represented by the Japanese Shinkansen.

A centralized power train is arranged with motor vehicles at the head and tail ends, and all trailer vehicles in the middle. There is no passenger compartment in its motor vehicles. Most high-speed trains in European countries use this kind of tractive mode, such as French TGV and ICE of Germany.

In China, high-speed railways, such as the CRH EMU series, are all power distributed and AC drive trainsets, adopting three-phase AC asynchronous electric motor. CRH series of EMU are self-propelled, fixed-composition and bi-directional trains, and their maximum speed is over 250 km/h. A trainset formation of CRH3 is shown in Fig. 2.8. EC01/EC08 are end vehicles, TC02/TC07 are transformer vehicles, IC03/IC06 are intermediate vehicles, BC04 is the bistro car, and FC05 is the first class car.

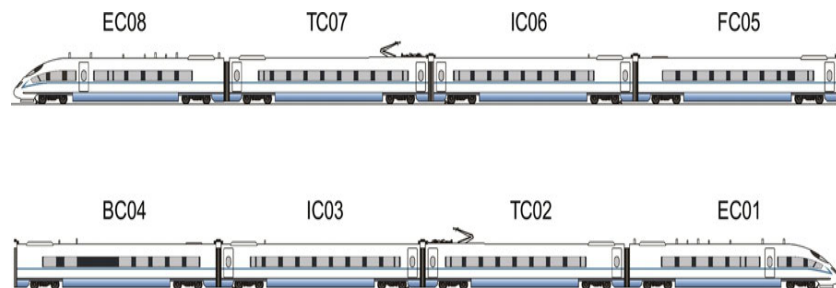


Fig. 2.8 A trainset formation of CRH 3 .

(2) Tractive characteristics curves of HSR

The tractive effort of high-speed EMU is determined by the total power of EMU, which can be provided by arranging the trainset formation.

The tractive effort can be taken on the tractive characteristic curve. Tractive characteristics curves provided by various manufacturers are different; some are given in single car, while others are given in the train. Fig. 2.9 shows the tractive characteristic curve of CRH1 EMU. In a low speed range, the tractive effort is restricted by starting current, such as CRH1 EMU, in 0–50 speed range, the tractive effort is restricted by the starting current to a certain value of 325 kN. When the speed is greater than a given value, tractive force shall be restricted by traction motor power, and decreases with the increasing of velocity.

The traction performance parameters of CRH series of high-speed EMU in China are shown in Table 2.5.

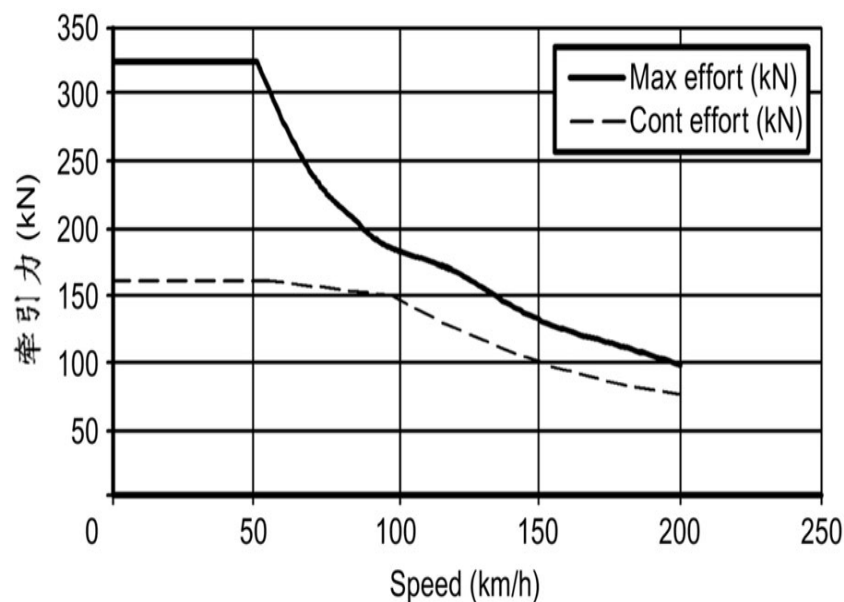


Fig. 2.9 Tractive characteristic curve of CRH 1 .

2.1.2 Train Running Resistance

2.1.2.1 Gross Resistance

Numerous forces oppose the movement and speed of a train and contribute to location and operating costs. These forces must be overcome by the propulsive force (tractive effort) of the locomotive.

Gross or total resistance is the sum of all resistive forces acting on a train at a given time or place, expressed as R . The total train resistance is equal to the sum of locomotive resistance R' and car resistance R'' . Much use is made of unit resistance measured in newtons per ton of train, locomotive, or car weight, expressed as r . A test shows that the resistance on the locomotive and vehicle are directly proportional to its mass, so using unit traction to calculate the total resistance. Unit resistance is the resistance that unit weight of locomotive or vehicle received, the unit is N/t ; the total resistance of locomotive or vehicles is that the unit resistance (N) is multiplied by mass of locomotive or vehicles in tons.

The resistive forces listed here are examined in detail in later chapters.

1. Internal resistance of the locomotive from cylinder and bearing friction, wind age in motors and generators, and power used by auxiliaries for lighting, heating, the air compressor, and so on. The train resistance of the locomotive is additional to its internal resistance.
2. Resistances varying directly from the axle loading, called journal friction but including (a) journal friction, (b) rolling resistance, and (c) track resistance.
3. Resistance that varies directly from the speed is known as flange resistance: (a) flange friction and (b) oscillation, swaying, and concussion.
4. Resistance, varying approximately from the square of the speed, is called air resistance.
5. Track modulus resistance.
6. Wind resistance.
7. Resistance of external axle loadings: (a) car-lighting generators, and (b) air-conditioning generators.
8. Curve resistance.
9. Grade resistance.
10. Acceleration resistance.
11. Resistance of inertia-starting resistance.

According to the traits, resistances can be classified into three categories:

1. Train basic resistance: A unit of train basic resistance is the number of Newtons of resistance per ton of train weight when the train is moving at a constant speed in still air on tangent level track. The train basic resistances are always present during train movements. The direction of basic resistance is the opposite direction with the train. Journal, flange, and air resistance are the customary components of the resisting force known as train resistance. Modifying factors to give weight to the minor effects of wind, track modulus, and external axle loadings may be added to train resistance for more precise results. The locomotive must always overcome the resistance of its own moving parts and inertia.
2. Additional resistance: A unit of additional resistance is the number of newtons of resistance per ton of train weight when the train is moving on nontangent level track, such as a ramp, negotiating curve, tunnel, etc. Additional resistances are determined by alignments of the train running through.

3. Starting resistance refers to the resistance when the train starts.

2.1.2.2 Train Basic Resistance

Train Basic Resistance Components

Resistance included in terms of (1)–(5) are always present during train movements. Journal, flange, and air resistance are the customary components of the resisting force known as train resistance. Modifying factors to give weight to the minor effects of wind, track modulus, and external axle loadings may be added to train resistance for more precise results. The locomotive must always overcome the resistance of its own moving parts and inertia.

Resistance Varying With the Load

This resistance, often loosely called journal resistance, is composed of three distinct elements: rolling resistance, track resistance, and the journal friction proper.

Rolling resistance. Rolling resistance comes from friction between the wheel tread and the head of the rail partly, which also comes from a certain minute amount of flattening of the surfaces in contact. The value of rolling resistance is a function of the coefficient of rolling friction between metals, which increases as the load is increased. Rolling friction is subject to too many variables for a direct mathematical determination. The types of metals in wheel and rail and the condition of wheel and rail surfaces—whether dirty or clean, wet, oily, rusted, or frosty—affect the coefficient of rolling friction. An average value for average conditions is included in gross journal resistance values as part of the residual resistance after net journal friction has been found.

Track resistance. When a track is stressed by the load at a single wheel or a group of wheels closely spaced, as in a car truck, the track is depressed in proportion to the loading and to the stiffness of the track structure. The track and supported rail have a reverse upward, which bending immediately in front of and behind the point where the wheel and rail make contact. The wheel is, in effect, “running uphill.” This deflection and reverse bending absorb some of the energy from and add resistance to the movement of the train, which varies with the applied load on the axles. As the rail weight is increased, the stiffness of the rail increases and the amount of rail flexure and resistance decreases. Increasing the stiffness of the rest of the track structures has the same effect.

Experiments have shown the value of track resistance which varies from a small fraction of 1 N to as much as 6.5 N/t. The possible reduction due to use of light weight equipment is not included in formulas used today.

Adjustments for such equipment might well be developed if the use of lighter axle loadings becomes more widespread. It is only empty cars that would be affected, however, since

even lightweight vehicles under load would probably fall within known weight values.

Journal resistance. Resistance arises from the friction between the journals (turned bearing surfaces) at the ends of each axle and the babbitted bearing surfaces of the brass blocks or “brasses” that fit on top of the journal and transmit to it the load of the car. About 30% of the journal is in contact with the bearing surface of the brasses at one time.

Lubrication is obtained by turning the journal through oil-soaked pads in the well beneath the journal, carrying oil up and onto the babbitted face of the brass to lubricate its surface.

The coefficient of rolling friction and hence the journal resistance decreases as the load (weight of car and loading) increases. Journal resistance also increases as the temperature of bearings and lubricants decreases. Thus one finds maximum journal friction and resistance occurring upon starting in cold weather, but this diminishes as movement and increasing speed warming the lubricant and bearing surfaces.

Roller Bearings

Expressions for journal resistance are based on the ordinary brass babbitted bearings. Roller bearings are finding increased use and value. Most of the new passenger vehicles run on roller bearings. First cost and problems of freight car interchange between railways have retarded the placing of roller bearings on freight equipment. Increased coasting speed with roller bearings in hump yards, as well as the necessity for setting hand brakes on yard tracks, have been additional deterring factors. Nevertheless, roller bearings are rapidly becoming standard on freight vehicles, especially on equipment for unit trains.

Roller bearings are most useful in reducing starting friction and resistance. At starting, car journal friction is reduced by about 80%, with a 10% reduction at speeds of 8–55 km/h. Tests have indicated an average starting resistance of 13–17 N/t for locomotives similarly equipped. Above 55 km/h the reduction tapers off until at high speeds there is little reduction at all. Other advantages are provided in smoother starting, which reduces maintenance costs, damage to loading, delays due to hot boxes, and in equalizing winter and summer tonnage ratings.

Flange Resistance

Even on a tangent track, the flange of a wheel comes in contact with the head of the rail and creates a retarding force. The path of a car or locomotive on a stretch of tangent track is not a straight line; neither the theoretical path of a locomotive or car wheel is a straight line, but, rather, a sinusoidal curve created by a so-called hunting action. Non uniformities in track geometry or in wheel load distribution cause irregularities in the hunting path. Impact occurs between the flange and the head of the rail. The wheel-axle set bounces against the opposite rail and receives an opposite impact and bounce in turn. Other irregularities impart additional lateral vibrations before the first has subsided (dampened). Thus the car or locomotive follows a zig-zag path, shifting laterally from one rail to the other within the limitation of gage tolerance or play. The severity of hunting is likely to increase with speed.

Any lateral movement of the wheel sets is a source of flange resistance, constituting a part of the second element of train resistance. Swaying, concussion, and oscillation of the vehicles add other losses. Since journal and air resistance can be closely evaluated in tests, the difference between these two and total train resistance is flange resistance. The effects of these factors, which are intensified by poor track conditions, vary directly from the speed. Some minor variation is due to the type of rolling stock. Theoretically, flange resistance varies inversely in proportion to the length of rigid wheel base. Practically this has a little effect with the slight differences in wheel spacing on car trucks. The modifying coefficient varies from 0.03 to 0.045 for most types of equipment.

Resistance Varying With the Square of the Velocity

The third element in train resistance is the resistance of quiet air, not the wind resistance. A series of tests and experiments indicate that for ordinary train speeds, resistance varies approximately with the square of the speed and directly with the cross-sectional area. Air resistance = CAv^2 in newtons; in newtons per ton $R_a = CAv^2 / wn$, where w is the weight per axle in tons, n is the number of axles, A is the cross-sectional area, and C is an experimental coefficient. More than mere square feet of cross section is included in the value of A . In addition to the direct frontal resistance, there is resistance offered by the car trucks, such as the space between the vehicles, the fittings under the vehicles, the skin resistance of the car sides, and the turbulence and partial vacuum produced by the rear end. The effects of these are sometimes included in C , so that the initial air resistance is shown in some writings as simply $R_a = Cv^2$.

It has even been suggested that resistance increases at high speeds because the rollers are crowded against the races by centrifugal force.

Effects of Temperature

One other factor, temperature, must be considered as giving rise to increased train resistance. The foregoing analysis and data are based on normal summer temperature conditions. Cold weather has little or no effect on the factors of air and flange resistance, but it materially affects journal resistance. In cold weather, the time lag in lubricating the journal bearing is intensified, since the oil is stiff and viscous. In comparative location studies, the factor may be omitted, since it would be present in all locations under consideration. It is given practical recognition in train makeup where the tonnage rating of a locomotive may be reduced according to temperature and other conditions as prescribed by the rules of each company.

Once again, the overload capability of electric drive may be utilized to assist the train.

Train Basic Resistance Models

Attempts have been made to develop direct mathematical expressions for train resistance. Thus far, the forces entering into train resistances have proved too complex for such direct mathematical analysis. The most reliable expressions are those derived as empirical formulas from careful field and laboratory experiments. These usually adopt the same form, a factor for each component, the sum of which equals total train resistance. These expressions have the general form $R=A+BV+CV^2$ and differ principally in the values selected for A, B, and C.

Experimental formulas are expressed in the form of a unit of resistance per ton weight r_0 , its form is

$$r_0 = a + bV + cV^2 \text{ (N/t)}$$

where constants a, b, and c are determined by test, and v is train operating speed (km/h).

In China, the basic resistance formula is obtained from experiments under the environments of that operating speed is not less than 10 km/h, the outside temperature is not less than 10°C, and wind speed is not more than 5 m/s.

1. The unit locomotive resistance

All the tractive effort developed by a diesel-electric or straight electric is not available at the rim of the drivers. Some energy is expended in overcoming internal resistance, including engine and shaft losses, wind age and heat losses in generators and motors, and energy consumed by auxiliaries-air compressors, lighting and air conditioning, heaters, and so on. These internal resistances are removed from calculation by using an efficiency factor of 0.82 applied to the nominal horsepower when computing diesel-electric tractive effort.

A locomotive must, moreover, overcome its own rolling, journal, flange, and air friction resistance. Locomotive resistance must be subtracted from tractive effort to obtain net tractive effort or drawbar pull (DBP), the force behind the locomotive available for hauling vehicles.

In China, experimental formula of basic unit resistance r'_0 locomotives' is commonly used as follows:

i. Electric locomotive

For SS1, SS3, SS4:

$$r'_0 = 22.5 + 0.190V + 0.00320V^2 \text{ (N/t)}$$

(2.14)

For SS7

$$r'_0 = 14.0 + 0.038V + 0.00348V^2 \text{ (N/t)}$$

(2.15)

For SS8

$$r'_0 = 10.2 + 0.035V + 0.00426V^2 \text{ (N/t)}$$

(2.16)

ii. Diesel locomotive

For DF4(H,P), DF4B(H,P), DF4C(H), DF7D, etc.

$$r'_0 = 22.8 + 0.293V + 0.00178V^2 \text{ (N/t)}$$

(2.17)

For DF8

$$r'_0 = 24.0 + 0.022V + 0.00391V^2 \text{ (N/t)}$$

(2.18)

For DF11

$$r'_0 = 8.6 + 0.054V + 0.00218V^2 \text{ (N/t)}$$

(2.19)

2. The unit basic vehicle resistance

Previous articles have related to freight vehicles in trains. The application to single vehicles, as in vehicles rolling down a hump incline, can lead to erroneous results. Instead, resort is made to test results. Not too many of these are available.

For single vehicles coasting, resistance varies with the mechanical condition (loaded or empty) of the car, and also varies with the incidence of adverse ambient conditions-head winds, low temperature, wet rail, and so on. The best or worst combinations of these gives

rise to the “easy roller” and “hard roller” concepts. Certain test values have been accepted for each.

i. Formulas for the unit basic resistance of passenger car

Passenger vehicles have truck, spring, and contour designs differing from those of freight vehicles. A series of tests on passenger trains indicates a lower unit resistance for passenger vehicles than for freight vehicles. These experiments were carried into higher-speed ranges up to 160 km/h for ordinary speed trains, and 200–380 km/h for high speed trains. Variations in resistance averages amounted to 8%.

As there is no obvious difference among passenger vehicles' loads, it is not necessary to distinguish empty cars from heavy cars; China's railway passenger vehicles are all mounted with rolling bearings. The unit basic resistance of passenger car formula is as follows:

$$\text{When } V \leq 120 \text{ km/h, for 21, 22 car: } r_0'' = 16.6 + 0.075V + 0.00155V^2 \text{ (N/t)}$$

(2.20)

$$\text{When } V \leq 140 \text{ km/h, for 25B, 25G car: } r_0'' = 18.2 + 0.10V + 0.00145V^2 \text{ (N/t)}$$

(2.21)

$$\text{When } V \leq 160 \text{ km/h, for fast car: } r_0'' = 16.1 + 0.04V + 0.00187V^2 \text{ (N/t)}$$

(2.22)

ii. Formulas for unit basic resistance of freight car

$$\text{Heavy car: Rolling bearing } r_0'' = 9.2 + 0.048V + 0.00125V^2 \text{ (N/t)}$$

(2.23)

$$\text{Sliding bearing } r_0'' = 10.7 + 0.011V + 0.00236V^2 \text{ (N/t)}$$

(2.24)

$$\text{Empty car: } r_0'' = 22.3 + 0.053V + 0.00675V^2 \text{ (N/t)}$$

(2.25)

iii. Formulas for unit basic resistance of high-speed EMU

Unit basic resistance of CRH EMU series can be calculated using the following formula:

$$\text{CRH}_1 : r_0'' = 11.2 + 0.0542V + 0.00146V^2 \text{ (N/t)}$$

(2.26)

$$\text{CRH}_2 : r_0'' = 8.8 + 0.0744V + 0.00114V^2 \text{ (N/t)}$$

(2.27)

$$\text{CRH}_3 : r_0'' = 6.6 + 0.0245V + 0.00132V^2 \text{ (N/t)}$$

(2.28)

$$\text{CRH}_5 : r_0'' = 6.9 + 0.063V + 0.0015V^2 \text{ (N/t)}$$

(2.29)

3. Total train basic resistance and average unit basic resistance of train

For ordinary trains, the total train basic resistance R_0 is equal to the sum of basic resistance of locomotive R_0' and basic resistance of car R_0'' ,

(2.30)

where P is the weight tons of locomotive, and G is hauled mass in tons.

The average unit basic resistance of train r_0 is the ratio of train basic resistance W_0 and train mass $(P+G)$, namely the basic resistance of unit train mass, is calculated using the following formula:

$$r_0 = \frac{R_0}{P+G} = \frac{P \times r_0' + G \times r_0''}{P+G} \text{ (N/t)}$$

(2.31)

For EMU,

$$(2.32)$$

where M is the total weight of EMU in tons.

The average basic resistance of train is equal to the unit resistance of vehicle, .

2.1.2.3 Additional Resistance

The important factors of grade, tunnel, and, to a lesser degree, curve resistance are closely related to locomotive performance, which is defined as additional resistance. Additional resistance depends on the alignments (grade, curve, tunnel) and climatic conditions (wind, cold, etc.). There is no reliable calculation method to calculate additional resistance caused by climate condition.

Grade Resistance

Railway grades are usually measured in per millage, i.e., meter of rise per 1000 m of horizontal distance—2 m of rise in 1000 m (or 1 m of rise in 500 m) would be a 2‰ grade. In China, meters are also applied to measure the rise per kilometer. The USA uses feet of rise per mile. The UK prefers to adopt the metric system, referring to the slope, that is, a rise of 1 ft in 40 ft or 1 ft in 60 ft (equivalent to 2.5% and 1.7% grades, respectively). European countries use the rise in millimeters per meter. Gradient is the rate of grade in per millage, rise per kilometer, or slope-2‰, 2 m/km, or 1 in 500 m, etc.

Unit grade resistance is determined by grade, which is derived as follows. In Fig. 2.10, a car of weight $W(=M \times g)$ is on a frictionless plane or track inclined at an angle α to the horizontal. The forces of gravity may be resolved into two components, of which F_2 tends to roll the car down the incline and F_1 is normal to the incline. To overcome F_2 and keep the car from rolling downhill F_2 must be opposed by an equal and opposite force F (locomotive drawbar pull). A relation can be established between similar force and distance triangles so that .

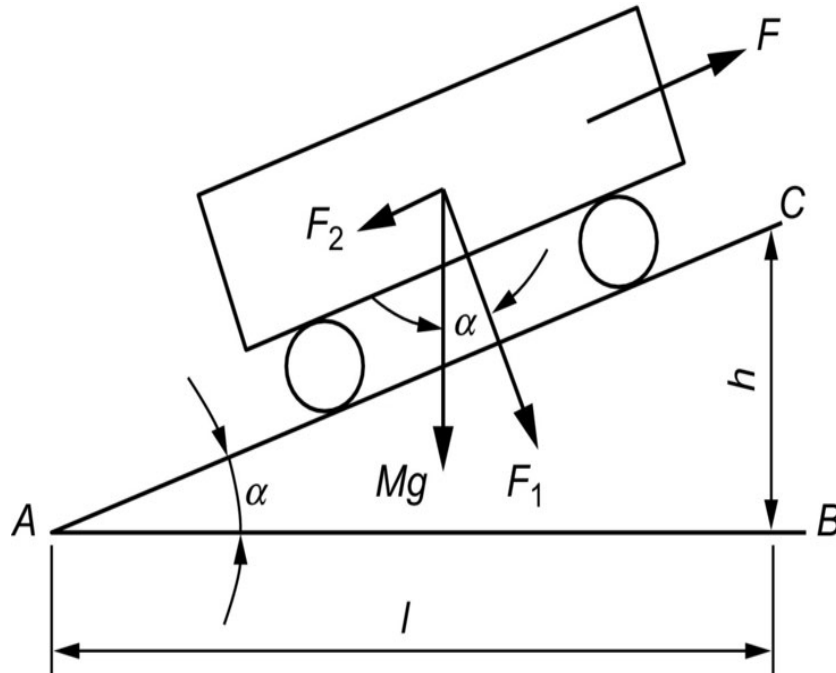


Fig. 2.10 Derivation of grade resistance.

In Fig. 2.5, we assume that M is the mass of the train in tons, the gravity when it running on the grade is , the component F_2 parallel to track is the additional gradient resistance. Therefore

$$F_2 = M \times g \times \sin \alpha (\text{kN})$$

Because angle α is generally very small (grade $i=34.9\%$, $\alpha=2^\circ$), and for small angles $\sin \alpha \approx \tan \alpha$, and consider units conversion of the train mass M , then

$$F_2 = 1000M \times g \times \tan \alpha (\text{N})$$

For a 1‰ grade and , grade i is expressed in per millage, that is , or , therefore

$$F_2 = M \times g \times i (\text{N})$$

Because the unit of resistance is defined as newtons of resistance per ton of mass, so the unit grade resistance r_G is

$$(2.33)$$

where i is grade (‰), upgrade takes positive, downgrade takes negative, g is the acceleration of gravity. Taking 10, then unit grade resistance is

$$(2.34)$$

The unit resistance of a 1‰ grade would be 10 N/ton, and that of a –2‰ grade is –20 N/ton.

Curvature Resistance

Resistance of trains rounding a curve is bigger than on straight, increased part is defined as the additional curve resistance. Factors which cause the curve additional resistance are mainly that; the longitudinal and transverse sliding between wheel and rail when locomotives and vehicles run on curve, the increased friction on the surface of the flange and rail inside, the increased friction of center plate and the relevant part of bearing because of the effect of lateral forces. The curve resistance relating to curve radius, speed of trains, rail ultra-high, gauge widening amount, fixed wheelbase and axle load of locomotive vehicles, and so on, therefore means that it is difficult to use theoretical formulas to calculate, and usually a test method is employed to obtain the experimental formula of a curve radius.

Sources of Curve Resistance

Curve resistance is the added resistance or “drag” on a train that must be overcome by the tractive effort in rounding a curve. Resistance is usually measured in newtons per ton of train weight. The difference between resistance on a curve and that on tangent level track divided by the radius of curve gives the curve resistance in newtons per ton.

In one form or another, curve resistance represents the work expended in overcoming friction between the flanges and treads of the wheels and the head and gauge corner of the rails, principally the outside rail. The exact reasons for the occurrence of curve resistance are complex and difficult to figure out. Theories differ chiefly in details regarding the action of a car truck in going around a curve.

The centrifugal force hypothesis says that flange pressure against the rail from centrifugal forces due to unbalanced super elevation; but experiments have shown no appreciable change in resistance with changes in super elevation. The area has generally accepted the rolling cylinder concept advanced by J.G. Sullivan as more nearly accounting for the actual performance of a car on a curve.

Sullivan’s explanation is based on the tendency for a cylindrical body, in this case the car wheels and axle rotate in a straight line at right angles to the axis of rotation (see Fig. 2.11). The flange of the outer front wheel of a four wheel car truck exerts a pressure

against the outside rail of the curve as the wheel is guided around the curve. Sullivan found that in a series of tests no evidence indicated slipping or skidding of the leading wheels, with the exception of a possible forward slippage caused by the resistance to rotation (of the flange against the rail) sufficient to retard the rotation of both wheels by a slight amount.

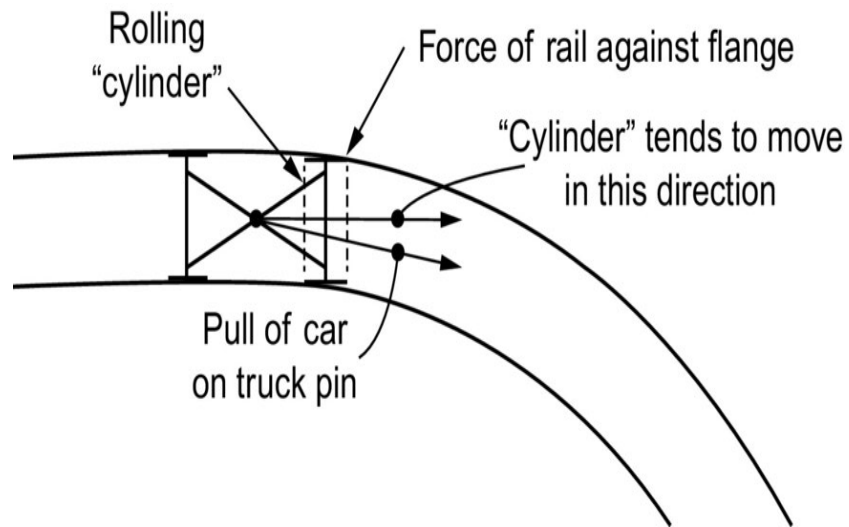


Fig. 2.11 Rolling cylinder concept.

Wheel-Rail Positioning

In reviewing these conclusions, the position that a wheel takes with respect to the head of a rail should be noted (Fig. 2.12). In practice, the tread of the wheel is given a 1-20 taper or coning, with a large radius fillet curve connecting to the flange.

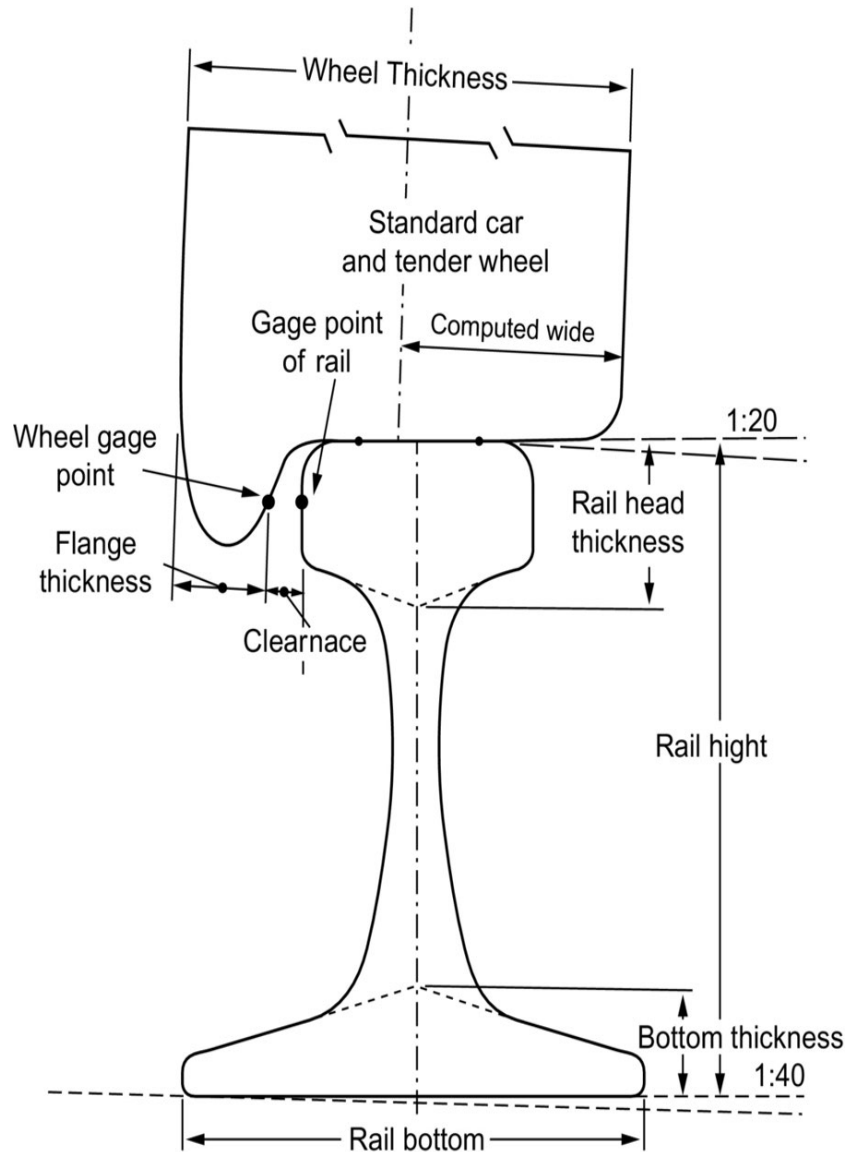


Fig. 2.12 Position of new wheel on new rail.

Under ideal conditions, a new wheel on a new rail track and wheels in perfect gauge, surface, and alignment, the wheel and vertical forces assume the position shown in Fig. 2.12. With perfect super elevation, the horizontal force component is minimum or negligible. Under these conditions the gage point of a new wheel may never bear on the rail. As the rail head, wheel, or both become worn, the wheel rides higher and higher on the fillet curve of the flange. The area of contact is increased, resulting in a higher value of curve resistance. Incorrect gage would have a similar effect.

Pressing of the flange against the rail increases the effective diameter of the wheel and helps prevent skidding. When the rail is canted by canted tie plates or canted ties, the area of contact between the rail and wheel is increased.

Rigidity of the wheel-axle assembly combined with the differences in radii of the outer and inner rails of a curve assures that either the inner or outer wheel of a wheel set will slip or creep in rounding a curve. Which wheel slips and by how much depends on speed, load distribution, the condition of the car and track, and tractive forces. In draft, tractive force tends to pull the car and lead truck laterally toward the curve center. In "buff," these forces are outward.

The truck wheels are guided by flange pressure against the rail. The angle of attack between the wheel and the rail is a function of the fore-going factors, also of the amount of flange lubrication, if any, and the lubrication and ease of swiveling within the center plate.

Wheel slip or creep causes "parallel of ramming" as the conventional three piece truck adjusts to unequal radii, whereby the inside flange is displaced ahead of the outside flange a small amount. The angle of attack and outward lateral pressure against the outside rail is increased and the inside wheel of the wheel-axle assembly bears toward the inner rail, with lateral pressure across the rail head to the curve center (Fig. 2.13). Conventional curve wear occurs on the high rail; plastic flow and field-side lipping occur on the inner rail. Insufficient super elevation increases high-side wear; excessive super elevation increases lipping, flaking, and even crushing on the low rail.

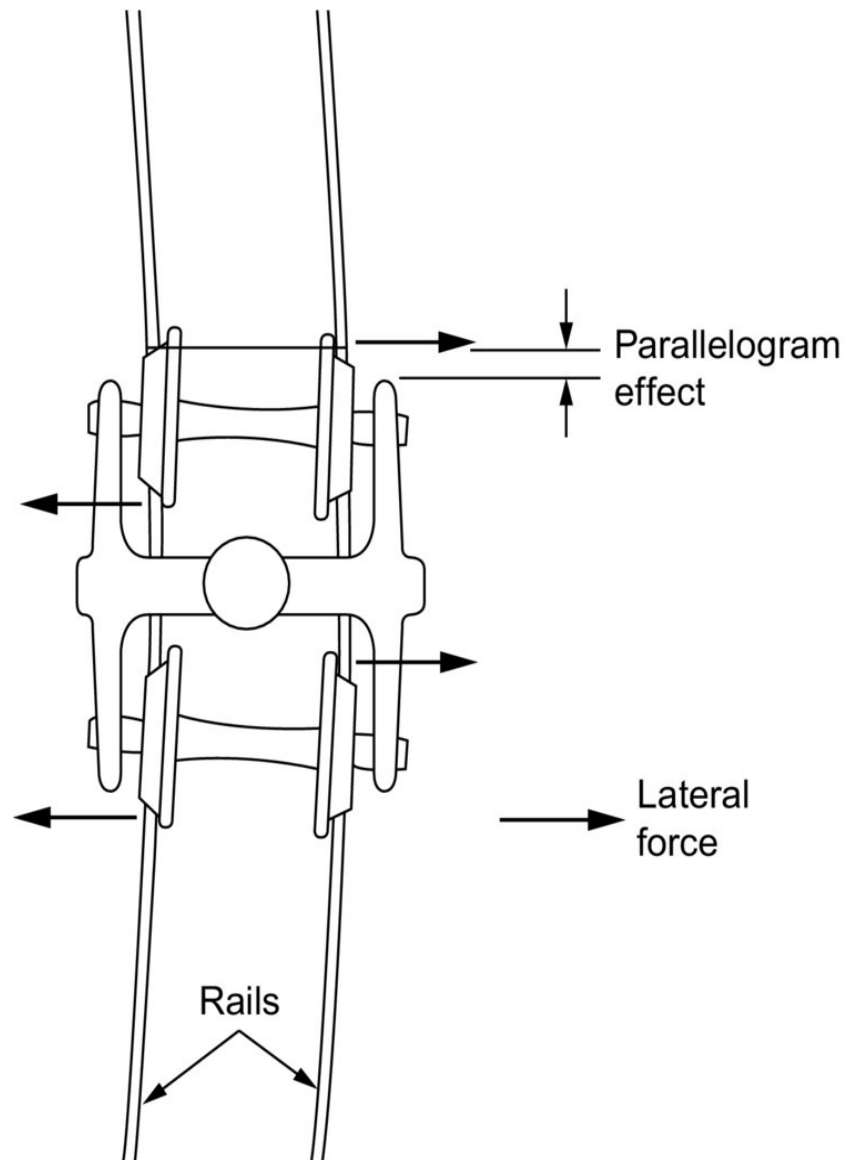


Fig. 2.13 Possible car/truck attitudes to rail and lateral forces.

These actions assure a certain amount of lateral slip as the inner and outer wheels pursue paths of unequal radii (Fig. 2.14). In moving a distance ΔL along the rail, the front wheel slides a distance inward across the rail head equal to the sine of the angle between the forward direction of the wheel at P and P' or

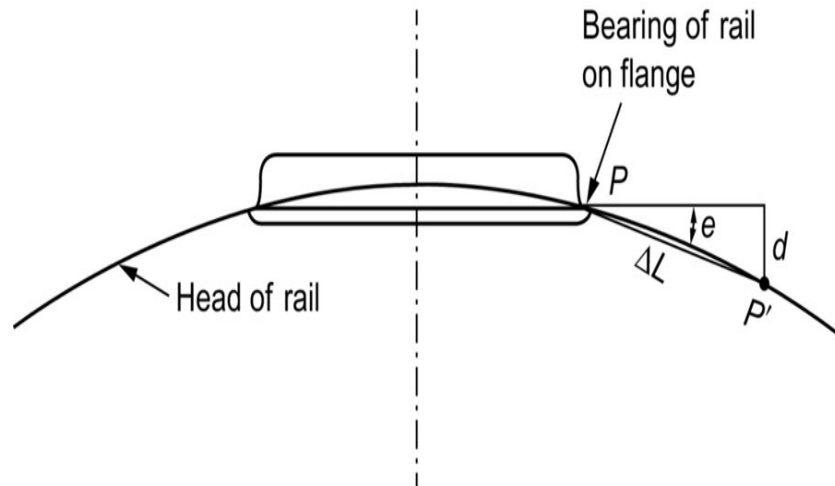


Fig. 2.14 Lateral slippage across rail head.

(2.35)

The trailing edge of the inner wheel is undergoing a similar slip inward. These slip ages contribute to curve resistance.

This phenomenon of a rigid wheel set exerting both inward and outward pressures is given a mathematical expression by C.T. Maller through a series of differential equations based on the degrees of freedom of the interrelated car, track, and sprung vehicle mass.

Research on car/truck action on curves has recognized this phenomenon: “The usual result of increased angle of attack is higher lateral forces. The angle of attack and wheel creep at high speed may be serious enough to cause wheel climb or gauge widening on tangent track.”

Models for Unit Curve Resistance

Unit curve resistance values are determined by test and experiment rather than through computations based on controversial hypotheses. On the basis of these tests, and to give a conservative value suitable for a wide range of conditions, Chinese railways have adopted a recommended model for unit curve resistance of $r_r = A/R$, where A is a constant number related to designed speed, for ordinary speed railway taking 600 g, for a high-speed railway taking 2000 g. Starting curve resistance is found to be about double that for a train in motion. This is important to consider when designing curvatures where trains are likely to be stopping.

In China, railway manufacturers have adopted a recommended value for unit curve resistance as shown in following formulas.

The unit curve resistance r_r for ordinary speed train can be calculated by

(2.36a)

Through analysis of the relevant results of “Beijing-Shanghai high-speed railway, bridge, tunnel study of main technical parameters,” the calculation formula of unit curve resistance r_r for HSR is

(2.36b)

If circular curve length $LC(m)$ and curve deflection angle ($^\circ$) are used to express curve radius, instead of R with $180LC/(\pi\alpha)$, Eq. (2.36a) can be written as

(2.37a)

Eq. (2.36b) can be written as

(2.37b)

where R is curve radius (m), α is the curve deflection angle ($^\circ$), and LC is the curve length (m).

Average Unit Curve Resistance of Train

Letting L_T be the length of train (m), and the mass of train are uniformly distributed along train, q is the unit mass per meter of train in tons per meter, therefore:

If $L_T \leq LC$, the whole train will be influenced by curve resistance, the total curve resistance exerted on the train is

$$R_r = \frac{600}{R} \times g \times L_T \times q \text{ (N)}$$

The average unit curve resistance of the train is

(2.38)

or

(2.39)

If $L_T > L_C$, only part of train will be affected by curve resistance, so the total curve resistance is

$$R_r = \frac{600}{R} \times g \times L_C \times q \text{ (N)}$$

The average unit curve resistance of train is

(2.40)

or

(2.41)

Sometimes, the intermediate straight between adjacent curves is short than the length of a train, then a train will lay out on several curves at the same time. In this case, the average unit curve resistance, and the sum of deflection angle within the total length of train is , then the average unit curve resistance of train shall be calculated as follows:

(2.42)

where $\sum \alpha$ is the total degrees of deflected angles of curves, in degrees.

The starting curve resistance is found to be about double that for a train in motion. This is important to consider when designing curvatures where trains are likely to stop.

Tunnel Resistance

When a train goes through a tunnel, there is directional airflow in tunnel. Then we can deduce the average aerodynamic drag formula theoretically.

Air cannot spread around when train is running in a tunnel because it is restrained by the tunnel. It leads to the piston phenomenon, which is the difference between head positive pressure and tail negative pressure, producing the resistance to the train. Meanwhile, the turbulent flow in tunnel, caused by the train shape, produces friction between air and surface of the train and tunnel, which also generates the resistance to the train. Therefore, when the train is running in a tunnel, the aerodynamic drag acting on the train is far more than that in the open area. The aerodynamic drag increment is called additional aerodynamic drag in a tunnel.

In the calculation of aerodynamic drag increment in a tunnel, a series of parameters need to be determined first, such as the frictional resistance coefficient of the train surface, friction resistance coefficient of tunnel surface, the pressure drag coefficient of the train head and tail, train shape parameters, and tunnel design parameters. These calculation parameters determine the correctness of the result. In particular, the pressure drag coefficient of the train head and tail and the frictional resistance coefficient of the train surface have a great influence on the correctness of the result.

When a train is going through a tunnel, the aerodynamic drag includes three items: pressure drag of the train head, pressure drag of the tail, and surface friction resistance of the body. The key to determine aerodynamic drag when a train passes through a tunnel is to determine pressure drag coefficient of the train head and tail, surface friction resistance coefficient of the train body, and wind speed in the tunnel.

The related studies show that additional aerodynamic drag in tunnel is related with driving speed, length of train, the superficial area of train against the air, train shape, tunnel length, area of tunnel cross-section, and tunnel surface roughness. The relation between aerodynamic drag in tunnel, air pressure difference, and tunnel cross-section area can be expressed as follows:

$$R_T = h \cdot A_{TU} \text{ (N)}$$

Unit aerodynamic drag in tunnel:

$$r_T = \frac{h \cdot A_{TU}}{(P + G)} \text{ (N/t)}$$

$$h = K \cdot \frac{\gamma}{2} (v - v_0)^2$$

where h is the unit difference of air pressure, in N/m^2 ; γ is the density of air, taken as 1.2 kg/m^3 ; v is the speed of train, m/s ; v_0 is the wind speed in piston, m/s ; and K is the effect coefficient of piston pressure.

$$K = \frac{N \cdot L_{TR}}{(1 - A_{TR}/A_{TU})^2} = \frac{86 \times 10^{-4} \cdot L_{TR}}{(1 - A_{TR}/A_{TU})^2}$$

In this formula LTR is the length of train, in meters; ATR is the area of cross-section of train, taken as 12.6 m²; and ATU is the area of tunnel cross-section, for the simplification of calculation, value can be taken from Table 2.6.

Table 2.6

The Minimum Effective Area of Cross-Section in Tunnel (Recommended Value in Calculation)

Design Running Speed of Passenger Train (km/h)		Electric Traction	
Single-Track		Double-Track	
≤120		37	
≤160		42	
200		50	
250		58	
350		70	
Remarks		Without considering requirements of double-decked contain	

$$v_0 = \frac{v}{1 + \sqrt{\zeta_s/K}} \text{ (m/s)}$$

In this equation, ζ_s is the total resistance coefficient of the tunnel.

$$\zeta_s = \sum \zeta + \lambda \cdot \frac{L_{TU} - L_{TR}}{d}$$

In this equation $\sum \zeta$ is the sum of part resistance coefficient at the entrances of tunnel, taken as 1.5; λ is the internal friction coefficient in tunnel, take 0.025; L_{TU} is the length of tunnel, in m; and d is the equivalent diameter of tunnel, in m, .

After substitution of the above parameters, the total resistance coefficient in the tunnel is

$$\zeta_s = \sum \zeta + \lambda \cdot \frac{L_{TU} - L_{TR}}{d} = 1.5 + 0.025 \frac{L_{TU} - L_{TR}}{4 \cdot A_{TU}/P_T}$$

where P_T is tunnel perimeter, when design speed is less than 160 km/h, for single-track tunnel, the value of 22.5 m is assigned for it; for double-track tunnel, the value of 31.55 m is assigned for it. When design speed is in range of 160–200 km/h, the value is 34.5 m for double-track tunnel. When design speed is in range of 200–250 km/h, 28.0 m is assigned for single-track tunnel and 35.0 m for double-track tunnel. When the design speed is in range of 250–350 km/h, it is 32.0 m for a single-track tunnel and 37.5 m for a double-track tunnel.

According to the above parameter, the calculation formula of unit air pressure difference can be deduced as follows:

$$\begin{aligned}
h &= K \cdot \frac{\gamma}{2} (v - v_0)^2 = 0.05K\gamma v^2 \left(1 - \frac{1}{1 + \sqrt{\zeta_s/K}} \right)^2 \\
&= 0.5K\gamma v^2 \left(1 - \frac{1}{1 + \sqrt{\left(1.5 + 0.025 \frac{L_{TU} - L_{TR}}{4A_{TU}/P_T} \right) / K}} \right)^2 \\
&= 0.5 \cdot \frac{0.0086L_{TR}}{(1 - A_{TR}/A_{TU})^2} \times 1.2 \times v^2 \\
&\quad \times \left(1 - \frac{1}{1 + \sqrt{\left(1.5 + 0.025 \frac{L_{TU} - L_{TR}}{4A_{TU}/P_T} \right) / \left[0.0086L_{TR} / (1 - A_{TR}/A_{TU})^2 \right]}} \right)^2 \\
&= 0.000398 \cdot \frac{L_{TR} v^2}{(1 - A_{TR}/A_{TU})^2} \cdot \\
&\quad \left(1 - \frac{1}{1 + \sqrt{\left(174.419 + 2.907 \frac{L_{TU} - L_{TR}}{4A_{TU}/P_T} \right) / \left[L_{TR} / (1 - A_{TR}/A_{TU})^2 \right]}} \right)^2
\end{aligned}$$

The formula of unit aerodynamic drag in tunnel is

$$\begin{aligned}
r_T &= \frac{h \cdot A_{TU}}{(P + G)} = \frac{0.000398A_{TU}}{(1 - A_{TR}/A_{TU})^2} \cdot \frac{L_{TR} \cdot V^2}{(P + G)} \cdot \\
&\quad \left(1 - \frac{1}{1 + \sqrt{(174.419(1 - A_{TR}/A_{TU})^2 + 2.907 \frac{(1 - A_{TR}/A_{TU})^2}{4A_{TU}/P_T} (L_{TU} - L_{TR}) / L_{TR}}}} \right)^2
\end{aligned}$$

Let

$$\begin{aligned}
A &= \frac{0.000398 \times A_{TU}}{(1 - A_{TR}/A_{TU})^2}, \quad B = 174.419(1 - A_{TR}/A_{TU})^2, \\
C &= 2.907 \frac{(1 - A_{TR}/A_{TU})^2}{4A_{TU}/P_T}
\end{aligned}$$

Then:

$$r_T = \frac{AL_{TR}}{(P+G)} \cdot V^2 \cdot \left(1 - \frac{1}{1 + \sqrt{\frac{B+C(L_{TU}-L_{TR})}{L_{TR}}}} \right)^2$$

In this formula, V is the speed of train in kilometers per hour. Others are as before.

Regarding the complex for computation, TCP suggested using the following simplified formulas for computing the united tunnel resistance:

$$\text{With rulling grade in tunnel : } r_T = L_{TU} \times V_{TU}^2 / 10^7 \text{ (N/t)}$$

(2.43)

$$\text{With no rulling grade in tunnel : } r_T = 0.00013 \times L_{TU} \text{ (N/t)}$$

(2.44)

where LTU is the length of tunnel (m); LTR is the length of train (m); P is the computational mass of locomotive axle load (t); G is the tractive mass (t); and VTU is the running velocity of train in tunnel (km/h).

Equivalent Grades of Additional Resistance and Total Conversion Grade

Equivalent Grades of Additional Resistance

It is frequently convenient to express curve resistance and tunnel resistance in terms of the equivalent grade that would offer the same resistance.

According to the calculative formula of unit grade additional resistance (Eq. 2.33), the additional resistance of curve and tunnel produced by grade of i_c and i_t , respectively, makes

$$r_r = 10i_r \text{ (N/t)}, \quad r_t = 10i_t \text{ (N/t)}$$

Thus curve resistance of r_r or tunnel resistance of r_t is equivalent to the unit grade resistance of $10i_r$ (N) or $10i_t$ (N) of the resistance offered by an i_r grade or i_t grade. In other words, the unit resistance of an R curve is the same as the resistance that a $600/R\text{‰}$ grade would offer. One can convert curve resistance to the equivalent grade, which is added to the profile grade and then used to compute the combined effects in one operation. However it is handled, curve resistance should not be overlooked. Therefore, we call i_r and i_t curve resistance conversion grade and tunnel resistance conversion grade, respectively, or curve equivalent grade and tunnel equivalent grade.

Total Converted Grade and the Average Unit Train Resistance

Total converted grade i_{con} refers to the sum of grade of profile i and the equivalent grade of curve resistance and equivalent grade of tunnel resistance in the same section, that is

$$(2.45)$$

The corresponding unit of additional resistance is

$$r_{con} = r_i + r_r + r_t = 10i + 10i_c + 10i_t \text{ (N/t)}$$

$$(2.46)$$

According to the idea of converted grade, if a 6000 m curve occurred on the 6‰ grade, the effective gradient would be 0.1+6, or 6.1‰. The total unit resistance would then be $6 \times 10 + 0.1 \times 10$, or 61 N/t.

The total resistance of a train is

$$R = R_0 + R_{con} = [P \times r'_0 + G \times r''_0 + (P + G)i_{con}] \times g \text{ (N)}$$

Or

$$R = R_0 + R_{con} = [M \times r''_0 + M^* i_{con}] \times g \text{ (N)}$$

The average unit resistance of a regular train is

$$\text{For ordinary train : } r = \frac{R}{P + G} = r_0 + r_i + r_r + r_{TU} \text{ (N/t)}$$

(2.47)

$$\text{For high-speed EMU train: } r = \frac{R}{M} = r_0'' + r_i + r_r + r_{TU} \text{ (N/t)}$$

(2.48)

Other Additional Resistance

Except for various additional resistances described above, there are other resistances caused by wind or cold climate conditions.

As the basic resistance formula of the locomotive and vehicle were conducted under a certain condition of climate test, so if the climate changes, the basic resistance of train will also change. The direction of the wind resistance is opposite to the running direction of the train, the resistance of the train increases. The direction of wind resistance is the same as the running direction of the train, the resistance of the train decreases. If the wind blows from the train's side, it will increase surface friction of the train, and the wheel flange gets close to the rail side, leading to greater friction. At the same time, the bearing of sliding friction between the wheel and rail is also exacerbated. The longer the train is, the greater the additional resistance is. Therefore, lateral wind is unfavorable to the train's operation.

In winter, in some areas the temperature is very low, and this will lead to additional resistance when a train runs. Due to viscosity, the lubricating oil of bearings increases as the temperature drops. The friction coefficient and friction resistance increase as well. The temperature decreases at the same time that air density and air resistance increase.

For the change of parameters above, the additional resistance should be determined by a specialized test, or appropriate measures should be applied to reduce the quality of traction.

Air resistance is based on the friction and other effects of still air. When a head wind is blowing, its resistive effects may be combined with air resistance by adding the opposing wind velocity to the speed of the train in the air resistance term only. The effects of tail winds or quartering in the direction of train movement are usually ignored. An opposing quartering wind probably offers the greatest resistance because it acts against the broad side of the train. It not only opposes forward movement but also can increase flange resistance by forcing the car wheels against the rail opposite to the wind direction. Turbulence and frontend effects are increased when car doors are open. Maximum side-wind resistance seems to occur when the angle of yaw is about 60° for wind speeds above 35 km/h. Wind direction may vary from tail to quartering winds within a few kilometer because of track curvature. It is not, however, an entirely academic subject. In an area with prevailing winds, tonnage reductions based on past experience may be observed in building trains.

2.1.2.4 Starting Resistance

The resistances thus far considered are those of the train in motion. Additional resistance is encountered when starting to overcome the inertia of the train and the low temperature of journal lubricants. When locomotives and vehicles stay on the rail, lubricating oil between journal and bearing will be squeezed out, and the oil film will become thin. At the same time, the temperature is dropped in the axle box, oil viscosity will become bigger, thus starting, and friction resistance between journal and bearing increases. In addition, the rail concave deformation when wheels stay on the rail is greater than runtime, and this will also increase the rolling resistance. On the other hand, it requires a larger acceleration forces to overcome the static force of inertia of the train at starting time. TCP considers that the starting acceleration should be also included in the starting resistance. Therefore, we should calculate the resistance when the train starts separately.

According to the experimental results of China railways, the starting resistance calculation of the train uses the following formula, which already includes the basic resistance and the additional starting resistance.

1. Starting resistance of locomotive

Diesel and electric locomotive $r'_t = 50 \text{ (N/t)}$

(2.49)

2. Starting resistance of vehicle

For rolling bearing vehicle $r''_t = 35 \text{ (N/t)}$

(2.50)

For sliding bearing vehicle $r''_t = 30 + 4i_t \text{ (N/t)}$

(2.51)

where i_t is the grade at starting section (‰). For sliding bearing truck, r''_t takes 50 N/t when the calculated result is less than 50 N/t.

Research of American railway assumed an average starting value of 80 N/t, with cold temperatures and long standing or poor lubrication it can be as much as 130, 140, or even 150 N/t. Resistance falls off rapidly as the train speed increases and the lubricants become warmer. At first glance this would seem to preclude starting the train, since tonnage ratings are based on the resistance offered by a train in motion. The entire train is not, however, started at one time. By reversing his engine momentarily, the engineman is able to bunch

the 15 cm of slack (on average) in the couplings of each car. As the locomotive then moves forward, it need start only one car at a time. Vehicles are placed in motion by a serial action moving back through the train. Starting a train on an ascending grade is a problem owing to the difficulty of bunching the slack. Sometimes the train cannot start and must be moved in two sections. Once in motion, starting resistance falls abruptly to the values given by the train basic resistance.

2.1.3 Braking Pressure of Train

To retard train movement artificially, including slowing down, stopping its motion or acceleration, is called braking. The operation to remove or reduce braking action from the train is called releasing. For braking and releasing the train, braking equipment is required.

The external force, which is produced by braking equipment and the direction is opposite to the train operation, is braking force; it is much larger than the train running resistance. Although the running resistance deters train motion during braking, the braking force still plays a major role.

2.1.3.1 Braking Modes

In terms of braking method, according to the kinetic energy transfer methods, there are three braking modes: friction braking, dynamic braking, and magnetic braking.

Friction Braking

At present, the friction braking generally use two modes: shoe brake and disc brake.

Shoe Brake

Shoe brake, also called tread brake, is powered by compressed air produced by the device of the air compressor on the locomotive, which drives brake shoes of locomotive and vehicles to press the wheel tires, and translate train's kinetic energy into heat energy, which dissipates in the atmosphere through the mechanical friction between brake shoe and wheel tread, and produces brake force. This method can produce a large braking force. Compressed air is used as the power, therefore this is called an air brake.

Disc Brake

The principle of disc brake is the same as shoe brake. Brake discs are installed on the axle or the side of car spokes board, brake champs make two brake shoes tightly suppressing dynamic plate profile while braking. Friction between the mechanical brake shoe and brake disc profile leads to braking effect, which converts kinetic energy into heat energy that finally dissipates in the atmosphere.

Compared with shoe brake, disc brake has the following advantages:

1. greatly reduce the surface heat load and mechanical abrasion of wheel tread;
2. can choose the best brake friction pair according to requirements; and
3. smooth braking, with almost no noise.

Therefore, compared with the shoe brake, disc brake is more suitable for high-speed EMU.

A system of air brakes is used on North American railroads to keep under safe control and to keep the momentum storing in a moving train. The European system of vacuum brakes is similar, but has the disadvantage of involving more difficulty in maintaining a vacuum than maintaining air pressure.

Dynamic Braking

Dynamic braking makes the wheels of the locomotive or vehicles drive the power transmission device, which produces an adverse effect, thus consuming the kinetic energy of train and producing a braking effect. For example, the hydraulic brake of hydraulic transmission internal combustion engine vehicle, the resistance brake of electric drive diesel locomotive, electric locomotives and EMUs, the regenerative brake of electric locomotive and electric vehicles, etc., which all belong to the category of dynamic brake.

Rheostatic Brake and Regenerative Brake

Using reversible principle of motor, the motor installed on electric locomotive and electric transmission diesel locomotive can be used as a generator. Under the effect of inertia force, driving wheel drives the drive gear, which makes the motor rotor rotate to generate power in order to produce braking torque to achieve the braking purpose. Because the electric energy produced by the motor is consumed by the rheostatic of the locomotive, it is called the rheostatic brake. If energy is used to feed the electricity grid, it is called regenerative braking.

Regenerative braking is more economic than resistance braking. Therefore, since the 1990s the regenerative braking has been widely applied in the EMU.

Hydraulic Brake

In the hydraulic transmission of the internal combustion locomotive, taking advantage of inertia motion of locomotive wheel, the drive gear drives the rotor inside the braking unit to make it spin in working oil. The working oil is accelerated in the rotor and decelerated in stator, generating a counteractive torque on the rotor. This torque is passed to the locomotive traction wheel to produce the hydraulic braking force.

The braking force of rheostatic is restricted by maximum braking current of traction motor, and the hydraulic braking force is restricted by braking power, etc. At high operating speeds, the locomotive braking force decreases as the speed increases. When the running speed is lower than the minimum speed to generate electricity or the speed to produce reverse torque, dynamic braking does not work. When the speed reaches zero, the braking force disappears. According to TCP regulations, power braking is only used as speed regulating brake when a train is running. When calculating the maximum allowable speed of a downhill train or calculating the braking when the train arrives at a station, no dynamic braking should be taken into account.

Electromagnetic Brake

For electromagnetic brake, brake force is produced by electromagnetic force of eddy current which is caused by the relative motion between the electromagnet and the electromagnetic induction body on the bogie.

Electromagnetic brake includes magnetic track brake and eddy current brake.

Magnetic Rail Brake

There are two electromagnets which are installed on the same side of the bogie side frame between the two wheels, respectively. They are let down and compress rail with electromagnetic suction. Through brake force which was produced by the sliding friction between the abrasion plate on the electromagnet and rails, the kinetic energy is converted into heat energy, which dissipated in the atmosphere.

Braking force of magnetic rail brake is not generated by wheel/rail adhesive, and shall not be restricted by the adhesive force between the wheel/rail, thus a braking force can be obtained outside the adhesion force. Cooperation with other braking can produce a high braking force. During emergency braking, it can satisfy the requirement of high-speed EMU in terms of braking distance.

Eddy Current Brake

Eddy current brake includes two methods: track eddy current brake and rotating eddy current brake.

1. The track eddy current brake is similar to magnetic track brake, but the electromagnet is down to the rail surface only a few millimeters while braking, it is not in contact with the rail. It uses the relative motion to produce electromagnetic suction as braking force. The relative motion of the electromagnet and rail makes rail inducing eddy current, from the energy scheduling, it converts the kinetic energy of the train track eddy current brake into electricity, then it is converted into thermal energy, and dissipates in the atmosphere.

2. The rotating eddy current brake is equipped with a metal plate on the axle, when braking, metal plate rotates in the electromagnet formation of the magnetic field, the surface of the plate induces eddy current and electromagnetic suction, thus producing a braking effect. Energy conversion process of rotating eddy current brake is similar to track eddy current brake. The rotating eddy current brake is widely used in Shinkansen 100 series, 300 series, and 700 series trailer of EMU in Japan.

A friction brake can generate a large braking force; when the velocity is zero, it also can produce brake function, thus it is the most widely used in China.

Electromagnetic braking is nonadhesive, which means the braking force is not restricted by the adhesion force between the wheel/rail, but the braking action is achieved by using electromagnetic force, and this method is widely used in high-speed trains.

2.1.3.2 Braking Pressure

Air Braking Pressure

Air Brake System

Brake equipped on locomotive and vehicles is applied for air braking. Fig. 2.15 illustrates the principle.

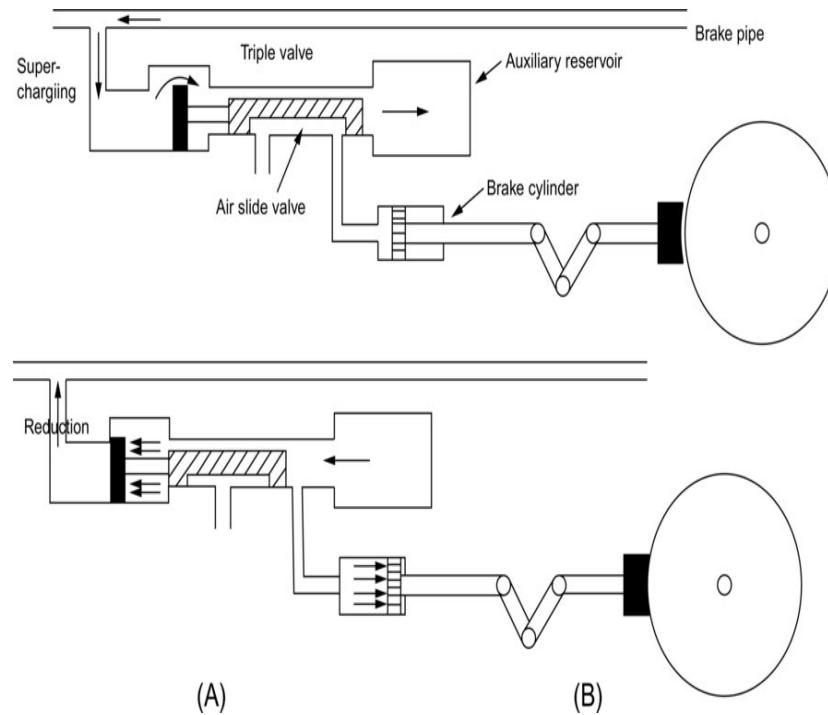


Fig. 2.15 Working principle of air brake: (A) releasing and (B) braking.

When releasing, the driver set the brake valve at releasing position, which makes the compressed air pass through the air cylinder, the brake pipe and the triple valve, and is finally stored in the auxiliary reservoir. At this time, there is no compressed air in the brake cylinder, and the brake shoe does not come into contact with the wheel, so this is called the wind filling remission.

When braking, a brake valve operated by driver interrupts the pathway of an air cylinder. At the same time the brake pipe is connected to the atmosphere and deflate decompression, while compressed air storage in auxiliary reservoir enters into the brake cylinder, driving the piston lever, making the brake shoe compress the wheel. It is therefore called the reduced pressure brake. The brake shoe pressure is associated with the decompression quantity of brake pipe.

Generation and Restriction of Brake Pressure

In the train stop process, a brake shoe bears against the revolving wheel treads with a radial force called the nominal brake shoe pressure P . Friction between the wheel and the brake shoe results in a tangential force F (Fig. 2.16), which is the braking force that resists the rotation of the wheel. Tangential force $F = Pf$, where f is the coefficient of friction between the wheel and the brake shoe. The nominal brake shoe pressure P equals the total force on the piston times the foundation brake rigging leverage ratio. Because of losses in the brake rigging levers, only a portion of the piston force P is available at the brake shoe, so that

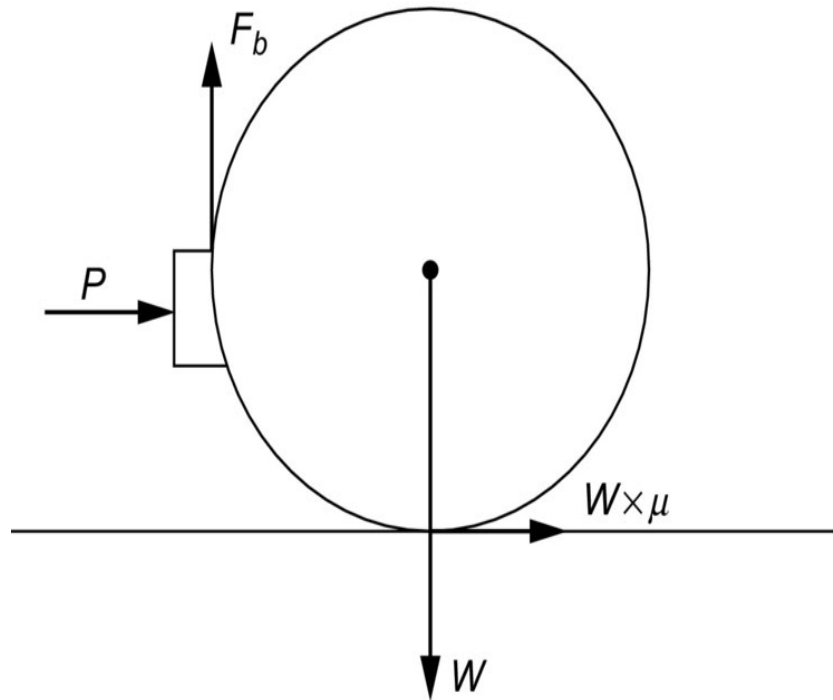


Fig. 2.16 Tangential force between the wheel and the brake shoe.

$$(2.52)$$

where f is the friction coefficient between brake shoe and thread or brake disc, its value is related to many factors, mainly the initial braking speed, operating speed, pressure of brake shoe, the material of brake shoe and wheel, etc.

e is the efficiency of the brake lever system, usually 90%–95%.

The retarding force of the brake shoe cannot be increased indefinitely. Referring again to Fig. 2.16, it can be seen that the wheel keep rolling as long as $W \times \mu \geq F$, where μ is the coefficient of static friction between the wheel and the rail, $W \times \mu$ is a maximum static friction force when the wheel rolls freely without slipping or sliding. When the wheel slips or slides, $W \times \mu$ becomes dynamic and of less magnitude.

Wheels will also slide as the result of excessive braking force. The braking force must be kept below $W \times \mu$ by a sufficient margin to insure that the wheels do not slide, even if the value of μ should drop excessively. The nominal brake shoe pressure P is commonly established, therefore, as a percentage of the empty weight W of the car. If the nominal brake shoe pressure (and thereby F_b) were based on the loaded weight W , the wheels of an empty car would slide. The practice has been to take something less than the empty or tare weight W related to that empty weight by the braking ratio R . The brake pressure P thus becomes the product of the braking ratio μ and the light weight of the car in tons. Similar to the tractive force, braking force is also limited by adhesive conditions between the wheel/rail, namely

(2.53)

where μ is the coefficient of friction between the wheel and the rail, or adhesion coefficient between wheel/rail; W is the axle loads on each wheel set, in tons; and f is the coefficient of brake friction, its value is based on the nominal braking pressure. It is not a constant but changes with the range of deceleration. Values of the dynamic coefficient between the wheel and the brake of friction shoe can only be determined satisfactorily by experiment.

From which a braking ratio can be computed. Because of variations in car weights, both loaded and empty, the selection of a braking ratio and the accordingly derived braking force must be considered only approximate, then

(2.54)

Using the brake shoe pressure on the unit axial load to express the inequality above as

(2.55)

is the unit brake shoe pressure, expressed by p . It should meet the requirement of the type when designing braking device of locomotive and vehicles.

Train Braking Pressure

The sum of the braking force of all shafts of the train is known as the train braking force, namely

(2.56)

There are factors in the braking formula that are difficult to determine with a high degree of accuracy. The coefficient of friction varies with the instantaneous speed and with the surface condition and type of metal in the wheel and brake shoe. Adhesion depends on conditions of rail and wheel and on the use or misuse of sand. Brake cylinder stroke may vary within wide limits. The rate and time of propagation of brake application vary with brake valves. Not all brake valves function at the same rate. No two enginemen handle their air in exactly the same way. For these and other reasons, experience has shown that

the theoretical values should be elevated by 25%–30%. Therefore, in the design of railway, engineer always employs a conversion method to compute the braking pressure.

Conversion method assumes that the brake shoe friction coefficient has nothing to do with brake shoe pressure, in order to simplify the calculation, using conversion coefficient of friction ϕ_h which is not changed with brake shoe pressure instead of the calculate coefficient of friction ϕ_K .

At present, according to all kinds of vehicle brake shoe pressure in our country, the average of the brake shoe pressure is 25 kN, the conversion formula for the friction coefficient is

$$\text{Phosphorus in the shoe } f_c = 0.356 \times \frac{3.6V + 100}{14V + 100} + 0.0007 \times (110 - V_0)$$

(2.57)

Among them, V and V_0 is the running speed and initial speed in braking respectively (km/h).

When calculating running time or unit force, using conversion friction coefficient formula which has parameter of original braking speed correction term can cause great difficulty. For this reason, we can use a simplified formula conversion of phosphorus in the brake shoe friction coefficient

(2.58)

According to the pressure of each brake piece, P is equal to 20 kN and converted to W tons of the wheel tread surface, the conversion friction coefficient of disc-shape dynamic brake is calculated, namely

(2.59)

Braking force calculated with the conversion friction coefficient shall be equal to actual values, therefore, the brake shoe pressure P also shall be converted to the conversion pressure of brake shoe, namely

$$P_c = P \times \frac{f}{f_c}$$

Conversion pressure of brake shoe of each vehicle is calculated according to the following formula.

(2.60)

conversion pressure of phosphorus brake shoe, which China's railway locomotive, vehicle use at the time of each vehicle emergency braking, is calculated according to the formula above and they are shown in Table 2.7.

Table 2.7

Brake Shoe Pressure of China Railway Locomotive, Vehicle Emergency Braking

The Type of Locomotive or Vehicles	Pressure Air of Train Pipe (kPa)
Type 120 or 103 brake, high friction composition brake shoe, tag load is 61 t	500
Heavy car 310	350
Empty car 180	210
Type GK, 120 or 103 brake, tag load is 50 t or over	Heavy car 250
Empty car 160	160
K2 brake	Tag load is 50tor over
Tag load is 40 t (include 25 t and less than 40 t Refrigerator car)	140
K1 brake, tag load is 30 t	120
Caboose	90
L3, GL brake (closing additional air cylinder), 104 brake	—
104 and F-8 brake, disc-shape device, high friction synthetic brake piece	Single bus
Double-deck bus	—
DF, DFH3	550
DF2, DFH2, NY6, NY7	500

DF4, DF4B, DF4C, DF4D, DF4E, DF5, DF7, DF8, DF11	650
DF7B, DF7C, DF7D (all are low friction composition brake shoe)	720
DF8B (powder metallurgy brake shoe)	450
SS1, SS3, SS6	700
SS3B, SS6B (high friction composition brake shoe)	300
SS4, 8 K (high friction composition brake shoe, single section)	200
SS7	840
SS8 (powder metallurgy brake shoe)	280

Train braking pressure is

$$(2.61)$$

where is the sum of conversion pressure of brake shoe of locomotive (kN); and is the sum of conversion pressure of brake shoe of vehicles (kN).

Other symbols keep the same meaning as previously.

Unit Brake Pressure of Train and Conversion Pressure of Brake Shoe of Train

According to conversion pressure of brake shoe and conversion friction coefficient, unit brake force of train b is calculated as following

$$b = \frac{B \times 10^3}{W} = 1000f_c \times \frac{\sum P_c}{W} = 1000f_c \theta_c \text{ (N/10t)}$$

(2.62)

where W is the weight of train (t), ordinary trains is $P+G$; f_c =conversion friction coefficient between the brake shoe and tire (owing to the different shoe material, calculating running time of hybrid brake shoe train with phosphorus, high and low phosphorus, the conversion coefficient of phosphorus brake shoe friction can be used); and θ_c is the conversion rate of train brake (it is the ratio of train conversion pressure of brake shoe to the gravity of the train, and it also refers to the average brake shoe pressure allocated on per kN of the train gravity. According to the management regulations of railway technology, θ_h shall not be less than: 0.28 for freight train, 0.58 for ordinary passenger train, 0.32 for fast passenger train with plate shape and high friction synthetic brake piece. For general freight train, it is allowed to be calculated with the formula , if calculated grade is under 20‰.

While emergency braking, the train brake conversion rate θ_c should take full value; while the train running into the station, it generally take the value of 0.5; while calculating the distance to stationary signal, it take the value of 0.8.

Dynamic Braking Pressure

Dynamic braking performance is quite different with air brake: under high speed, braking force increases with the decreasing of speed, and under low speed braking force decreases with the decreasing of speed. On long and big ramp road, the dynamic braking can make the train safely with greater speed and improve the line capacity. Through the station or slowing section, dynamic braking is used for deceleration with less abrasion of wheel and shoe. However, the power braking system can only be found in locomotive-hauled trains and EMU trains, so it is not a substitute for the air brake and can only be as a kind of auxiliary braking. Because braking force decreases with the decreasing of velocity at low speed, it has to rely on air brake in low speed and parking condition.

Calculation of dynamic braking force is similar to the traction power. Thus, based on braking characteristic curve, it is solved with linear interpolation or curve fitting method. In the case of electric braking, the calculation method of dynamic braking will be introduced.

Principle of Electric Braking

Downhill inertia drives the motor armature to rotate, converting the motor into generator, which is driven by the wheel, and the kinetic energy of train is converted into electricity. For Resistance brake, it uses brake resistance to convert the electrical energy into heat energy and dissipates the heat. For regenerative braking, the electrical energy feeds to the electricity grid. Fig. 2.17 is rheostatic braking circuit diagram. The input power of traction motor D is cut off and the circuit is connected with the braking resistance R . Separately excited motor is applied instead of series-excited motor, field current is supplied by another power source after the field windings are wound in series. Its magnitude can be adjusted, which means the braking force can be adjusted, so as to control train operation speed.

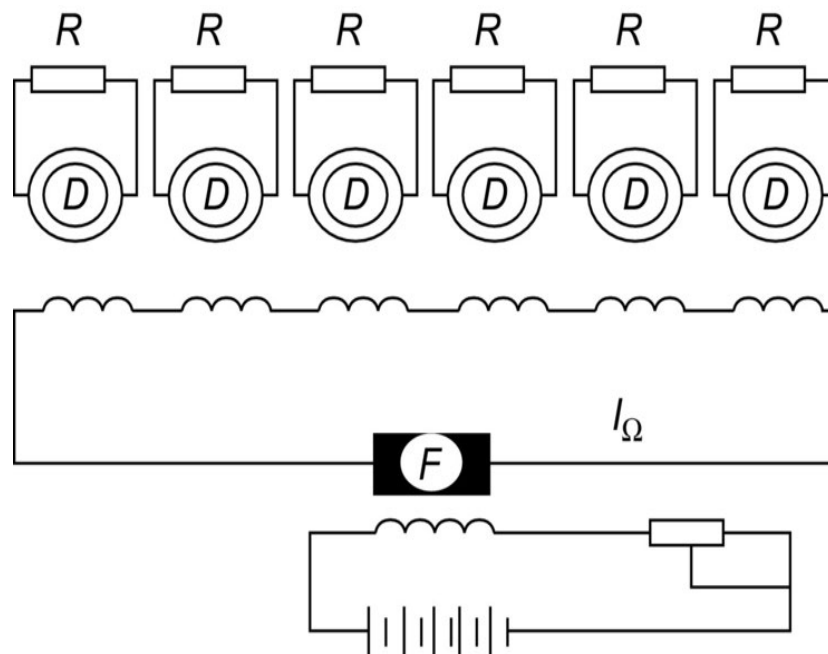


Fig. 2.17 Rheostatic braking circuit diagram.

Braking Resistance Characteristic Curve of an Electric Locomotive

[Fig. 2.18 shows the outsourcing curve of resistance braking characteristic of an SS3 electric locomotive. In this figure, the straight line at left is the maximum limit line of excitation current; the curve at the right side is the maximum braking current \(motor armature current\) limit line, a high braking current can damage electrical safety rectification. Because the exciting current can be adjusted stepless, thus the necessary braking force can be provided according to the operational needs within the limit.](#)

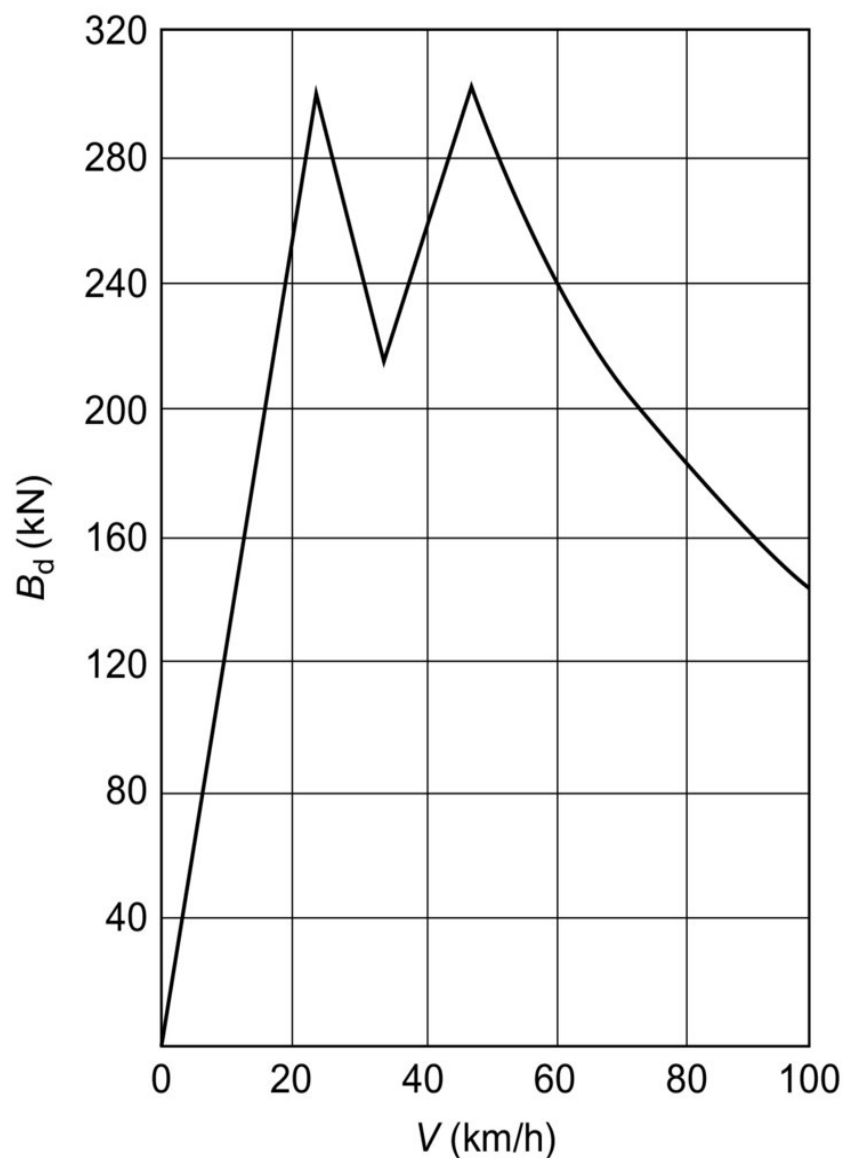


Fig. 2.18 Rheostatic braking characteristic curve of an SS3 electric locomotive.

Rheostatic Brake Characteristic Curve of a Diesel Locomotive

[Fig. 2.19 is the outsourcing curve of rheostatic braking characteristic of DF4Bb \(freight\) diesel locomotive, its corresponding diesel engine speed is 850 r/min. In order to provide the required braking force for train operation, the other speed has their respective characteristic curve.](#)

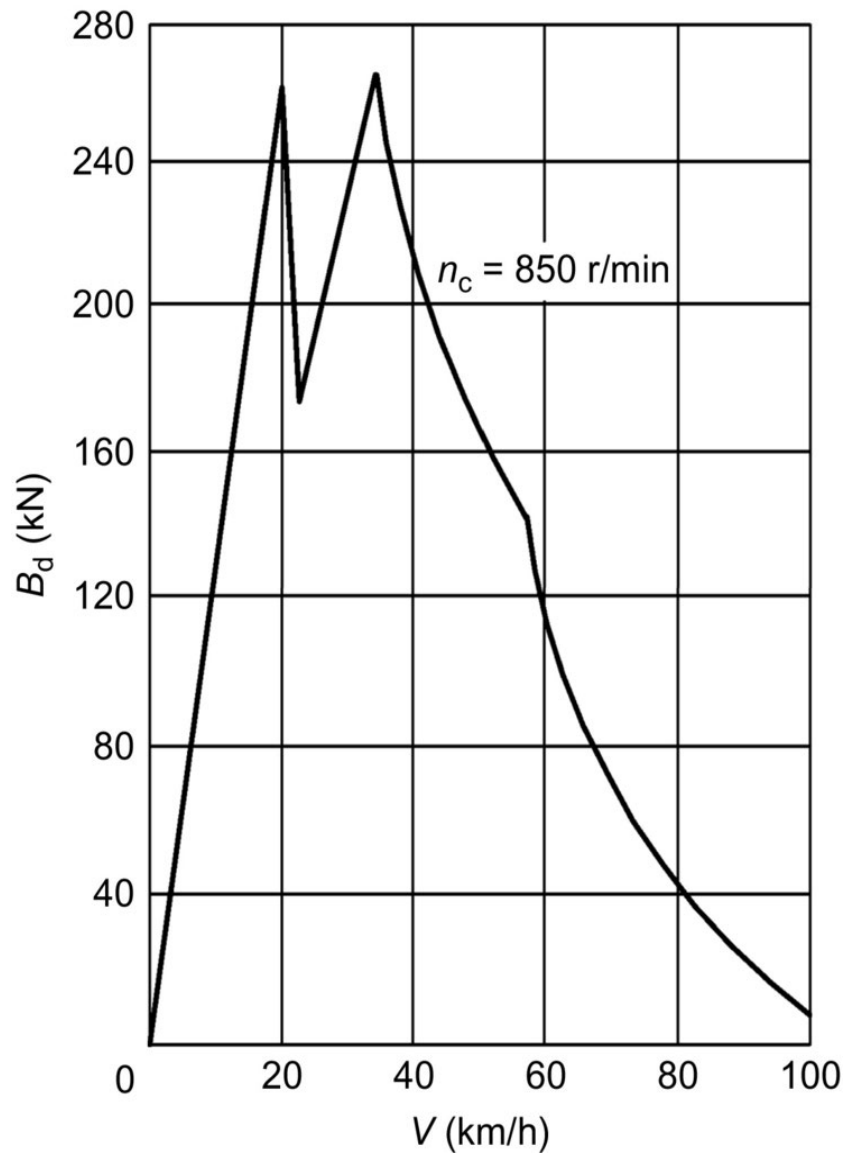


Fig. 2.19 Resistance braking characteristic curve of a DF4Bb (freight) diesel locomotive.

Regenerative Braking Characteristic Curve of a High-Speed EMU

Fig. 2.20 shows the performance curve of regenerative braking of each CRH2 EMU. All axle of CRH2 EMU have electric braking, the electric braking system consists of pantograph, traction transformer, traction converter, and traction motor. CRH2 EMU has the common brake of level 1-7. For service braking, it is controlled according to speed—adhesive characteristic curve, it has adjustment function of empty or heavy vehicle load; the braking force can be adjusted according to the load. When the operation speed of a train is low, the electric braking force will be sharply attenuated. Therefore, electric braking is not used when the operation speed is lower than 15 km/h. The speed range 15–70 km/h is the VVVF control of constant force (or torque) area. When the speed range is 70–250 km/h, the braking force is restricted by the power of motor and decreases with the increasing of velocity. Deceleration characteristics of regenerative braking which is commonly used in the highest level are as follows: 0.747 m/s² when the speed is under 70 km/h; 0.619 m/s² when the speed is 118 km/h to; and 0.505 m/s² when the speed is 200 km/h.

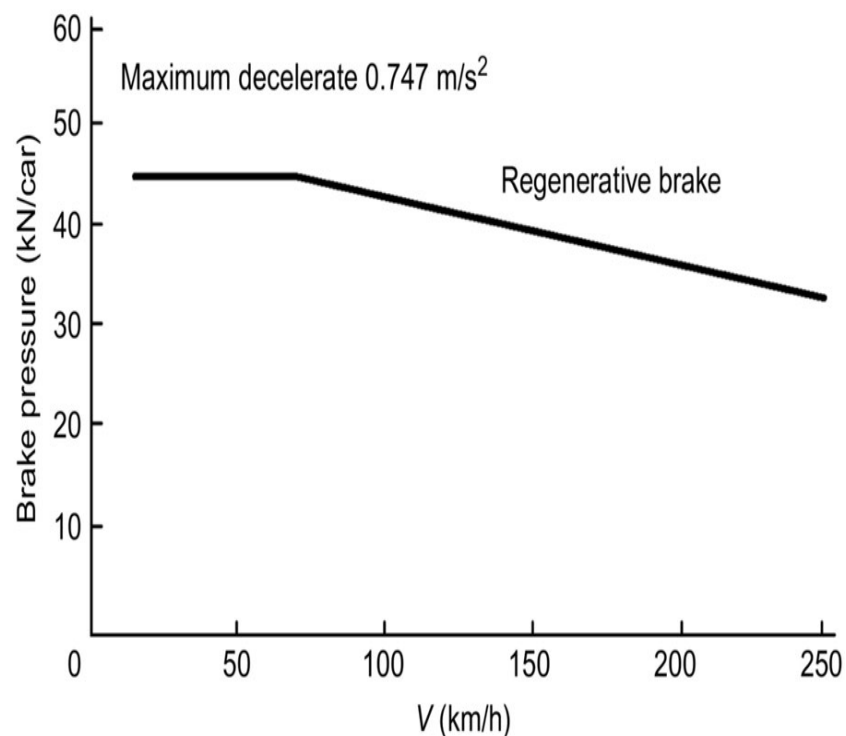


Fig. 2.20 CRH 2 EMU regenerative brake characteristics.

The Determination of Necessary Electric Braking Pressure

If adopting electric brake control, i.e., with a certain limit on constant downhill speed, according to 0 resultant force, the electric braking force required $B_{e(N)}$ can be calculated.

$$\begin{aligned} \text{By: } (P + G) \times i_c - P \times r'_0 - G \times r''_0 - B_{e(N)} &= 0 \\ B_{e(N)} &= (P + G) \times i_c - P \times r'_0 - G \times r''_0 \text{ (N)} \end{aligned}$$

(2.63)

where $B_{e(N)}$ is the electric braking force required (N); r'_0, r''_0 is the unit of basic resistance of locomotive and vehicle which are calculated at the limit speed (N/10t); and i_c is the absolute value of equivalent grade in section of train running (‰).

Once $B_{e(N)}$ is obtained, the corresponding electric braking characteristic curve can be checked according to the machine type. If $B_{e(N)}$ is within the range of application, resistance braking can be used to control the train operating with a constant downhill speed (limit speed). If $B_{e(N)}$ is beyond the range of application, the air brake will still need to be used to make the train operating at the limit speed together with electric braking.

Example 2.1

Railway line for mixed passenger and freight traffic, SS3 electric locomotive, locomotive mass $P=138$ tons, tractive Mass $G=2620$ tons, traction rolling bearing freight train; running on the slope of 9‰, limited speed is 77 km/h, try to solve the question that whether it can control the train at a limited speed constantly downhill by using the resistance brake method.

Solve

$$r'_0 = 22.5 + 0.19 \times 77 + 0.0032 \times 77^2 = 56.10 \text{ (N/t)}$$

$$r''_0 = 9.2 + 0.048 \times 77 + 0.00125 \times 77^2 = 20.31 \text{ (N/t)}$$

$$B_{e(N)} = [(138 + 2620) \times 9 - 138 \times 56.10 - 2620 \times 20.31] = 183,707.9 \text{ (N)}$$

In Fig. 2.18, when $V=77$ km/h, the maximum rheostatic braking force provided is 188,000 N, $B_d(x)$ is within the using scope, so only using rheostatic brake can control a train operating at the limit speed.

2.2 Train Motion Equation

Section 1 has analyzed the formation of locomotive or EMU tractive effort, train running resistance, and braking pressure. This section will discuss the mathematical relations between acceleration (deceleration) and resultant force while three different forces are acting on train; this is the train motion equation. We then employ the motion equation to solve some practical operating problems, such as traction mass, running speed, running time, braking, etc.

2.2.1 Train Motion Status

Train movement states (acceleration, constant velocity, deceleration) depends on the resultant force acted on the train, the magnitude of resultant force relates to the working condition of locomotive and profile conditions of lines. A locomotive has three working conditions:

1. Tractive operation. At this working condition, the force acted on the train includes tractive force F and running resistance force R , the resultant force C is

$$C = F - R$$

2. Coasting operation. At this condition the force acting on the train is only running resistance force R , so the resultant force C is

$$C = -R$$

3. Braking operation. At this condition the forces acting on the train includes running resistance force R and braking force B , so the resultant force C is

$$C = -(R + B)$$

As F , R , and B change with the speed, the resultant force C also varies with speed. When $C > 0$, a train runs to accelerate; when $C = 0$, a train runs at a constant speed; and when $C < 0$, the train runs to decelerate.

2.2.2 Train Movement Equation

The time and distance required to bring a train to maximum operating speed following a stop or a speed reduction directly affects the overall running time and track capacity, especially in a commuting service, where stops are frequent. A slow-accelerating locomotive might not attain its maximum operating speed in the short distance between station stops. Switching and yard service, where stops and starts are frequent, also places a premium on rapid

acceleration, an advantage inherent in electric and diesel-electric locomotives.

Only that portion of tractive effort not required to overcome other terms of resistance is available for acceleration. Acceleration itself may be considered a form of resistance.

The ability to attain speed is important, but even more important for safe operation is the capability of controlling that speed. A tremendous amount of momentum is stored in a moving train.

2.2.2.1 General Form of Train Movement Equation

The equations of train movement can be derived by using Newton's second law of motion.

Movement of train consists of two parts: translation of train and rotation of wheels. Kinetic energy is the indication of ability to do work. From physics, kinetic energy of translational motion is ; it is a measure of the amount of work required to impart a speed of v in mph to a mass m in kilograms; kinetic energy of rotation is ; it is a measure of the amount of work required to impart a angular speed of ωR in radian per second to a moment of inertia J , therefore, the total kinetic energy KE of the train movement can be computed as follows:

$$KE = \frac{mv^2}{2} + \frac{\sum J\omega_R^2}{2}$$

If the average radius of rotation part is R_a , then

$$KE = \frac{mv^2}{2} + \frac{\sum Jv^2}{2R_a^2} = \frac{mv^2}{2} \left(1 + \sum \frac{J}{mR_a^2} \right) = \frac{mv^2}{2} (1 + \gamma)$$

where m is the mass being accelerated in kilograms; v is the running speed of train in meter per second; J is the moment of inertia of rotating parts; ω_R is the angular velocity of rotation parts in radian per second; R_a is the average rotation radius of rotation part, in meters; and γ is the mass coefficient of rotation parts. In China, it allows about 5%-11% for rotation effort. For ordinary trains it takes 0.06 generally, for centralized power EMU it takes 0.06-0.08, for power distributed EMU it takes 0.08-0.11.

If we regard the train as rigid system, its kinetic energy increment is

$$dKE = m(1 + \gamma)v dv$$

According to the law of kinetic energy, the increased kinetic energy of rigid system is equal to the work which has been done by all forces on the system in this period. And in this period the work the resultant force C in newtons acted on the train is $C \times v \times dt$, so

$$m(1+\gamma)v dv = C \times v \times dt$$

$$\frac{dv}{dt} = \frac{C}{(1+\gamma) \times m} (\text{m/s}^2)$$

This is the basic equation of train movement.

For practical use, speed should be expressed in kilometers per hour, M in tons, and the numerical value used for g.

Taking $m=1000 M$ and $V= 3.6 v$ to the equation of acceleration, it then becomes

$$\frac{dV}{dt} = \frac{C \times 3600^2}{(1+\gamma) \times 1000 \times 1000M} = \frac{12.96C}{(1+\gamma)M} = \frac{12.96}{(1+\gamma)} c$$

where c is the unit resultant force (N/t).

Let ; it is known as the acceleration coefficient, that is, the acceleration produced by the resultant force of 1 N/t. Taking it in the above formula, we obtain

$$\frac{dV}{dt} = \zeta \times c$$

The equation above is the general form of the train movement equation. Acceleration coefficient ζ depends on the value of rotary mass coefficient, and varies with different locomotive or vehicle type. If takes $\gamma=0.06$, ζ in round numbers, the equation becomes

(2.64)

If the reciprocal of the acceleration at various speeds and values of c is given, the integration of the equation represents the time required to attain those various speeds. Integrating Eq. (2.64), the time to accelerate is found in the following:

$$t = \int \frac{dV}{12c} (\text{h}) = \int \frac{5dV}{c} (\text{min}) = \int \frac{300dV}{c} (\text{s})$$

(2.65)

The distance required to accelerate to any speed within the corresponding time is equal to the product of the speed and the time, whereby

$$S = \int dS = \int V \cdot dt = \int \frac{V dV}{12c} (\text{km}) = \int \frac{83.33V dV}{c} (\text{m})$$

(2.66)

The unit resultant force is related to work condition of locomotion and alignment condition (curve resistance, gradient resistance, etc.). Although traction, basic

resistance, and the braking force are functions of speed, curve and grade resistance are only related to the route conditions where the train is running. Therefore, the unit resultant force $c=f(V)$ varies from place to place and time to time. Methods for solving Eqs. (2.65), (2.66) include the direct integral method and approximate integral method. The approximate integral method is normally used.

2.2.2.2 Approximate Formulas of Train Movement Equation

Dividing the speed range between higher and lower speed into several smaller speed interval ΔV in Eqs. (2.65), (2.66), considering the unit resultant force in each small interval as constant c (for unit resultant force c_a at average speed in ΔV interval), setting V_1 and V_2 for the initial speed and final speed, respectively, in ΔV interval, the time and distance to accelerate can be computed with the approximate integral formulas.

The running time required to accelerate from a speed of is derived from the foregoing expressions, giving

$$(2.67)$$

The total time in the acceleration procedure is

(2.68)

The distance S required to accelerate from a speed of is found in a similar manner:

$$\Delta S = \int_{V_1}^{V_2} \frac{83.33V dV}{c_a} = \frac{41.7(V_2^2 - V_1^2)}{c_a} \text{ (m)}$$

(2.69)

(2.70)

The smaller the ΔV , the higher of calculation accuracy is in computation of time and distance. Generally, ΔV takes 5–10 km/h.

Under different work conditions, due to forces acted on train c_a in Eqs. (2.67), (2.69) has different forms:

Traction operation $c_a = f - r$

Coasting operation $c_a = -r$

Braking operation $c_a = -(r + \beta_b \times b)$

where f is the average unit tractive effort in ΔV speed interval, in N/t; , and according to the average speed , F can be found in traction performance figure; r is the Average unit resistance in ΔV speed interval, $r = r_0 + r_i + r_c + r_t$, V_a is

applied to calculate r_0 and r_s ; b is the unit train braking force, which can be calculated with Eq. (2.62); and β_b is the value coefficient of unit train braking force, take 1.0 for emergency braking, take 0.5 for service braking to enter station.

2.3 Tractive Tonnage

Tractive tonnage tell how many tons a given locomotive or locomotive consist can haul over a particular engine district. Comparative tractive tonnage over alternative routes can be a major factor in route location. In building trains, yardmasters need to know how many tons can be placed behind a given locomotive consist or power required to move a proposed tonnage.

2.3.1 Computation of Tractive Tonnage

The tonnage rating of a locomotive or locomotive consist is that tonnage which can be hauled at a specified minimum speed over a given territory.

2.3.1.1 Tractive Tonnage Factors

Chapter 1 and the former sections have demonstrated that the hauling capacity of a locomotive is a function of its power and tractive effort, speed, weight, as well as a function of gradient, curvature, and weather. This suggests

that a tonnage rating must be established separately for each class of motive power or consist and for each type of traffic and desired minimum speed. It varies from district to district, depending on the ruling grade of a district. For ordinary line, as the limiting factor on a territory is usually the ruling grade, a rating is the tonnage that can be hauled up that grade at a given minimum speed. For rapid line, as the limiting factor is usually the upgrading speed, a rating is the tonnage that can be hauled up on level track at a given minimum speed with certain acceleration allowance.

2.3.1.2 Tractive Tonnage on the Ruling Grade

On considering the ruling condition, the tractive tonnage is generally determined according to that the train runs ascending the ruling grade in uniform motion at calculated speed of a given locomotive.

According to the resultant force equilibrium conditions, when the train runs at a constant speed, the resultant force is zero, namely $F - R = 0$ or $F = R$.

Let the computed speed of locomotive for v_c , and corresponding computed tractive force for F_c , when a train running up the ruling grade i_{rul} in constant speed, the resultant force equilibrium condition becomes

$$\lambda_u F_c - P(r'_0 + 10 \times i_{rul}) - G(r''_0 + 10 \times i_{rul}) = 0$$

then

(2.71)

For multilocomotives traction, the tractive tonnage is

$$G_{ML} = \frac{\left(1 + \sum \lambda\right) \lambda_u F_c - \sum P(r'_0 + 10 \times i_p)}{r''_0 + 10 \times i_p} \text{ (t)}$$

(2.72)

where G,GML is the tractive tonnage of single locomotive traction or multiple locomotives traction in tons, taking the result in round numbers of 10 tons; is the mass of locomotive or the sum of locomotive in work order (ton); F_c is the computed tractive force of locomotive (N), for commonly used locomotives, values can be found in Tables 2.1 and 2.2; λ_u is using coefficient of locomotive traction, usually 0.9; i_r, i_p is the ruling grade, pusher grade (‰); r'_0, r''_0 is the basic resistance of locomotive, vehicles at computed speed V_c (N/t); and is the under the condition of multilocomotives traction or the pushing of banking locomotive, it refers to the sum of using traction coefficients of multilocomotive or banking locomotive. Theoretically, the tractive effort that two or more locomotives can exert together should be the sum of their drawbar pulls. Actually only about 90% of each can be realized because of the difficulties in securing perfect coordination between the two.

Therefore, for electric and diesel locomotive the value of λ takes as follows: 1 for multilocomotive traction; 0.98 when controlling the later machines; 0.95 when pushing banking locomotive.

2.3.1.3 Computation of Tractive Tonnage on Tangent Level Track

For the rapid railway, the tractive tonnage is determined according to the train operating on tangent level track at maximum speed and keeping certain acceleration allowance for conditions to determine.

Let maximum speed of train be V_{max} (km/h), the corresponding locomotive traction be F_m (N), unit basic resistance of locomotive and vehicle respectively be r'_{0m} and r''_{0m} (N/t), to keep the acceleration of allowance for a (m/s^2), tractive tonnage for G_m (t). After the deduction of the acceleration allowance, the locomotive traction F becomes

$$F = F_m - 1000 \times (P + G_m) \times (1 + \gamma) \times a(N)$$

The total train resistance R is

$$R = (P \times r'_{0m} + G_m \times r''_{0m})$$

When the train running at uniform speed, the resultant force $C=F-R$ should be zero, namely $F=R$, when γ takes 0.06, then

$$(2.73)$$

As stipulated in "Traction calculation procedures": when the highest speed $V_{\max}$ of passenger train is 120, 140, 160 km/h, the acceleration allowance of a respectively is 0.01, 0.015, 0.02 m/s², respectively. For freight train $a=0.005$ m/s².

Example 2.3

Railway line for mixed passenger and freight traffic, SS8 electric locomotive traction quasi high speed single passenger vehicles, maximum speed on the straight line is 160 km/h, to solve the hauled mass when train keeping acceleration allowance of 0.02 m/s².

Solution

For SS8 electric locomotive, when $P=88$ t, $V_j=48$ km/h, $V_{\max}=160$ km/h, $F_g=74100$ N.

$$r'_{0m} = 10.2 + 0.035 \times 160 + 0.00426 \times 160^2 = 124.9 (\text{N/t})$$

$$r''_{0m} = 16.1 + 0.04 \times 160 + 0.00187 \times 160^2 = 70.4 (\text{N/t})$$

$$G_m = \frac{F_m - P \times r'_0 - 1060P \times a}{r''_0 + 1060a}$$

$$= \frac{74100 - 88 \times 124.9 - 1060 \times 88 \times 0.02}{70.4 + 1060 \times 0.02} = 668.59 (\text{t})$$

So $G_m = 660 \text{ t}$.

2.3.2 Checking Tractive Tonnage

The tractive tonnage just described might be termed as “section” tonnage. Its derivation is based on the assumption that all trains are hauled by the same tractive effort, running up the given grade with the computed speed of uniform motion, hence the same resistance or an average value of resistance may be assumed. This assumption is obviously an approximation in some conditions, such as in stations, pusher grade section, etc. Therefore, the “section” tractive tonnage should be checked whether it is restricted by the following conditions:

1. starting conditions at stopping section;

2. effectively length of arrival and departure track of station;
and

3. the coupling strength.

If it is limited by one of the above conditions, it is necessary to reduce the tractive tonnage, or to take other technical measures to adjust the train tonnage.

2.3.2.1 Starting Check

As starting resistance is greater than train resistance in motion, it is necessary to check whether the train with “section” tractive tonnage can start smoothly after stopping.

The tractive tonnage G_s limited by starting condition can be computed in terms of the resultant force equilibrium condition that the locomotive traction F_s is equal to the total resistance when the train starts,

$$\lambda_u F_s = P(r'_s + 10 \times g_s) - G_s(r''_s + 10 \times g_s)$$

then

$$(2.74)$$

where F_s is the calculating starting tractive force of locomotive (N), for commonly used locomotives it can be found in Table 2.1 or Table 2.2; r_s' is the unit starting resistance of locomotive (N/t), for electric power and internal combustion locomotive it is assumed 50 N/t in China railway; r_s'' is the unit starting resistance of vehicle (N/t), it is calculated according to Eq. (2.50) or (2.51); and g_s is converted gradient of starting area (‰).

If $G_s \geq G$, train can start smoothly; if $G_s < G$, trains cannot start, and the “section” tractive tonnage G or the design grade of station should be reduced.

Example 2.4

(See Example 2.2.) It is known that the tractive tonnage $G=2560$ t, if the converted gradient of starting section $g_s=1.83$ ‰, try to check whether the train with G can start at the station.

Solution

Calculate starting traction effort $F_s=470,000$ N from Table 2.1, then according to Eq. (2.74),

$$G_s = \frac{0.9 \times 470,000 - 138 \times (50 + 10 \times 1.83)}{35 + 10 \times 1.83} = 7759.37 \text{ (t)}$$

As $G_s > G$, the train can start smoothly at the station.

Example 2.2

Railway line for mixed passenger and freight traffic, use SS3 electric locomotive, traction rolling bearing trucks. Compute the tractive tonnage of single locomotive traction at ruling gradient $g_r = 9\text{‰}$.

Solution

From Table 2.1: $V_c = 48 \text{ km/h}$, $F_c = 317,800 \text{ N}$, $P = 138 \text{ t}$. So

$$r'_0 = 22.5 + 0.19 \times 48 + 0.0032 \times 48^2 = 38.99 \text{ (N/t)}$$

$$r''_0 = 9.2 + 0.048 \times 48 + 0.00125 \times 48^2 = 14.384 \text{ (N/t)}$$

$$G = \frac{\lambda_u F_c - P(r'_0 + g_r \times 10)}{r''_0 + g_r \times 10}$$

$$= \frac{0.9 \times 317,800 - 138 \times (38.99 + 9 \times 10)}{14.384 + 9 \times 10} = 2569.54 \text{ (t)}$$

Taking G as the rounding numbers of 10 t, $G=2560$ t.

2.3.2.2 Effective Length of Arrival and Departure Track Checking

In order to guarantee operation work at station, a train must stop in the area of the effective length of arrival and departure track (or reception-departure track). For a given effective length of station departure line L_{yx} , the maximum tonnage G_{ad} can be computed using the following formula.

$$G_{ad} = (L_{ad} - D_s - N_{Loc} \times L_{Loc}) \times q \text{ (t)}$$

(2.75)

where L_a is the safety distance (m), generally take 30 m, value of which can be larger for overloading lines; L_{ad} is the effective length of arrival and departure track (m); L_{Loc} is the locomotive length (m), as shown in Table 2.1 or Table 2.2; N_{Loc} is the number of locomotives of the train; and q is the load per meter of train (t/m), taking 5.677 t/m.

If $G_{ad} \geq G$, the tractive tonnage is not restricted by the effective length of arrival and departure track.

Example 2.5

(See Example 2.2.) The effective length of reception-departure track is known as 650 m, checking whether the tractive tonnage is restricted by the effective length of reception-departure track.

Solution

$$G_{ad} = (650 - 30 - 21.7) \times 5.677 = 3390 \text{ (t)} > 2560 \text{ (t)}$$

Therefore the tractive tonnage is not restricted by the effective length of reception-departure track.

2.3.2.3 The Coupling Strength Checking

On a pusher grade, if multiple locomotives use multiheading traction, the coupling tension of the first car shall be the maximum value and may exceed the allowed strength. The train tonnage in a locomotive is limited by the pull force that the couplers can withstand. The tonnage restricted by

coupling tension G_c can be calculated using the following formula:

$$(2.76)$$

where F_c is allowed pulling force of coupler (N); g_p is gradient of pusher grade (‰); and r_s'' is the basic vehicle resistance on pusher grade computed in terms of the balancing speed (N/t).

If $G_c < G$, the train with G should not adopt double-headed tractive, and can only use pushing of banking locomotive in the rear.

Example 2.6

According to Example 2.2, the tractive tonnage $G=2560$ t, 4 N/t, van coupler for 13# coupler, checking whether the train can adopt double-headed locomotive traction on pusher grade of 18.4‰ g_p .

Solution

The allowance pull force of 13# Coupler $F_c=562,500$ N, then according to Eq. (2.76):

$$G_s = \frac{562,500}{14.38 + 10 \times 18.4} = 2835.47 \text{ (t)}$$

According to Eq. (2.72):

$$\begin{aligned} G_{ML} &= \frac{\left(1 + \sum \lambda\right) \lambda_u F_c - \sum P(r'_0 + 10 \times g_p)}{r''_0 + 10 \times g_p} \\ &= \frac{(1 + 1) \times 0.9 \times 317800 - 2 \times 138 \times (38.99 + 10 \times 18.4)}{14.38 + 10 \times 18.4} \\ &= 2573.32 \text{ (t)} \end{aligned}$$

As $G_c > G_{ML}$, the train can use double-headed locomotive traction on the pusher grade of 18.4‰.

2.3.3 Computation of Train Parameters

After determined the tractive tonnage of train, the number of vehicles, net loaded and the length of train can be calculated.

2.3.3.1 The Number of Vehicles of a Freight Train

The number of vehicles n , including caboose, can be calculated using the following formula with caboose:

$$(2.77)$$

without caboose:

$$(2.78)$$

where w_{cab} is the weight of the caboose (tons), taking 16 t for four axis caboose, 9 t for two axis caboose, and w_{ag} is the average gross weight of a wagon (t), taking 78.998 t.

2.3.3.2 Net Loading Capacity of a Freight Train

The net loading capacity of freight train G_{net} can be calculated using the following formula: with caboose:

(2.79)

without caboose:

(2.80)

where q_{net} is the average net weight per freight train (t), taking 56.865 t, and K_{net} is the net load coefficient of freight train, taking 0.72.

2.3.3.3 The Length of a Freight Train

The length of a freight train LL can be calculated using the following formula:with caboose:

(2.81)

without caboose:

(2.82)

where L_{Loc} is the locomotive length (m), as shown in Tables 2.1 and 2.2; L_a is the average length of each freight train (m), it takes 13.914 m; and L_{cab} is the caboose length (m), taking 8.8 m for four axis caboose, 7.7 m for two axis caboose.

2.3.4 The Tonnage Rating

In order to reduce the resorting work of through freight train at district station or marshalling station, enhance railway transportation capacity, and accelerate car turn-round, it is necessary to unify the tractive tonnage of same direction railway lines. This is called tonnage rating.

To determine tonnage rating is a comprehensive technical and economic problem; many factors need to be considered. It should be on the basis of analyzing the line profile and all technical measures to determine the reasonable traction tonnage. For determining the traction tonnage, the following principles should be considered:

1. Traction tonnage of adjacent district or adjacent railway line should be unified as possible, otherwise resorting capacity of district station or marshalling station should be taken into account. If a district station or marshalling station cannot be qualified for restoring working of each train, smaller traction tonnage should be selected.
2. On determining traction tonnage, the balance pairs of up train and down train, the problem of the reasonable

arrangement of empty and heavy traffic, and the transport tasks and carrying capacity of the entire district or railway at the same time, should be taken into account.

3. In order to determine traction tonnage, in addition to a series of calculation and checking, train movement simulation analysis is also required to check route profile design and dynamic rationality of train operation.

The empirical formula of basic resistance of locomotive and vehicle that is obtained under the assumption that the outside temperature is not lower than -10°C and the wind speed is no more than 5 m/s. The influence of the additional resistance which caused by lower temperature and wind is not taken into account. Therefore, in a cold or windy area or season, it is allowed to reduce traction tonnage by 10%–20%, but the running time and the consumption energy is calculated according to the original traction tonnage.

2.3.5 Adjusted Tonnage Ratings

The tonnage rating just described might be termed a “straight” tonnage rating. Its derivation is based on the assumption that all vehicles in the train have the same weight and hence the same resistance—or that an average value of resistance may be assumed which applies to vehicles of different weights. The latter assumption is obviously a crude approximation. The former situation may exist in solid trains of empty vehicles or loaded vehicles of products such as coal, iron ore, oil, and wheat. Passenger vehicles in any one train may also be assumed to have the same weight.

Ordinarily, however, a freight train is composed of full loads, part loads, and empties. Chapter 6 reminds the reader that the unit of train resistance varies inversely with weight. A straight tonnage rating based on empty vehicles with high unit resistance under loads a locomotive when loaded vehicles are hauled. A rating based on loaded vehicles will exceed the locomotive's capacity when empties are used. A solution to the problem would be the use of an adjustment factor that could be applied to vehicles of any weight to equalize the drag at the locomotive drawbar. Such a method was reported in Bulletin No.26, "Train Resistance and Tonnage Rating," prepared in 1915 by the Test Department of the Pennsylvania and other railroads.

2.4 Train Running Speed and Time

The running speed and running time of a train in the section is one of the important operation indications of railway, and it is also an important indicator to evaluate optimal design of railway and estimation the operating cost. In fact, the method of calculating the operating speed and running time of train is to solve the movement equation, on considering route condition. Unit force $c=f(V)$ is of great importance to solve the train movement equation. This section will introduce how to draw the unit resultant force curves first; then, based on this, the methods of calculating speed and running time will be introduced.

2.4.1 The Unit Resultant Force Curve

Although the computed resultant force may be used in location and train performance studies, the wide margin of error is a good reason for not placing too much using. Resultant force curves plotted for a specific train with given tractive rating and locomotive should be used wherever these curves are available. When preparing speed-distance and time-distance curves, we must have a set of resultant fore curves similar to Fig. 2.21, which show the unit resultant force in given speed on all grades to be encountered.

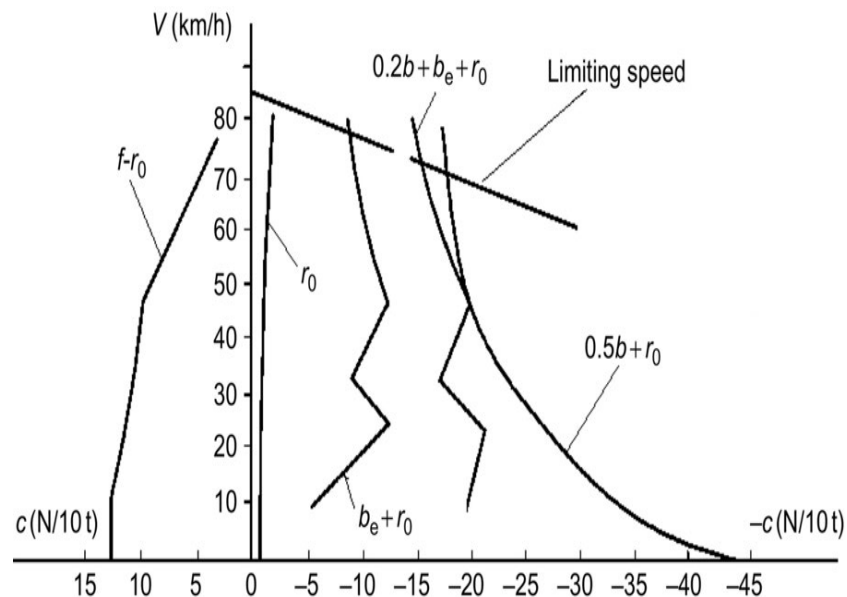


Fig. 2.21 Unit resultant force curves.

The resultant force curve graph is the coordinate graph which shows the relationship between unit resultant force and speed.

2.4.1.1 The Unit Resultant Force Curve Graph

As grade resistance, curve resistance, and tunnel resistance varies with planes and profiles where the train is. These resistances could not be taken into account while plotting the unit resultant force graph at first. The unit resultant force curve can be computed according to tangent level track. For specific applications, add the converted gradient to the resultant force in terms of the actual alignment where the train is passing through.

Calculation of Unit Force

First, list the calculated unit resultant forces at various speed under three conditions, and then plot the unit resultant force curve as Fig. 2.21.

[Table 2.8 is a specific example, listing the calculation content and order. The calculation points will be explained as follows:](#)

Table 2.8

Unit Resultant Force Curve Calculation Table of SS3 Electric Locomotive Single Traction Freight Train (irul=9‰, P=138 t, G=2 620 t, Vc=48 km/h, Fc=317 800 N,)

Operating Conditions	No.	V (km/h)				
		Formula	0	10	20	23.6
Traction	1	F(N)	373,680	373,680	348,750	
2	r ⁰ (N/10 t)	2.47	2.47	2.76	2.88	3
3	r ⁰ (N/10 t)	0.98	0.98	1.07	1.10	1

4	(N/10 t)	12.514	12.514	11.516		1
Coasting	5	(N/10 t)	1.035	1.035	1.129	1
Air braking	6	ϕh	0.356	0.264	0.214	0
7	(N/10 t)	92.56	68.64	55.64	47.06	
8	$c=0.5b+w0$ (N/10 t)	47.315	35.355	28.949	24.699	
Rheostatic braking	9	Bd(N)		127,800		3
10	(N/10 t)		5.669		12.108	
Air brake and braking resistance	11	(N/10 t)		19.397		2

Notes: (1) Column 3 r_0'' according rolling bearing heavy truck to calculate.

(2) Column 7 ϕ_h according to phosphorus braking shoe type of original TCP simplification to calculate.

i. Speed V : start from zero to the limit speed of level track, value is picked with the interval of 10 km/h, and the corresponding speed of all change points on the locomotive traction performance curve and dynamic braking curve should be listed in the table. When $V=0$, F , r_0' , r_0'' are calculated in terms of 10 km/h.

ii. Locomotive traction F : the F value corresponding with speed v from all the columns, which can be detected from the locomotive traction performance curves or tables. When using an outsourcing line, it should be multiplied by the using coefficient of traction λ_y (0.9). For diesel traction, it should be calculated according to Eq. (2.13) and then multiplied by λ_y .

iii. The unit air braking force b : only using air braking, it takes 0.5 b for common braking; it takes 0.2 b when air braking is used together with rheostatic braking.

iv. Rheostatic braking b_e : The value is taken in terms of the rheostatic braking characteristic curves or table.

Limited Speed of Down Grade

There is a limited speed curve for down grade in the unit resultant force curve graph; it will be used to determine the limited speed and running time of a downgrade train.

With a specified braking distance and conversion rate of braking, for safety, the train must go down the specific grade in speed of less than the maximum one. This is called brake speed limiting. The brake speed limiting can be calculated using the train motion equation.

While braking, from the driver moving the brake handle to the train completely stopping, the distance that train moved is called braking distance S_b . For emergency braking, at present the maximum braking distance used in Chinese railways is shown in Table 2.9. The limiting speed downgrade is the initial speed to stop a train at the emergency braking distance. For certain route conditions, the higher the braking capacity is, the higher the allowance limit speed is.

Table 2.9

The Limit of Emergency Braking Distance

Railway Type	Passenger Dedicated Line	Passenger and Freight Train Mixed Railway
Design speed (km/h)	350	300
Emergency braking distance (m)	4500	3500

The braking distance of train is the sum of idle running distance S_i and effective braking distance S_e , namely

(2.83)

Computation of Idle Running Distance S_i

Idle running distance S_i refers to the distance that trains run during the period from driver moving the lever to the brake shoes begin to work, namely

$$S_{idle} = \frac{1000V_i \times t_{idle}}{3600} = \frac{V_i \times t_{idle}}{3.6} (m)$$

(2.84)

where V_i is the initial speed during the emergency brake application time (km/h), and t_{idle} is the idle running time of emergency brake(s). This can be calculated with the following formula:

Passenger train:

Emergency braking:

$$t_{idle} = 3.5 - 0.08i_{con} (s)$$

Service braking:

$$t_{idle} = (4.1 + 0.002\gamma \cdot n)(1 - 0.03i_{con})(s)$$

Freight train:

Emergency braking:

$$t_{idle} = (1.6 + 0.065n)(1 - 0.028i_{con})(s)$$

Service braking:

$$t_{idle} = (3.6 + 0.00176\gamma \cdot n)(1 - 0.032i_{con})(s)$$

where i_{con} is the converted gradient, when $i_{con} > 0$, it is calculated in terms of $i_{con} = 0$; Γ is the brake pipe pressure reduction, kPa, it takes 50–200 kPa; n is the number of hauled vehicles; and t_{idle} is the same value as emergency braking, that is 2.5 s regardless of type.

Computation of Effective Braking Distance S_e

The effective braking distance S_e refers to the distance that train runs during the period from braking shoes begin to work to train completely stops. It is calculated using Eq. (2.66).

$$(2.85)$$

where V_i , V_f is initial speed and final speed of brake (km/h), and c is unit resultant force, in N/t:

$$c = -(r_0 + \beta_b \pm i_{on}) = -(r_0 + 1000g_{con} \times \phi_{con} \times \beta_b \pm i_{on}) (N/t)$$

Among them, β_b is the utilization coefficient of braking force. Others are as before.

If using approximate integral method, by using Eq. (2.70), c_a is computed in braking conditions, then

$$(2.86)$$

where V_1, V_2 is the initial and final speed within speed interval between upper and lower speed, and c_a is the unit resultant force according to the average speed $V_a = (V_1 + V_2)/2$ of every speed interval to calculate (N/t).

Computation of Limiting Speed

As the braking distance S_b is given, and the final speed of braking is zero, the initial speed V_i computed in above formula is the limiting speed. Taking and S_e into Eq. (2.83), S_b is

$$S_{\text{idle}} = \frac{V_i \times t_{\text{idle}}}{3.6} + \sum \frac{41.7 \times (V_2^2 - V_1^2)}{-(r_0 + 1000g_{\text{con}} \times \phi_{\text{con}} \times \beta_b \pm i_{\text{con}})}$$

(2.87)

In the above formula, the sign “±” indicates the direction of grade, for traction, work takes positive numbers, and for braking and coasting, work takes the negative sign.

One additional term can be added to obtain the full stopping distance. This is the engineman’s reaction time t_e , the time he or she takes to respond to a signal or emergency situation. It varies from 0.5 to 2.5 or 3.0 s, depending on the individual’s alertness, whether wide awake or drowsy or under the influence of drugs or alcohol. Reaction time and distance would be added to the value of t_b , and to S_b .

According to the calculation result of Eq. (2.87), the technical rules formulated the brake shoe pressure table of freight and mixed train using automatic brake, as shown in Table 2.10. The limiting downgrades speed can be obtained directly according to the conversion brake rate θ_h of the train from the table. It also can be approximately calculated in terms of the following formula:

Table 2.10

Limiting Speeds for Freight Train and Mixed Train (km/h) (Calculated Braking Distance is 800 m, High-Phosphorous Brake Shoe)

Grade (‰)	Conversion Pressure of Brake Shoe (kN) Per 100 Tons of Train Weight (Except for the Weight
24	26
0	80
1	79
2	78
3	78
4	77
5	76

6	75
7	74
8	73
9	72
10	72
11	71
12	70
13	69
14	68
15	67
16	66
17	65
18	64
19	64
20	64
22	62
24	60
26	58
28	56
30	54

(2.88)

For example, when $i=0$, limiting speed $V_{\text{limit}}=85$ km/h; on 10‰ downgrade, the limiting speed $V_{\text{limit}}=76$ km/h.

Drawing Unit Resultant Force Curve Graph

According to the results of Table 2.8, a certain scale plot of unit resultant force is shown in Fig. 2.21. Taking the vertical axis as speed, the horizontal axis as unit resultant force, the left side of the origin is positive, and the right side of the origin is negative. The curve drawn according to the value in the fourth column in Table 2.8 is the unit resultant force curve of traction running $f-r_0=f(V)$. The curve that is drawn according to the value in the fifth column is the unit resultant force curve of idle running $r_0=f(V)$. The curves that are drawn according to value in the eighth, tenth, and eleventh column, respectively, are the unit resultant force curve of air braking $0.5b+r_0=f(V)$, resistance braking $b_e+r_0=f(V)$, air braking and resistance braking $0.2b+b_e+r_0=f(V)$. These curves are generally referred as the unit resultant force curve.

2.4.1.2 The Characteristics of the Unit Resultant Force curve

Application for Actual Alignment

The unit resultant force curve is calculated under the condition of tangent level track, namely, $i_{\text{con}}=0$. If there are grades, including equivalent curve grades or equivalent tunnel grades, it is necessary to deduct the converted additional resistances from the unit resultant force, namely $c=f(V)-10i_{\text{con}}$. So just move the vertical axis of the resultant force diagram in Fig. 2.21 by an i_{con} value. If i_{con} is positive, the vertical axis is moved to the left; if i_{con} is negative, the vertical axis is moved to the right. Then the $c=f(V)$ curves in the new coordinate axis refers to the unit resultant force curve when train runs on the i_{con} grade.

Determination of Equilibrium Speed

On the resultant force curve diagram, considering converted grade resistance and the moving of the vertical axis, at the intersect point of speed axis and unit resultant curves ($c=f(V)$), the resultant force $c=0$. Then, the train will run at a stable speed of the corresponding speed of this point; this is called the equilibrium speed V_{eq} of this grade. The equilibrium speed varies with route conditions (though conversion grade is different) and the work status of the locomotive. For example, in Fig. 2.21, the train is running in ascending grade of 4‰, $c=0$, $V_{eq}=73$ km/h. It can be obtained by moving the vertical axis left by 40 N/t.

Judge Train Motion Status

On any grade, if the running speed of train is lower than the corresponding equilibrium speed, the resultant force acting on the train is bigger than zero and the train will accelerate until reaching the equilibrium speed. On the other hand, if the running speed of train is greater than the equilibrium speed, the resultant force acting on the train is negative, and the train will decelerate to the equilibrium speed.

Take Fig. 2.21 as an example to illustrate the application of resultant force curves.

Tractive operation: for example, under tractive operation, a train entering an ascending 4‰ grade with speed of 45 km/h; as the equilibrium speed of 4‰ grade is 73 km/h, the resultant force is larger than zero and the train will accelerate.

Coasting operation: in coasting operation of locomotive, a train enters a descending 2‰ grade at speed of 50 km/h; as the equilibrium speed of this grade is 67 km/h, the train will accelerate. Under the same condition, once the train arriving at ascending 1.5‰ grade, as the equilibrium speed of this grade is 44 km/h, the train needs to decelerate.

Determination of the Braking Mode

For example, a train is running on descending 18‰ grade with the limiting speed of 70 km/h. Determine the braking mode.

Moving the vertical axis in Fig. 2.21 right to $c=-18$ N/10 t, the corresponding $c=-20$ N/10 t at the intersection point of vertical axle and air braking ($0.5b+r_0$) unit resultant force curve. It means that the train needs to decelerate. It should therefore adopt the method of alternating locomotive, vehicle braking (cycle braking) to maintain the train running within limit speed.

Rheostatic braking: a train runs on descending 5‰ grade, the limiting speed is 80 km/h, the vertical axis in Fig. 2.21 moves right to the 5 N/10 t, for coasting operation, the unit resultant force is greater than zero, the train will accelerate and exceed the limiting speed. If using air braking, the unit resultant force is less than zero, the train will decelerate. If using a certain level of rheostatic braking, this can make the unit resultant force zero, and the train will run constantly at a limiting speed 80 km/h.

2.4.2 Calculating Running Speed and Time

Generally, there are two methods to solve the running speed and time: one is the precise solution method based on the train motion equation, the other is the approximate solution method based on equilibrium speed. According to the computational tools, it can be divided into graphic method and computerization method. With the popularity of computer, whether accurate solution method or equilibrium velocity method, the computer have been used to solve the numerical methods. The numerical solution method based on the train motion equation and equilibrium speed will be briefly introduced as follows.

2.4.2.1 Simplifying Gradient Route Profile

In order to improve efficiency of computation, the design profile can be simplified to a longer length of grade section. The simplified gradient ism shall be calculated according to the following formula:

$$(2.89)$$

where H1, H2 is elevation of the beginning and end point of simplified grade section (m), Lsim is the length of simplified grade section (m), and , li is the length of each design grade in simplified section (m).

The length Li of each grade in simplified section must meet the following experimental formula:

$$(2.90)$$

where 2000 is an experimental constant in meter, and Δi is the absolute value of gradient difference between simplified gradient and each design grade in this section, namely .

In order to eliminate the calculation error caused by simplifying gradient in these grades areas, such as station, kinetic energy profile or other grade sections needed to check tractive tonnage shall not be simplified together with each other. Meanwhile, the inverse grades should not be simplified together.

The converted gradient of grade for simplified profile can be calculated according to the following formula:

(2.91)

where i_r , it is the equivalent grade of curve resistance and tunnel resistance (‰);

$$i_r = \frac{10.5 \sum \alpha}{L_{\text{sim}}} (\text{‰}), \quad i_t = \frac{\sum (r_t \times L_t)_i}{L_{\text{sim}}} (\text{‰})$$

where $\sum \alpha$ is the sum of curve deflection angles within reducing grade section, (°), and $\sum (r_t \times L_t)_i$ is the sum of tunnel resistance times the tunnel length within reducing grade section.

Additional gradients shall be calculated separately according to the direction.

2.4.2.2 Running Speed and Running Time

Speed-Distance Curve and Speed-Time Curve

The numerical method is used to calculate the train operating speed and running time according to the direct integral, the approximate integral or numerical integral of the train movement equation (it also can calculate the energy consumption and mechanical work at the same time). The speed that the train runs at a section is restricted by many factors; the driver shall change the working condition of the locomotive reasonably according to different circumstances, making the speed of the train meet the requirements. The change of slope directly affects the operating speed of the train, therefore, slope is usually used as the basic unit for calculations. The key aim of the numerical method is to determine the reasonable working condition and its change point.

According to the train movement equation, the calculation formulas of train running time, running distance, locomotive traction mechanical work, and energy consumption can be derived. The unit resultant force, tractive mechanical work, and energy consumption are the interpolation functions of operating speed V , so the interpolation formula (such as Lagrange interpolation formula) can be used to interpolate values, and the numerical integral method (e.g., Gaussian numerical integral) is used to solve the above formulas.

Although the computed distance, time, and speed may be used in location and train performance studies, the complex errors prevent engineers from relying on the computed results. Speed-distance and time-distance curves for specific train should be prepared wherever these curves are available, which show the running distances and times on all grades to be encountered.

A fragment of a train performance study using the procedures of this section appears in the profile and curves of Fig. 2.22. Super imposed on the profile of a line are the corresponding portions of speed-distance curves $V=f(s)$ and time-distance curves $t=f(s)$ for the performance of single SS3 locomotion pulling 2560-ton freight vehicles. On 950 m of level grade, the train accelerates to a speed of 45.5 km/h. The corresponding portion of the

speed-distance curve for a 0.0‰ grade is transferred to the profile by tracing or replotting. There is thus an advantage in using the same scales on the speed-distance curves as on the physical profile.

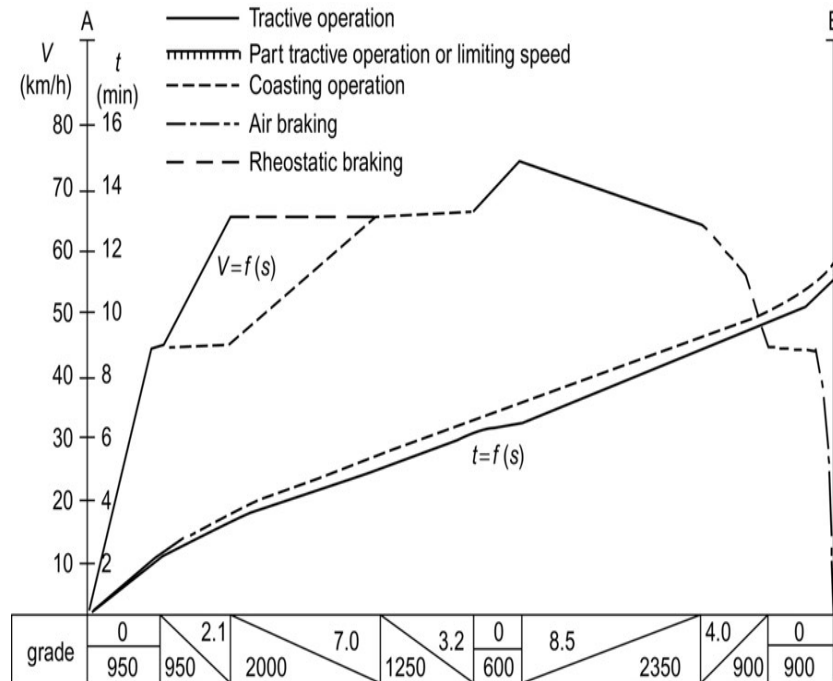


Fig. 2.22 $V = f(s)$ and $t = f(s)$ curves of a section.

On attaining a speed of 45.5 km/h, the train encounters 950 m of descending 2.1‰ grade that acts to accelerate the train along the corresponding speed-distance curve from 45.5 km/h to the limiting speed of 68.5 km/h in tractive operation. With the limiting speed of 68.5 km/h and rheostatic braking, the train runs at uniform speed through 2000 m of descending 7.0‰ grade and 1250 m of descending 3.2‰ grade. After entering the 600 m of level grade, the train accelerates again. At a speed of 75 km/h, the train enters 2350 m of ascending 8.0‰ grade. As the limiting speed is less than 75 km/h, the train decelerates under the tractive operation to 65 km/h and enters 900 m of ascending 4.0‰ grade. Although 65 km/h is less than the limiting speed of this grade, for entering and stopping at the forward station, the brakes are applied and the braking distance curve (Fig. 2.21 for 900 m of 4‰ grade and 900 m of level grade) is followed to a stop. The combination of these several portions of speed-distance curves gives a graphic presentation of the demand of the locomotive and its capabilities at every point in running period. The profile shows where limiting conditions occur and where the locomotive is not working to its maximum capacity. Note that where the locomotive is maintaining a constant speed, the speed-distance profile would become a horizontal straight line.

A speed-time curve is plotted in the same way, using the data from Fig. 2.22. This curve plotted on the physical profile shows the overall time to traverse the route as the maximum ordinate distance. The time between any two points may also be read graphically. Note that if the train in Fig. 2.21 had stopped on route, the continuing time during the stop would have increased on a straight vertical line.

Equilibrium Speed Method for Computing Running Time

Equilibrium speed method assumes that when the train running on a grade section, regardless of the length, no matter what is the initial train velocity at the foot of the grade, a train will run at uniform speed in equilibrium speed or limiting speed. Using such a principle to calculate the train operation energy consumption and running time is called the equilibrium speed method. Fig. 2.23 shows the speed-distance curve between A station and B station: the dotted line expressed the speed-distance curve drawn in actual running speed; the solid line expressed the speed-distance curve obtained from equilibrium speed method (train runs with uniform equilibrium speed or limiting speed at every grade section, each portion of $V=f(s)$ is horizontal line). It is obvious that there is difference between the two groups of speed-distance curves. Comparing the curves of equilibrium speed method with actual speed curves, when grades change little, the excess part (vertical shadow line) with insufficient part (horizontal shadow line section) in general can be offset. However, there is a significant difference when it accelerates to leave the station or decelerates to enter the station. Therefore, additional start-stop times t_a and t_d should be added when calculating the running time with equilibrium speed method. The error increases if there is a significant difference of height between adjacent grades. Therefore, the equilibrium speed method can only be used to compute running time in general design.

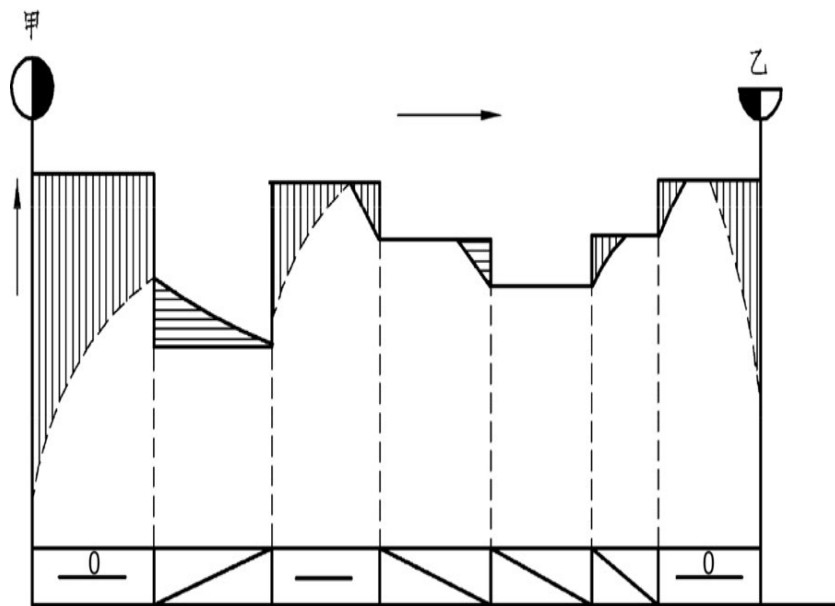


Fig. 2.23 Speed-distance curves of equilibrium speed.

In Fig. 2.23, train is running between station A to station B, considering that the train stops at both A and B stations, the running time is

(2.92)

where t_a, t_d is the additional starting time, stopping time, related to traction type, tractive tonnage, route profile at the two ends of station, generally, for electric, diesel traction, $t_a=1-3$ min, when $t_d=1-2$ min; L_i =length of a grade section (km); and t_i =run time per km on a grade (min/km), ascending grade $t_i=60/V_{eq}$, V_{eq} is the equilibrium speed (km/h) from resultant force curve graph; descending grade $t_i=60/V_{lim}$, V_{lim} is down grade limiting speed (km/h), freight train can be calculated according to Eq. (2.88).

The calculation should be carried out under the condition of same direction. The determination of whether to attach t_a+t_d should be made according to whether a train will stop at the station.

Chapter 3

Railway Plane and Profile Design

Abstract

This chapter first looks at the design of planes. The design of a railway plane needs to combine straight lines, circle curves, and transition curves into a unified horizontal alignment to provide a safety and smooth track for train running. The work of profile design includes determining the maximum gradient of grade, length of grade section, connection of point of gradient change, etc. The chapter then investigates plane and profile design at bridge, culvert, tunnel, and subgrade zones, followed by plane and profile design at station site. Finally, line plans and profile are discussed; these are the basic documents in railway design. The line plans comprehensively and clearly reflect the railway plane position and the terrain and its features of the places along the line; the profiles reflect the spatial location and relief of the line.

Keywords

Design of plane; Alignment; Profile design; Subgrade; Station site; Line plans; Profile details

3.1 Introduction

Railway permanent way is a three-dimensional space strip civil engineering works. In general, railway alignment means the position of the central line of a railway's permanent way. It is expressed in the line linked central points of cross-section longitudinally, as shown in Fig. 3.1, usually called center line for short.

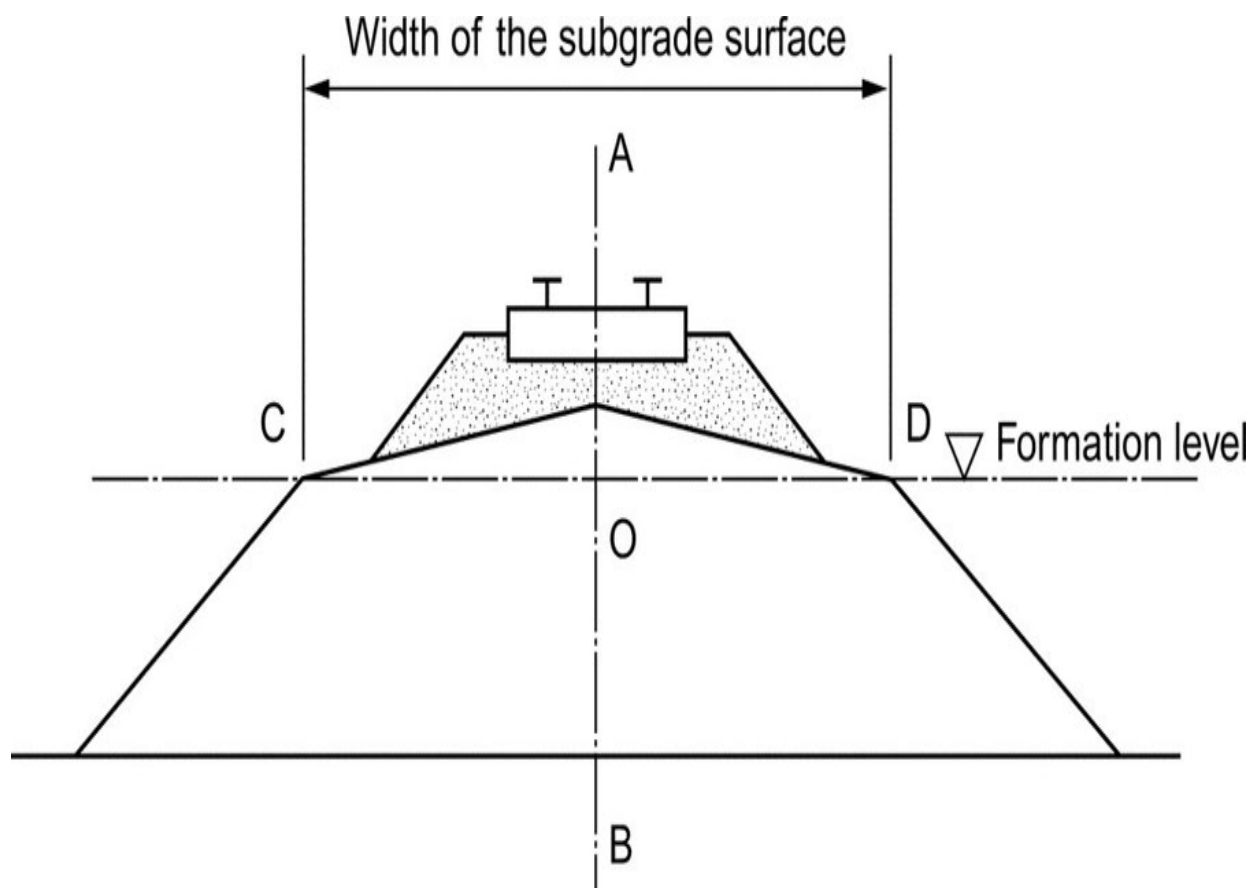


Fig. 3.1 Cross-section of sub-grade.

The three-dimensional center line (space curve) is determined by superposition of the horizontal and vertical alignment projections. In the case of multi-track railways, each center line shall be aligned separately.

Plane of railway is the projection of alignment on the level surface; it expresses the exact horizontal position of railway line. Profile is the projection of longitudinal section of alignment on vertical plane. It expresses the rising and falling conditions. The elevation on profile is the formation level.

The route alignment in horizontal and vertical projection can be carried out separately.

The horizontal alignment has to be drawn up on contour map. One or more possible alignments are laid on a contour map, as in Fig. 3.2. In Fig. 3.2, contours express the characteristics of topography and landform. Villages, small towns, and roads express characteristics of surface features. In Fig. 3.2, the thick line expresses railway plane, mark kilometer-age points, curve control points, stations, and gives information of curves' main elements (changing direction angles of curve, radius of curves), characteristics of bridges and tunnels, etc.

Fig. 3.2 Simple plane drawing and profile drawing.

Once a particular route has been selected, the line is laid out in detail. Curves are staked and cross sections are taken from which earthwork yardages are computed. The intersection points and the beginning and ending of curves should be carefully referenced so that these can be reestablished during construction.

The profile drawing is composed of up part and down part; the up part is the sketch map of vertical profile; the down part shows the basic data of alignment, including plane information, kilometers, design gradient, designed formation level, and engineering geological conditions.

The space curve resulting from superposition of the horizontal and vertical projections has to meet all the following requirements:

1. Guarantee driving safety and riding comfort. Thus, coupler separation, coupler breakage, train derailment, train running behind scheduled time and unexpected stopping, etc., should be prevented.
2. Work hard for saving funds. The design of alignment aims to reduce works quantity, to cut down construction cost; and to provide favorable conditions for construction, operation, and maintenance. On the consideration of reducing construction cost, the alignment should be designed crawl on ground surface; but, as the alignment curve is too sharp with rising and falling, troubles appear while operating, which leads to higher expenditure of operation. On the consideration of saving expenditure of operation, alignment should involve a flatter curve and flatter grade; which leads

to increasing work quantity, increasing construction cost.
Therefore,

1. Meet the overall plan of railway networks.
2. Enhance construction quality and transport efficiency and reduce maintenance cost.
3. Cover major cities for passengers' convenience and trip attraction.
4. Coordinate with overall plan of urban, local traffic, farmland and water conservancy and other relevant engineering constructions to make proper arrangements.
5. The location and overall design shall consider side slope protection, waterproofing and drainage in a system-engineering way, in order to optimize the plane and profile of the track and to determine the best engineering scheme after comparison.
6. Detour all kinds of unfavorable geologic body. As for unfavorable geologic bodies which are difficult to detour around, engineering improvement measures shall be taken based on geological exploration in order to ensure operation safety.
7. The sub-grade construction shall avoid high filling, deep or long cutting. As for special ground and bad geologic areas, the cutting and filling height of sub-grade shall be strictly limited.
8. As for deep gully sections located in complex terrain and unfavorable geologic areas, the design of plane and profile shall be compatible with design requirements of bridges or culverts.

9. The design shall be in accordance with environmental protection, water and soil conservation, land saving, and protection of historic relics.

This section gives a complete analysis of curve design. Considerations of the effects that curves have in the design, location, and operation of a railway must be left to the sections on that subject.

3.2 Design of Plane

3.2.1 Composition of a Plane and Its Basic Alignment

For rolling stock, there are three relations between the swing surface of steering wheel and the longitudinal axle of car body, including angle of zero, constant, and variable. Corresponding with these three relations, the locus of center of gravity position of car body will take three trajectories:

- ① Curvature is zero: straight line;
- ② Curvature is constant: circle curve; and
- ③ Curvature is variable: transition curve.

Design of railway plane is to combine straight line, circle curve, and transition curve into a unified horizontal alignment to provide a safety and smooth track for train running. In this case, the running locus of car body has the following features:

- ① It shall be continuous and smooth; there is no jagged point or break point.
- ② Its curvature shall be continuous, which means only one curvature for one point.
- ③ Rate of curvature should change continuously, so that a sharp change is not permitted on the whole alignment.

A railway horizontal line is composed of straight or tangent segments with curves (arcs of simple circles) connecting tangents of differing directions. To meet the above requirements, the horizontal alignment is a composition of curves and tangent straight lines, and curvatures of curves are changing continuously, as shown in Fig. 3.3.

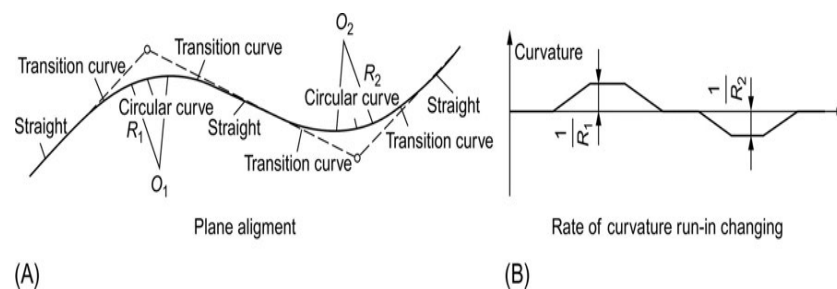


Fig. 3.3 Plane with continuous curvature.

In the above alignment, the transitions in the connected points are strictly tangential, and the shape of the curvature is continuous.

The location of a line refers to its horizontal and vertical position. A combination of traffic distance, curvature, rise and fall, gradient, and locomotive characteristics gives the best economic outcome for the line are determined during the location process.

Curves usually create more problems than tangents. Problems of line, gage, cross level, tie wear, rail life, and ballast are intensified on curves. Train speeds and safety are directly related to the degree of curve and superelevation carried. Spiral approaches contribute to the smoothness of the ride.

3.2.2 Straight Line

3.2.2.1 General Regulations for Designing Straight Lines

Straight alignment has characteristics of short distance, fast arrival, simple wheel-rail force, and easy survey, etc. It is difficult to use a long straight line to fit topography, and it is difficult to detour around unfavorable geologic bodies and existing facilities. For these reasons, natural and engineering conditions should be taken into account when choosing location of railway lines. Design principles are as follows:

1. Selection of straight line position shall base on comprehensive study of straight and curve, on considering topographic conditions and surface features, the railway line must be in the most reasonable position.
2. In order to shorten distance of a projected railway, to improve operation conditions, the alignment shall be laid out longer straight line and reduce intersection points. Only where there are topographic obstacles, geological obstacles, and surface features will curves be designed to detour around them.
3. A straight position should be selected to reduce angle of intersection point. A bigger angle or sharper curve will have a longer distance of line, which leads to more curve resistances and operation expenditure.

The curve resistance work caused by angle on per ton of train weight can be computed using the following equation:

$$A_r = w_r \times L_C = \frac{600}{R} \times \frac{\pi \alpha R}{180} = 10.5 \alpha \quad (\text{J/kN})$$

(3.1)

where w_r is unit curve resistance (N/kN), and L_C is the length of circular curve (m).

3.2.2.2 Length of Intermediate Straight Line

In sections of curve adjoining curve, the straight line between two adjacent curves should have enough length to ensure the alignment continuity and the train running smoothly. This straight line, between the ending point of front curve (ST₁) and beginning point of behind curve (TS₂), is called the intermediate straight line, seen in Fig. 3.4. The two adjacent curves with the same changing direction are named as curves of same sense; those with opposite changing direction are named as reverse curve.

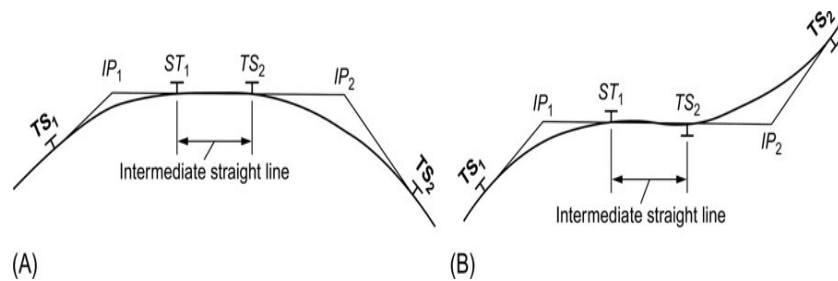


Fig. 3.4 Intermediate straight line. (A) Curves of same sense (B) Reverse curve.

Minimum Length of Intermediate Straight Line

In order to provide favorable conditions for train running and maintenance, the intermediate straight line shall be designed as long as possible. The minimum length shall meet the following requirements.

1. To meet the requirements of track maintenance

When the train passes through a short straight line, especially in reverse curves, thrust exerted on rail by wheel will increase, and maintenance of track will become difficult. At the same time, as the effect caused by curves at the end of straight line, the direction of straight line is hard to maintain.

The practice of maintenance has proved that: in order to maintain the direction of straight line, the length of intermediate straight line shall be not shorter than 2-3 sections of rail. As the standard rail length is 25 m, the minimum length of intermediate straight line shall be 50-75 m, at least, not shorter than one standard rail length, that is 25 m.

On a high-speed line for passenger traffic, heavy permanent way machine is employed to maintain track. In order to check track geometry tolerances, the length of a straight line should not be shorter than 50 m. On the other hand, in order to orientate construction machine, the length of straight line shall not be shorter than 50-75 m.

2. To prevent the lateral swaying of train from influencing a train's smooth travel

While a train run through a straight line from the front curve to behind one, as the change of superelevation and curvature, the lateral swaying and acceleration of train will change quickly, especially for reverse curve. In order to ensure the running safety and riding comfort, the length of straight line shall be not shorter than 2-3 cars length. In China, the length is 24 m for 22 type car, and 25.5 m for 25 type car, so that the length of intermediate straight line shall be not shorter than 48-76.5 m. The EMU is 25-27.6 m long, so that the corresponding straight line length shall be not shorter than 56-84 m.

3. Vibration of rolling stock shall not affect riding comfort

While passing the intermediate straight line, the train will meet the ending point (TS point) of front curve and beginning point (ST point) of behind curve. The jerk between wheel and rail at TS point and ST point will cause vibration of truck. In order to avoid the vibrations at ST-point and TS-point occurring at the same time, the straight line shall be long enough to ensure the ride's comfort. That is, to ensure that the traveling time t of that train with the maximum speed shall be longer than the time t_z of that truck's vibration disappear. That is:

From $t \geq t_z = n \times T$, give:

$$\frac{L_J - L_q}{V_{\max}/3.6} \geq n \times T$$

(3.2)

where t_z is the disappear time of spring vibration(s); n is the number of cycles of truck vibration disappearing, take 1.5-2.0; T is the cycles of car vibration (s); it is about 1.0-1.5 s; $V_{\max}$ is the design speed (km/h); and L_q is the total wheel base of passenger car.

$$\text{Let } \tau = \frac{n \times T}{3.6}, \text{ then } L_J = \tau \times V_{\max} + L_q \text{ (m)}$$

(3.3)

On considering that car is not a rigid body, so that $L_q=0$, then Eq. (3.3) can be simplified as

(3.4)

τ is a coefficient with time dimension, it can be determined according to construction conditions. It can take as 0.8 (general condition) and 0.5 (difficult conditions) for lines of mixed service with designed speed of 160-140 km/h; 0.6 (general condition) and 0.4 (difficult conditions) for lines of mixed service with designed speed 120 km/h; 0.8 (general condition) and 0.5 (difficult conditions) for lines of passenger traffic. For high speed railway lines, the minimum length of intermediate straight line is (0.4-1.0) $V_{\max}$.

The minimum lengths of the intermediate straight line between two adjacent transition curves shall be calculated with Eq. (3.4), and shall conform to the values listed in Table 3.1.

Table 3.1

Minimum Length of Intermediate Straight Line (m)

Railway Classification	Railway Line for Passenger Traffic	Railway Line for Mixed Service		
Design speed (km/h)		350	300	250
Construction condition	General	280	240	200
	Difficult	210	180	150

To Ensure the Length of Intermediate Straight Line

In plane design, it is necessary to check the length of straight line between two adjacent curves. It should meet the following equation:

$$(3.5)$$

In reconnaissance paper location, it is not necessary to draw out transition curves on a map. The curve is only a single curve. In that case, the intermediate straight line between two adjacent circular curves shall meet the following equation:

$$(3.6)$$

where L_j min is the minimum length of intermediate straight line (m), taking the value in Table 3.1, and l_{01} , l_{02} is the length of transition curves of two adjacent curves (m).

If the above equation is not met, the design should be revised to conform to the requirement, such as to change radius of circular curve, change transition length, or the position of straight line (see Fig. 3.5).

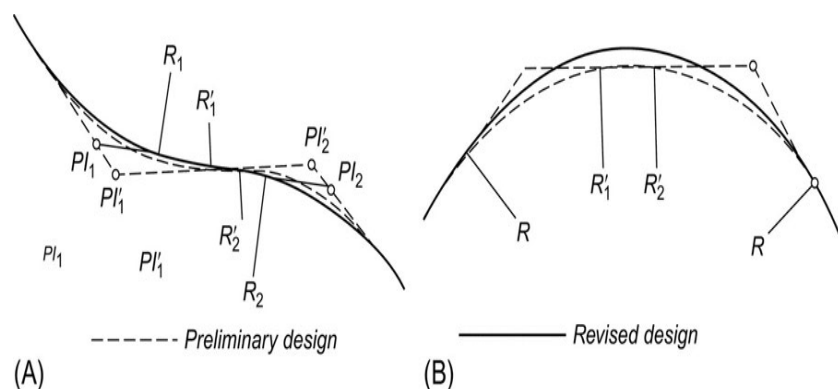


Fig. 3.5 Revising plane design.

3.2.3 Circular Curve

Curves are introduced between portions of straight or tangent track to bypass obstacles, provide longer and easier gradients, and route the line through traffic centers.

Curves usually create more problems than do tangents. Problems of line, gage, cross level, tie wear, rail life, and ballast are intensified on curves. Train speeds and safety are directly related to the degree of curve and superelevation carried. Spiral approaches contribute to the smoothness of the ride.

3.2.3.1 Elements of Curve

To complete the needed curve function, one must know the degree and the length of the curve. Railway curves are usually designated by the radius of circle arc. (In the United States, the degree of curvature is generally used instead; If an arc of 100.007 ft is assumed to subtend D of central angle, then the circumference of a circle of 360° is $(360/D) \times 100.007$, and $R = 5730/D$.) The curve may also be defined as the change in angular direction between two intersecting straight lines tangent to the circle arc as measured by the exterior deflection angle of the two tangents (Fig. 3.6).

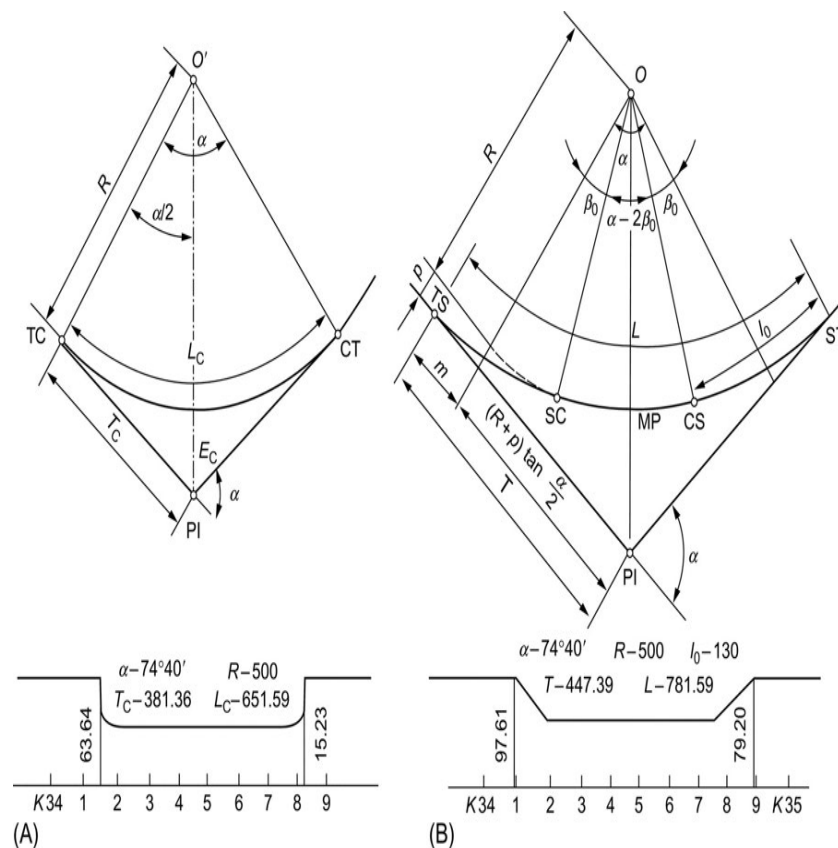


Fig. 3.6 Functions of a curve (A) Simple curve (B) Common curve.

Two tangents are projected to a point of intersection (the PI) (Fig. 3.6). An arc of a circle, a simple curve, is used to connect the two tangents. Spiral or easement curves are used with simple curves to provide a gradual change of degree and easier riding in going from the tangent to full curvature.

For a simple curve, main elements include: the exterior deflection angle of the two tangents α , radius R , tangent distance of circle curve TC , length of circle arc LC , and external distance EC .

When the radius and deflection angle are given, the following functions of a simple curve, used in the design and layout of a simple curve, are derived from Fig. 3.6A:

$$(3.7a)$$

$$(3.7b)$$

$$(3.7c)$$

where TC is the tangent distance of circle curve; LC is the length of a circle curve; and EC is the external distance of circle curve.

For an easement curve, the following functions are derived from Fig. 3.6B:

$$(3.8)$$

$$L = \frac{\pi(\alpha - 2\beta_0)R}{180} + 2l_0 = \frac{\pi \times \alpha \times R}{180} + l_0 \quad (\text{m})$$

$$(3.9)$$

$$(3.10)$$

where p is the offset from the tangent to the spiral, (m); m is the distance from TS to perpendicular tangent point, (m); and β_0 is the total spiral deflection angle, ($^\circ$).

Major points of curve can be calculated as follows:

Kilometers of TS are measured on the map:

Kilo of ST=TS+L

Kilo of SC=kilo of TS+I0

Kilo of CS=kilo of ST-I0

3.2.3.2 Superelevation on Curved Tracks

In rounding a curve, a train is subject to a centrifugal force F_c acting radially outward:

$$(3.11)$$

where w is the weight of the car or locomotive in tons; v is the speed in meter per second; R is the radius of the curve in meters; and g is the acceleration due to gravity, 9.81 m/s^2 .

To counteract the effects of F_c , the outside rail of the curve is raised or super-elevated a distance h in millimeter above the inside rail. A state of equilibrium is reached, in which both wheels bear equally on the rails, where e is sufficient to bring the resultant force F_c at right angles to the plane of the top of rails. A proportion can be set between terms in the force triangle and corresponding terms in the triangle formed by h and by the horizontal projection of the distance between the bearing points of the wheels on the rails. In Fig. 3.7A, the following equations can be concluded:

(3.12)

where h is the equilibrium superelevation in millimeter; V is the train speed in kilometer per hour; and R is the radius of curve.

The effect of lateral roll, lateral play, or offset on the position of the resultant is seen in Fig. 3.7B.

Centrifugal force is the force peculiar to the rolling stocks negotiating the curved tracks. In order to balance this force, the outer rail of the curved tracks is slightly elevated so as to form what we call superelevation. By means of the horizontal component of the gravitational force of the car, the centrifugal force is counter-balanced. As a result, both rails will be equally stressed and worn. There will be also acceptable traveling comfort, high track stability, and safe train operation.

Actually, all trains run with different speeds around the curved tracks, therefore the average speed V_a should be used instead of the train speed V in the above equation, that is,

$$(3.13)$$

The suitability of the superelevation used depends greatly on the selection of the average speed. There are different ways for selecting the average speed V_a , among which are the following.

1. With consideration to the speed and mass of trains.

For a given curved track, the superelevation h and the distance between rail centers S ; are constant and unchangeable, but the mass of train, its speed and centrifugal force are different for different trains, in order to equalize the vertical wear on both rails of the curved track, we must have

$$(3.14)$$

in which V_a is the average speed, equal to

$$(3.15)$$

where M is the mass of the train, V is the train speed, and N is the number of trains passing daily with the same mass and speed.

2. Without consideration to the mass of train, calculate V_a according to the trains with different speeds.

$$(3.16)$$

where N is the number of trains passing daily with the same speed.

3. Empirical equation for calculating V_a for new lines

$$(3.17)$$

Substituting Eq. (3.15), we thereby have

$$(3.18)$$

in which V_{max} is the maximum speed expected (km/h).

Maximum Superelevation Allowed

A superelevation equal to h causes the wheels to bear equally on the rails, with no lateral thrust. F_r falls perpendicular to the plane of the rails and midway between. The velocity V corresponding to h is the equilibrium speed.

The deficient or surplus superelevation caused by the unsuitability between the actual speed and superelevation on curved tracks should ensure not only the traveling comfort of passengers, but also the stability of track and safety of train operation.

Cars negotiating the curved tracks will suffer the combined actions of the centrifugal, centripetal, wind forces and gravity, as shown in Fig. 3.8. When the resultant of all forces passes through the center of track is 0, the car is in an absolute stable state. Because of the unsuitability between the superelevation and the actual train speed, the resultant will decline with an eccentricity e . The degree of stability against overturning of the cars on curved tracks depends upon the magnitude of the eccentricity. Usually, we define the factor of stability n as the ratio between one half of the distance between rail centers $S/2$ and the eccentricity e , by means of which the degree of stability for cars negotiating the curved tracks is evaluated.

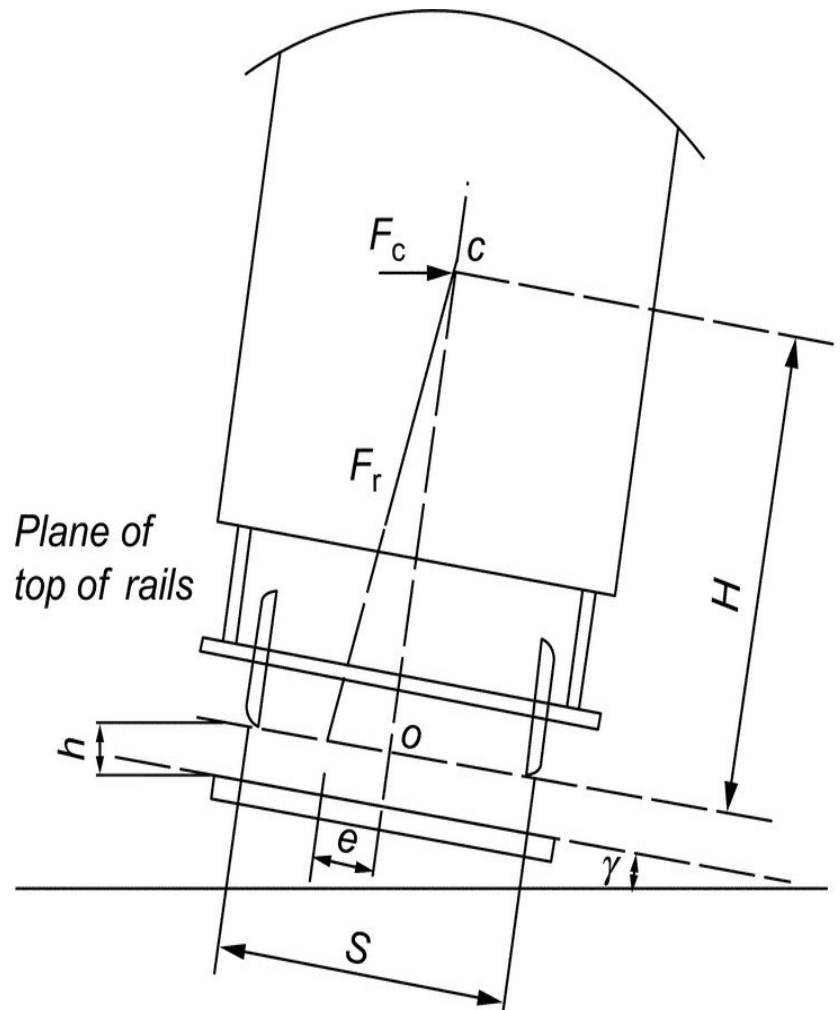


Fig. 3.8 The impact that the car-track action has on the resultant force.

(3.19)

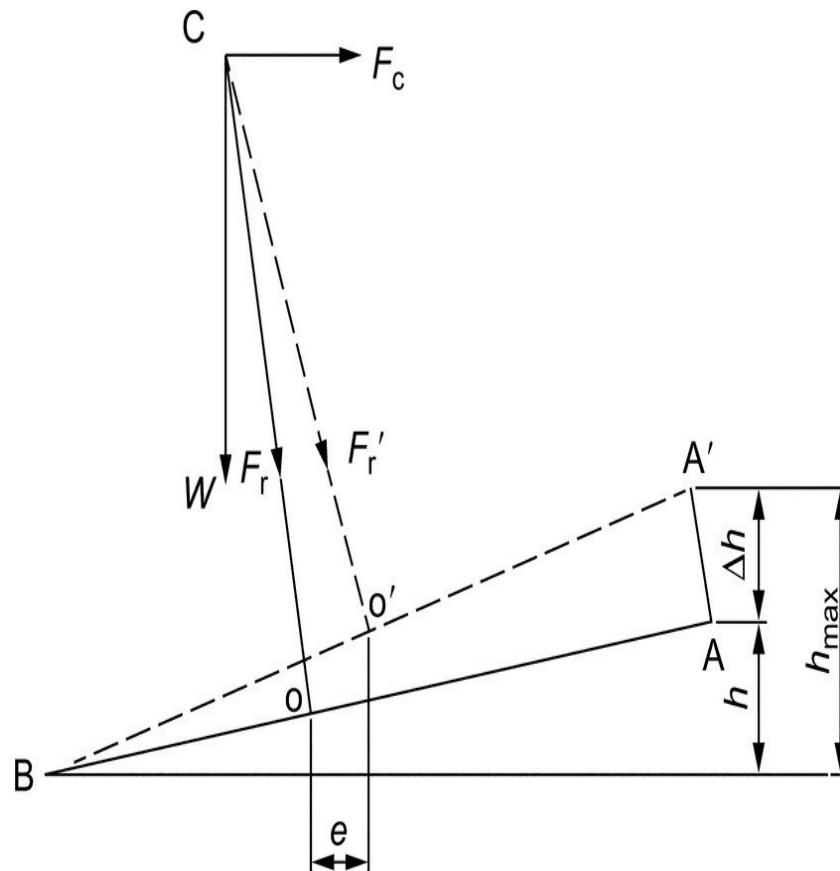
where

absolute stable state;

critical stable state;

overturns due to loss of stability; and

The magnitude of the eccentricity e depends upon the unbalanced superelevation (deficient superelevation) existed. If the superelevation h matched perfectly with the train speed V , resultant R will pass through the center of the track O . In cases where there are deficient superelevation Δh , resultant R' will intersect the rail surface line at some other point O' outside of the track center O (see Fig. 3.9). Since line CO is perpendicular to the rail surface line BA with superelevation h , and line CO' is perpendicular to the fictitious rail surface line BA' with superelevation $(\quad)$, triangles COO' and BAA' are similar to each other, therefore we have


$$OO':CO=AA':BA$$

(3.20)

Substituting into Eq. (3.19), we have

$$(3.21)$$

Substituting the value of the allowable deficient superelevation and height of o. g. for freight cars into Eqs. (3.20) and (3.21), the eccentricity e and factor of stability n will be:

$$h=60 \text{ mm}, e=88 \text{ mm}, n=8.5$$

$$h=75 \text{ mm}, e=110 \text{ mm}, n=6.8$$

$$h=90 \text{ mm}, e=132 \text{ mm}, n=5.7$$

For trains negotiating the curved tracks or stopping in an emergency, the value of n necessary to ensure the stability of cars should be testified from the long-term experience. It generally holds that n should be not less than 3. In China, we specify that the maximum superelevation should not exceed 150 mm. In this case, when a train stops on the curved tracks, the surplus superelevation including the allowable error of 4 mm will be 154 mm, the train is under most unfavorable condition, with the value of n being

$$n = \frac{S'_1}{2H \cdot \Delta h} = \frac{1.5^2}{2 \times 2.2 \times 0.154} = 3.3$$

which can still ensure sufficient factor of stability.

On ordinary single track lines, where the speeds for up and down trains vary considerably, if we still specify 150 mm as the maximum allowable superelevation, the inner rail will suffer too great eccentric load under the action of low speed trains. In order to ensure the loads acted on the two rails do not differ too much, the maximum superelevation allowed on single track line should not exceed 125 mm.

On high-speed railway, $H=1370$ mm. for electric motor unit car. If n still takes 3, thereby, the maximum allowable superelevation is

$$\Delta h = \frac{S_1^2}{2H \cdot n} = \frac{1.5^2}{2 \times 1.37 \times 3} = 0.273(\text{m}) = 273(\text{mm})$$

European and Japan experience and practice has shown that 200 mm is feasible. But experience and studies have indicated that 200 mm of superelevation may not be comfortable for a high-speed car. A recommendation from the Track-Train Dynamics Program would restrict the maximum allowable superelevation within 170–180 mm.

Unbalanced Centrifugal Acceleration—Deficient or Surplus Superelevation

On any curved track, once the superelevation is fixed based on the average speed, it is unalterable. But the actual speed of the trains may be either greater or smaller than its average value; as a result, it will not match with the superelevation and will unavoidably give rise to the unbalanced centrifugal acceleration.

Eq. (3.12) is expressed in terms of one speed only, the equilibrium. Trains are likely to run at different speeds on the same track. A certain leeway is obtained from the so-called comfortable speed concept.

If h is too great for the operating speed, there is an inward component of force, F' toward the center. F_r falls toward the inside rail, subjecting it to excessive crushing forces. If h is less than required for V , F_r falls closer to the outside rail, causing excessive lateral pressure and degradation on the gage corner of that rail.

With train speed v (m/s), radius of curve R (m), and superelevation h (mm). the centrifugal acceleration caused by the centrifugal force will be v^2/R , the centripetal acceleration caused by the superelevation a will be $\frac{gh}{R}$, and the unbalanced centrifugal acceleration a_u will be

$$(3.22)$$

When $v = V$, $a_u = 0$, which means that there will be no unbalanced centrifugal acceleration while the train is passing over the curved tracks. If $v > V$, the unbalanced centrifugal acceleration will be $a_u > 0$. When $v < V$, the unbalanced centrifugal acceleration will be $a_u < 0$.

The unbalanced centrifugal acceleration should not exceed a certain allowable limit, otherwise it will not only influence the smooth running of the trains, but also cause discomfort to the passengers; in addition, under high-speed operations, it may give rise to the instability of cars and thus endanger the safe operation of trains. Therefore, we have to specify a rational allowable limit for the unbalanced centrifugal acceleration, designated as a_0 . Letting $v_{\max}$ be the maximum speed of the passing trains, we have

$$(3.23)$$

Substitute a_u into the above equation, and rewrite $v_{\max}$ (m/s) as $V_{\max}/(3.6 \text{ km/h})$, then

$$(3.24)$$

Evidently, the first item on the left side of the equation represents the superelevation required for $V_{\max}$, designated as $h_{\max}$, and the second item represents the superelevation required for V_0 , designated as h_0 . The difference between these two values is the superelevation difference, designated as Δh . When Δh is positive, called deficient superelevation. When Δh is negative, which is called surplus superelevation. Deficient or surplus superelevation is another means of expression for the unbalanced centrifugal or centripetal acceleration. The relation is

$$(3.25)$$

In China, it is specified that the unbalanced centrifugal acceleration should not exceed 0.4–0.65 m/s². Under special circumstances, acceleration under 0.6 m/s² is selected to ensure the travelling comfort of passengers. With reference to Eq. (3.25), we also specify that the allowable deficient superelevation should not exceed 60–75 mm, under special circumstances, not exceed 90 mm.

In high speed railway lines for passenger service, for higher riding comfort, the allowable deficient superelevation should not exceed 40–70 mm, under special circumstances, not exceed 100 mm.

Passenger trains with swing hangers and roll stabilizers can negotiate curves comfortably with 100 mm. of unbalance. European and British experience and practice with swing or tilt suspension passenger equipment (that permits the car body to swing, outward on curves) has shown a feasible unbalance of 150–230 mm. However, an excessive imbalance introduces problems of increased rail wear, gauge widening, derailed wheels, and overturned rails.

Recent experience and studies have indicated that 7.5 mm. of unbalance may not be safe for car with a high center of gravity, such as those in the 2200–2500 mm center-of-gravity range. Increased high rail wear may also ensue. A recommendation from the Track-Train Dynamics Program would restrict the maximum speed for cars with 2500 mm centers of gravity to no more than 50 mm of unbalanced superelevation.

3.2.3.3 Minimum Radius of Curve

Riding comfort is the basic requirement for railway construction. The minimum radius of curve should meet the following equation:

$$(3.26)$$

where $V_{\max}$ is the the designed maximum speed of passenger train (km/h); $h_{\max}$ is the maximum allowable superelevation (mm); Δh_d is the allowable deficient superelevation (mm); and $R_{\min}$ is the the minimum allowable radius for railway with designed speed.

In railway lines for mixed passenger and freight traffic, the plane curve radii shall match different-speed trains’ comfort requirements. The minimum radius should also comply with requirements to counterbalance the centrifugal force, making both rails be equally stressed and worn. That is, the radius shall meet the following equations:

$$(3.27)$$

$$(3.28)$$

From Eqs. (3.27) and (3.28), thereby,

$$(3.29)$$

where V_{min} is the minimum designed speed. For lines of passenger traffic, it is the designed speed of middle-speed train; for mixed service lines, it takes designed speed of freight train; and Δh_s is the allowable surplus superelevation (mm).

For lines of mixed traffic with high speed trains and middle speed trains, the minimum radius shall take the maximum one of the results calculated by Eqs. (3.27)–(3.29).

The plane curve radii of main line shall be selected according to geographical and environmental conditions. The plane curve radii matching different speeds are listed in Table 3.2.

Table 3.2

Minimum Radii of Plane Curve (m)

Railway Type	Line for Passenger Traffic		Line for Mixed Service		
Vmax (km/h)	350	300	250	200	200
Type of track	Ballast	Ballastless	Ballast	Ballastless	Ballast
Rmin (m)	General	7000	7000	5000	4500

Special	—	(5500)	(4500)	(4000)	(3500)

Notes: (1) numbers in () can only be used under special cases.

(2) The use of minimum allowable radius on special case may only be allowed on prerequisite of technical and economic comparison with full verification by MOR.

However, elevating the curve for equilibrium speed is only the first step. The curve must then be observed in the field to see how the rail is worn in light of the actual running speeds, actual subgrade support and car loadings, and the way in which the enginemen handle their trains. Some slight adjustments may be necessary. The situation should then be reviewed from time to time, to note any changes required to compensate for new types of equipment and car loadings and changes in train speed or in track support. It should be noted that speed reduction is a more potent factor than curve reduction in equalizing the required superelevation, since superelevation varies with the square of the speed—but only as the first power of the radius of curve.

3.2.3.4 Range of Allowable Superelevation and Establishing Superelevation Calculation

Range of Allowable Superelevation

The question is how much the outside rail should be elevated over the inner rail. The best approach is to elevate to equilibrium speed for the prevailing volume of traffic. As for the mixed high-speed passenger line and low-speed line, influence factors include speed for trains negotiating the curve, maximum superelevation, allowable deficient superelevation, allowable surplus superelevation, etc. Designed superelevation shall meet the following requirements:

1. It shall not exceed the maximum superelevation and not be less than the minimum one, that is,

$$(3.30)$$

2. There is no deficient superelevation for highest-speed trains and no surplus superelevation for lowest-speed trains, that is,

(3.31)

3. The deficient superelevation for high-speed trains and surplus superelevation for low-speed trains shall not exceed the allowable value, that is,

$$11.8 \frac{V_h^2}{R} - \Delta h_d \leq h \leq 11.8 \frac{V_l^2}{R} - \Delta h_s \quad (\text{mm})$$

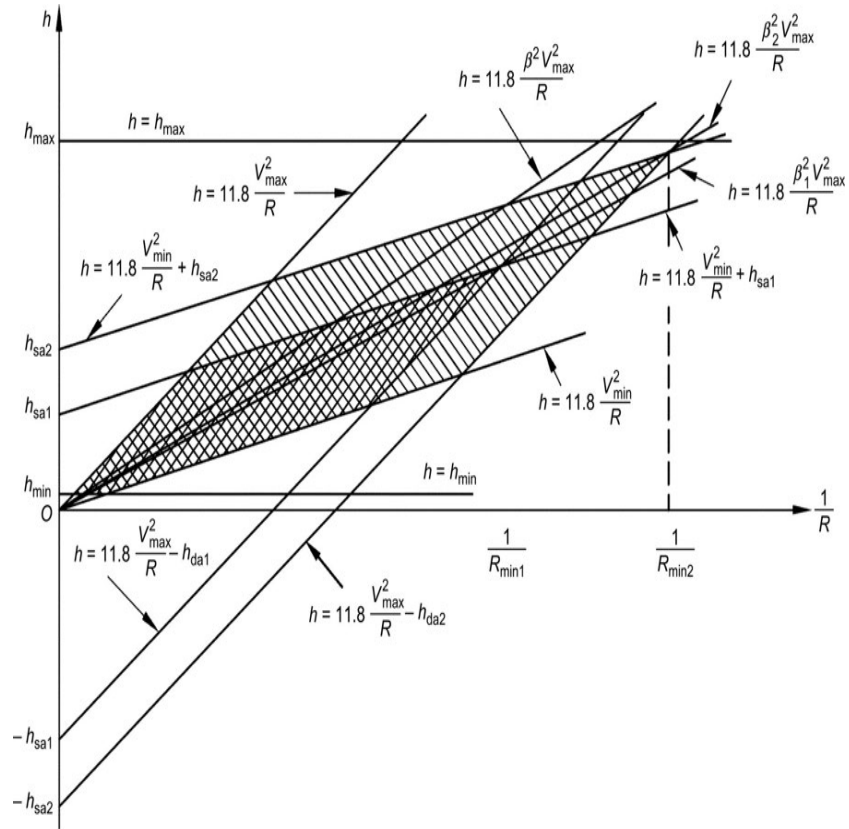
(3.32)

The necessary condition for assuring Eq. (3.32) is

(3.33)

where h is the curve superelevation (mm); R is the radius of curve (m); V_h , V_l are the running speed of high-speed train or low-speed train (km/h); h_d , h_s are the allowable deficient superelevation for highest speed train, or surplus superelevation (mm); and $h_{\max}$, $h_{\min}$ are the allowable maximum superelevation, minimum superelevation (mm).

Eqs. (3.30) and (3.31) formed the allowable range for laying out superelevation; see the shaded parts on Fig. 3.10.



Note: h_{da1} , h_{da2} : allowable deficient superelevation under general condition and difficult condition respectively;

h_{sa1} , h_{sa2} : allowable surplus superelevation under general condition and difficult condition respectively;

Fig. 3.10 Range of establishing superelevation.

Calculation of Actual Superelevation

From Eqs. (3.20)–(3.23) and Fig. 3.10, superelevation can be determined as follows:

If

$$R \geq R_{\min 1} = 11.8 \frac{V_{\max}^2 - V_{\min}^2}{h_{da1} + h_{sa1}},$$

the up limit is

$$h_{\text{sup}} = \max \left\{ \min \left[11.8 \frac{V_{\min}^2}{R} + h_{\text{sa1}}, 11.8 \frac{V_{\max}^2}{R}, h_{\max} \right], h_{\min} \right\} (\text{mm})$$

and the down limit is

$$h_{\text{down}} = \min \left\{ \max \left[11.8 \frac{V_{\max}^2}{R} - h_{\text{da1}}, 11.8 \frac{V_{\min}^2}{R}, h_{\min} \right], h_{\max} \right\} (\text{mm})$$

The middle for check is

$$h_{\text{chl}} = 11.8 \frac{\beta_1^2 V_{\max}^2}{R} = 11.8 \frac{V_{\max}^2}{R} \left[\frac{(V_{\min}/V_{\max})^2 h_{\text{da1}} + h_{\text{sa1}}}{h_{\text{da1}} + h_{\text{sa1}}} \right] (\text{mm})$$

When

$$R_{\min 1} > R \geq R_{\min 2} = 11.8 \frac{V_{\max}^2 - V_{\min}^2}{h_{\text{da2}} + h_{\text{sa2}}},$$

the up limit is

$$h_{\text{sup}} = \max \left\{ \min \left[11.8 \frac{V_{\min}^2}{R} + h_{\text{sa2}}, 11.8 \frac{V_{\max}^2}{R}, h_{\max} \right], h_{\min} \right\} (\text{mm})$$

and the down limit is

$$h_{\text{down}} = \min \left\{ \max \left[11.8 \frac{V_{\max}^2}{R} - h_{\text{da2}}, 11.8 \frac{V_{\min}^2}{R}, h_{\min} \right], h_{\max} \right\} (\text{mm})$$

The middle for check is

$$h_{\text{chl}} = 11.8 \frac{\beta_1^2 V_{\max}^2}{R} = 11.8 \frac{V_{\max}^2}{R} \left[\frac{(V_{\min}/V_{\max})^2 h_{\text{da2}} + h_{\text{sa2}}}{h_{\text{da2}} + h_{\text{sa2}}} \right] (\text{mm})$$

3.2.3.5 Maximum Allowable Radius

The maximum radius will affect the track precision after laying out, curing, and maintenance. It will therefore influence the track regularity conditions directly, and the running speed and riding safety indirectly.

When a railway radius is larger than 8000 m, it is difficult to improve the running condition obviously by enlarging the radius. On the other hand, a very small curvature makes the maintenance of track regularity difficult.

The maintenance of track regularity is dependent on the laying out of a new constructed line, and track state detection and repair of a existed line. The alignment of curve or the track regularity is conserved by controlling the curve versine. Curve versine is proportion to the curve radius, and is inverse proportion to the square of chord, that is,

$$(3.34)$$

where f is the curve versine (mm); l is the chord (m); and R is the circle curve radius (m).

When the radius is larger than 8000 m, the curve versine is very small, then maintaining the survey precision and maintenance precision become very difficult. In that case, a large radius is a hidden problem of track irregularity. It is thus necessary to determine the maximum allowable radius on consideration of survey precision and maintenance precision.

In China, facilities on track inspection car can check the track regularity precisely for curves with radius not larger than 8000 m. When the radius is larger than 8000 m, the recorder will generally give out a “F” mode, that means the check results has problems.

It has been testified by the practice of railway engineering in Japan, France, and Germany that on curve section, it is necessary to set a basic control stake per 10 m along the line. The maximum allowable error is 1 mm.

In China, the allowable maximum radius is 12,000 m for line of mixed service; it shall be not larger than 10,000 m under general conditions, or 12,000 m under difficult condition for line of passenger traffic, even in extremely difficult conditions, it shall be not larger than 14,000 m.

3.2.3.6 Radius Influence on Engineering Work and Operation

Maximum Speed Allowed on Curved Tracks

As the resultant approaches either the outer or the inner rail, the vehicle becomes more unstable and likely to derail. There is general agreement that the vehicle is in a stable situation if the resultant falls within the middle third of the distance between the wheel-rail

contact points, assuming the middle 500 mm approximately, between these bearing points.

When V is so high in relation to e that F_r falls through or outside the head of the outside rail, overturning speed has been reached.

On any curved tracks, the superelevation is fixed in accordance with the average speed, therefore the maximum speed for trains negotiating the curved tracks will be limited by the allowable unbalanced superelevation as specified. From minimum radius equation we have

$$(h + \Delta h_d) = 11.8 \frac{V_{\max}^2}{R}$$

or

$$V_{\max} = \sqrt{\frac{(h + \Delta h_d)R}{11.8}}$$

where $V_{\max}$ is the maximum speed in kilometers per hour permitted with the value of h ; h is the actual superelevation in mm; Δh_d is the allowable deficient superelevation, mm; R is the radius of curve, m.

With maximum superelevation as 150 mm, the relations between the maximum allowable speed and radius of curve are as follows,

$$\Delta h_d = 60 \text{ mm}, V_{\max} = 4.2\sqrt{R}$$

$$\Delta h_d = 75 \text{ mm}, V_{\max} = 4.3\sqrt{R}$$

$$\Delta h_d = 90 \text{ mm}, V_{\max} = 4.5\sqrt{R}$$

Under ordinary conditions, the maximum allowable speed may be calculated by the following equation.

(3.35)

When the maximum superelevation is 125 mm, and Δh_d is 90 mm, the maximum allowable speed will be

$$V_{\max} = 4.27\sqrt{R}$$

If we limit the maximum train speed on curved tracks according to the unbalanced superelevation allowed, the safety of train operation can be guaranteed.

For high-speed railways with a designated speed of 350 km/h, with maximum superelevation of 180 mm, the relations between the maximum allowable speed and radius of curve are as listed in Table 3.3.

Table 3.3

Maximum Speed Allowed on Curved Tracks

Operation Mode	Single High Speed Train	Mixed Running with High Speed Train and Middle Speed
Engineering condition	General	Difficult
Limited speed		

In American Railroad, Wellington gives overturning speed equal to $2.45 R^{1/2} (185.1/D^{1/2})$ for a center of gravity 1.828 m above the rails. It is common practice with modern equipment to assume the center of gravity as 2.13 m above the rails, leading to an overturning speed of $2.245 R^{1/2} (170.0/D^{1/2})$, a more conservative and safer value. For a 2.44 m center of gravity, the overturning speed would be $2.118 R^{1/2} (160.3/D^{1/2})$, and for a center of gravity of 1.58 m, it would be $2.622 R^{1/2} (198.5/D^{1/2})$. A train seldom “overturns” from high speed; it often derails before the overturning speed is reached, due to track or/and equipment irregularities. The effects of superelevation become negligible at overturning speed because the springs will be fully compressed and the car body and center of gravity will not be offset by superelevation.

3.2.3.7 Field Work

The intersection angle at the PI is measured by its external deflection. The tangent distance (TD) can then be calculated using a radius for the flattest curve practicable at the given location. (The maximum and minimum radii of curve may be set by the chief engineer, an engineering policy decision.) The TD is then measured backward on one tangent to establish the PC, and forward on the other to the point of tangency (PT).

The curve is run in by setting the transit on the PC and turning successive deflection angles to intersect a 20-m chord measured from each successive station (Fig. 3.11). The deflection angles ϕ_i is equal to half the center angle for each 20-m station, that is $a_1=10/R$, $a_2=2 \times 10/R$, $a_3=3 \times 10/R$, and so on. The total deflection angle will, from trigonometry, be equal to half the intersection angle and should coincide with the PT, a check on the accuracy of the work. The transit may, however, be moved to the PT after running in half the curve from the PC and the second half running backward to meet the first half. This is advantageous in that any slight discrepancy in alignment can more easily be adjusted on the curve than at the tangent.

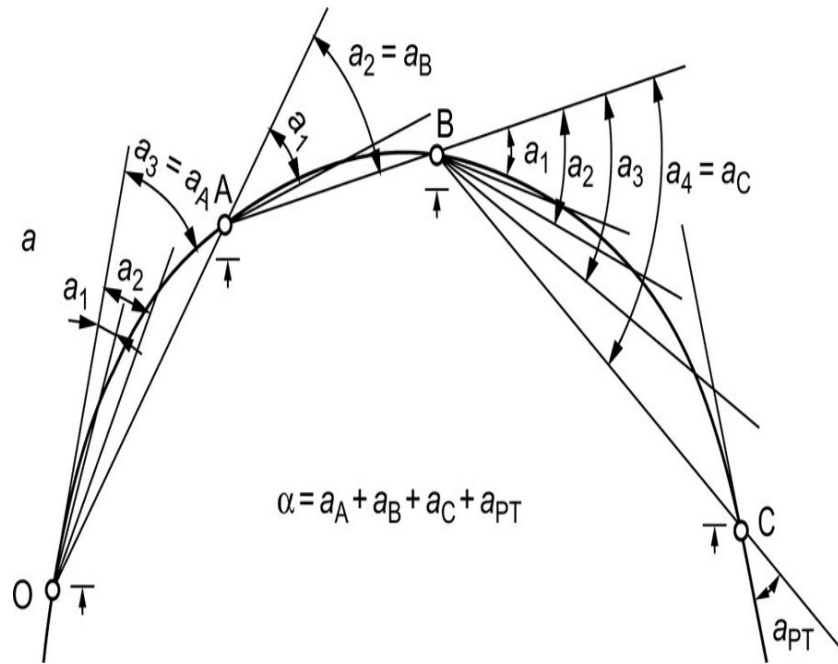


Fig. 3.11 Curve layout procedure with obstructed body.

If the line of sight is obstructed, the transit may be moved ahead to one of the points already established. The transit is moved to the last station established. A backsight, transit inverted, is taken on the former position with the total deflection to the station to which the transit has been moved on the plates. The transit telescope is again reversed and the full deflection to the next station is laid off. The procedure with the successive deflection angles as computed then continues (Fig. 3.12). The center angle of the whole curve is equal to the total deflection of the transit stations.

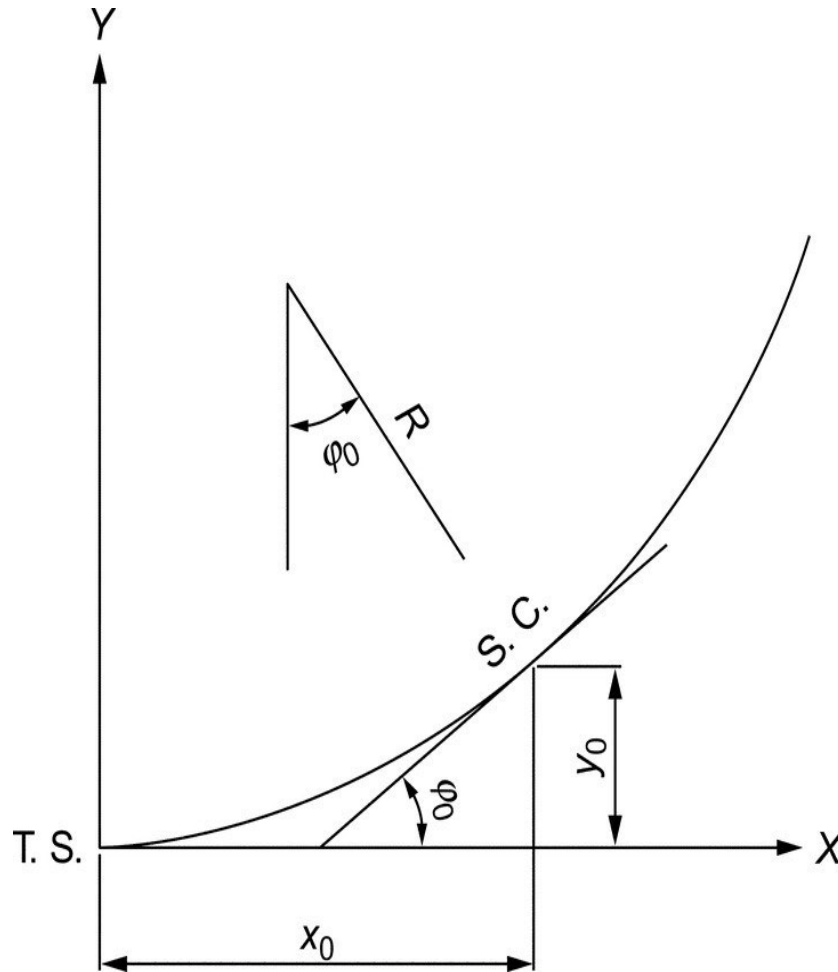


Fig. 3.12 Basic parameters of easement curve.

3.2.4 Easement Curve or Transition Spiral

When the rolling stocks negotiate the curved tracks, there will be forces which are non-existent on straight tracks, such as centrifugal force, impact in the vertical and horizontal directions, etc. These forces should not appear or disappear abruptly, otherwise they will give rise to vibrations, causing unsteadiness in train operation.

In addition, there are superelevation and possibly also gauge widening on curved tracks, which are also non-existent on straight tracks. If they are connected directly with each, the requirement of uniform transition cannot be satisfied.

Therefore, a transition curve with varying degree of curvature should be inserted between the straight and curved tracks, called easement curve or transition spiral.

Spiral or easement curves are used with simple curves to provide a gradual change of degree and easier riding in going from the tangent to full curvature. Spirals provide a

means of introducing superelevation at a rate corresponding to the rate of increase in curvature and varying from 0 mm. at the point of spiral (PS or TS) to full elevation at the point of full curvature (SC). Spirals also permit a gradual increase to full lateral acceleration at a comfortable, non-destructive rate.

3.2.4.1 Track Geometry Requirements

For any easement curve, the following track geometry requirements must be satisfied (see Fig. 3.12):

1. Coordinate requirement. At the beginning of the transition spiral T.S., abscissa $x=0$, ordinate $y=0$; at the end of the transition spiral S.C., $x=x_0$, $y=y_0$ with systematical changes between them.
2. Angle of inclination requirement. At T.S., angle of inclination ; at S.C., ; with systematic changes between them.
3. Curvature requirement. In order to avoid the abrupt change of centrifugal force, at T.S., curvature ; at S.C., (ρ is the radius of curve at any point on the transition spiral, R is the radius of circular curve); with systematic changes between them.

Superelevation requirement. At T.S., superelevation $h=0$; at S.C.; spiral, the average speed v_0 is constant, which means the superelevation at any point on the transition spiral is proportional to the curvature at the same point, $h=11.8 v_0^2 k=E_k$ (E is constant). Evidently, once the curvature requirement is satisfied, the superelevation requirement will be also satisfied.

4. Change of curvature (dk/dl) requirement. The longitudinal profile of the outer rail of the curved track after being super-elevated is called superelevation run-in. There are two type of superelevation run-ins, straight and curved, as shown in Figs. 3.13 and 3.14. The straight ones (Fig. 3.13) has a deflection angle both at T.S. and S.C., which will give rise to impact while trains passed. On high speed lines, curved run-in should be used instead (Fig. 3.14), so as to get rid of the effect of impact caused by the trains. Thus, at T.S. and S.C., we must have

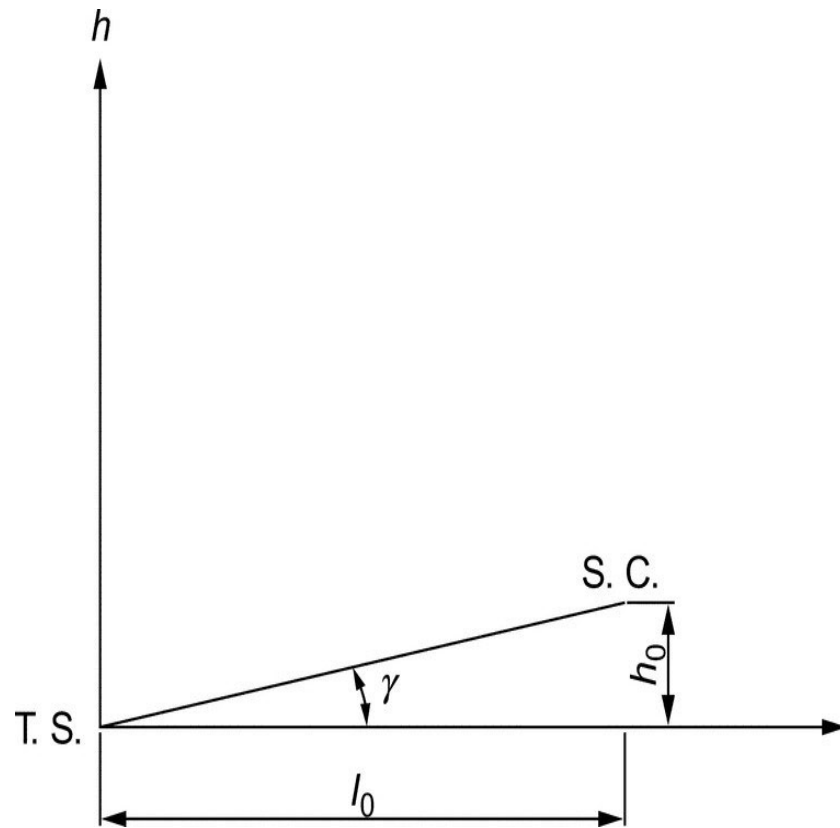


Fig. 3.13 Straight superelevation.

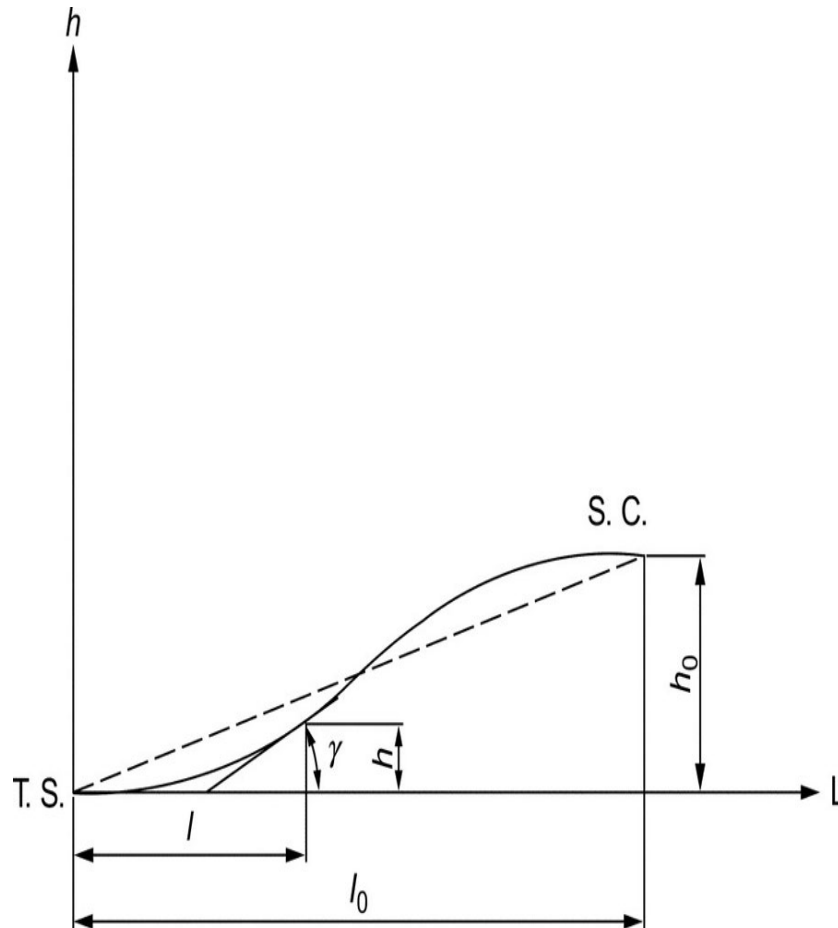


Fig. 3.14 Curved superelevation.

$$\tan \gamma = \frac{dh}{dl} = 0$$

Since $h = Ek$, therefore at T.S. and S.C., we must have $dk/dl = 0$, with systematic changes between them.

5. Change of dk/dl (d^2k/dl^2) requirement. When the trains negotiate the curved tracks, the angle of inclination between the axle and horizontal is ψ , as shown in Fig. 3.15. The angle ψ increases with the increases of avoid the abrupt change of forces acting on the rail due to the tilting of the car body, at T.S. and S.C., we must have the angular acceleration of the axle with systematic changes between them. Since also $h = Ek$, therefore

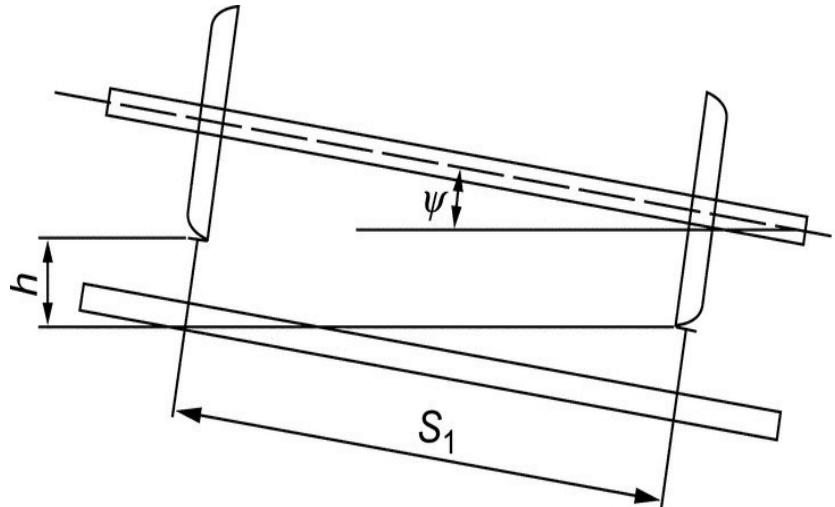


Fig. 3.15 The angle of inclination between the axle and horizontal.

$$\frac{d^2\psi}{dt^2} = \frac{E}{S_1} \cdot \frac{d^2k}{dt^2}$$

Since , finally we obtain

$$\frac{d^2\psi}{dt^2} = \frac{Ev^2}{S_1} \cdot \frac{d^2k}{dl^2}$$

At the beginning and end of the transition spiral T.S. and S.C., we must have , or , with systematic changes between them.

As mentioned above, the track geometry requirement of the transition spirals can be listed in Table 3.4.

Table 3.4

The Track Geometry Requirement of the Transition Spirals

Items	Symbols	At T.S. l=0	At S.C. l=l0	Between T.S. and S.C.
1	y	0	y0	Systematic change

2	φ	0	0	Systematic change
3	k	0	1/R	Systematic change
4	dk/dl	0	0	Systematic change
5	d^2k/dl^2	0	0	Systematic change

It can be shown that items 1 and 2 are fundamental requirements, while 3–5 those are derived from mechanical conditions. On railways where the train speed is not too high, transition spirals fulfilling the first three items will suit all necessary requirements, while on high-speed railroads, either item 4 or 4 and 5 have to be fulfilled simultaneously. Generally speaking, the more the items to be fulfilled there are, the more complicated will be the configuration of the transition spiral used and more difficult its maintenance will be. Therefore, we have to consider the question comprehensively.

When deriving equations for transition spirals, it is necessary to set out a basic equation which will fulfill the highest order of geometrical requirement. For instance, while fulfilling the first three requirements, we have to set up the basic equation for k ; while fulfilling the first four requirements, we have to set up the basic equation for dk/dl ; and while fulfilling all five requirements, we have to set up the basic equation for d^2k/dl^2 . After that, the basic equation is integrated successively until the final equation for the transition spiral is derived.

3.2.4.2 Cubic Spiral

The spiral commonly used is some form of the cubic parabola, where the offsets from the tangent to the spiral vary approximately from the cubic of the distance along the curve, the mid-ordinates increase at a constant rate, and the deflection angles vary with the square of the distance along the curve. The offset O_s and the spiral length are mutually bisecting, and the degree of spiral d increases at a uniform rate k .

Cubic spiral fulfilling the first three requirements (or cubic spiral as it is commonly called), is most commonly used on railroads at present. The superelevation run-in of such spiral is straight in shape, and the boundary conditions of the basic equation are:

$$l = l_0, k = k_0 = 1/R; 0 < l < l_0, 0 < k < k_0.$$

The basic equation which will satisfy all these boundary conditions is

$$(3.36)$$

where k is the curvature at any given point on the spiral, equal to $1/\rho$; l is the distance between T.S. and any given point, measured along the spiral; k_0 is the curvature at S.C., equal to $1/R$; and l_0 is the length of spiral.

At any given point on the spiral, its curvature k , angle of inclination ϕ , distance from T.S. l , and rectangular coordinates x, y are shown in Fig. 3.16.

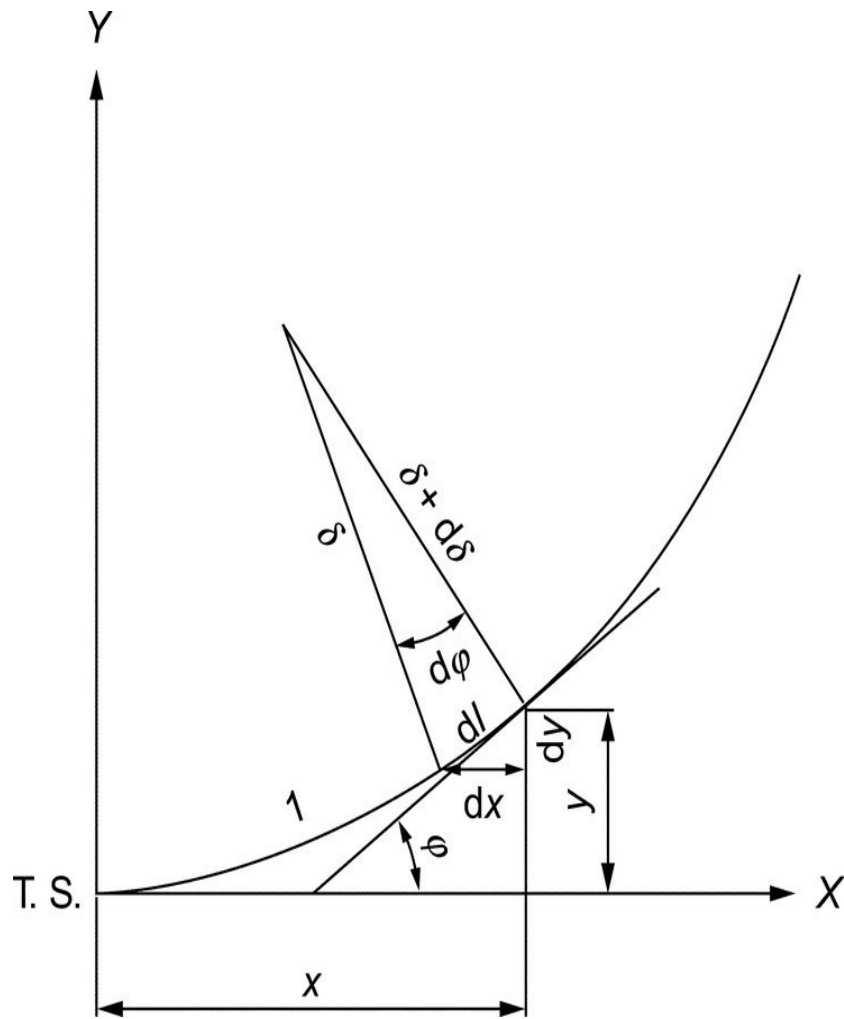


Fig. 3.16 Indicative diagram of parameters calculation.

It can be seen from the figure,

$$d\phi = \frac{dl}{\rho} = kdl$$

From which,

$$d\phi = k_0 \frac{l}{l_0} dl = \frac{1}{Rl_0} l dl$$

$$\varphi = \int d\varphi = \frac{l^2}{2Rl_0} + C$$

When

$$l = 0, \varphi = 0, C = 0,$$

we have

$$\varphi = \frac{l^2}{2Rl_0}$$

At S.C.,

$$l = l_0, \varphi = \varphi_0 = \frac{l_0}{2R}$$

Also, from Fig. 3.16,

$$dx = dl \cos \varphi, \quad dy = dl \sin \varphi$$

Angle φ is very small, we can approximately take

$$\sin \varphi = \varphi, \quad \cos \varphi = 1 - 2 \sin^2 \frac{\varphi}{2} = 1 - \frac{\varphi^2}{2}$$

Hence we have,

$$dx = \left(1 - \frac{\varphi^2}{2}\right) dl = \left(1 - \frac{l^4}{8R^2 l_0^2}\right) dl$$

$$dy = \varphi dl = \frac{l^2}{2Rl_0} dl$$

Integrate the above two equations,

$$x = \int \left(1 - \frac{l^4}{8R^2l_0^2} \right) dl = l - \frac{l^5}{40R^2l_0^2} + C,$$

$$y = \int \frac{l^2}{2Rl_0} dl = \frac{l^3}{6Rl_0} + C,$$

Since so finally, we obtain,

(3.37)

This is an approximate parametric equation of Archimedes spiral. Eliminate parameter l from the above equations, we have,

(3.38)

This is an approximate equation of Archimedes spiral with rectangular coordinates. When we take the first item only, we obtain,

(3.39)

This is the equation of cubic parabola most commonly used at present.

3.2.4.3 High Order Transition Spirals

We call transition spirals fulfilling the first four or all five requirements as high order spirals. The superelevation run-in of such spirals are curved in shape. The equations finally derived may be either trigonometric or algebraic, depending upon the functions we used for the basic equation. Take the trigonometric basic equation fulfilling the first four requirements and algebraic basic equation fulfilling all five requirements as example, the derivation of the high order spirals are outlined as follows.

Transition Spiral Fulfilling the First Four Requirements

Take the trigonometric basic equation as

(3.40)

in which A is an arbitrary constant and boundary conditions to be fulfilled are

$$l=0, \frac{dk}{dl}=0; l=l_0, \frac{dk}{dl}=0; 0 < l < l_0, \frac{dk}{dl} > 0.$$

From which we have:

$$k = \int k' dl = -A \frac{l_0}{\pi} \cos \pi \frac{l}{l_0} + C_1$$

When

$$l=0, k=0, C_1 = A \frac{l_0}{\pi}$$

$$k = A \frac{l_0}{\pi} \left(1 - \cos \pi \frac{l}{l_0} \right)$$

When

$$l=l_0, k=\frac{1}{R}, A = \frac{\pi}{2Rl_0}$$

$$k = \frac{1}{R} \left(\frac{1}{2} - \frac{1}{2} \cos \pi \frac{l}{l_0} \right)$$

$$\varphi = \int k dl = \frac{l_0}{2R} \left[\left(\frac{l}{l_0} \right) - \frac{1}{\pi} \sin \pi \frac{l}{l_0} \right] + C_2$$

When

$$l=0, \varphi=0, C_2=0$$

$$\varphi = \frac{l_0}{2R} \left[\left(\frac{l}{l_0} \right) - \frac{1}{\pi} \sin \pi \frac{l}{l_0} \right]$$

$$y = \int \varphi dl = \frac{l_0^2}{6R} \left[\frac{3}{2} \left(\frac{l}{l_0} \right)^2 - \frac{3}{\pi^2} \cos \pi \frac{l}{l_0} \right] + C_3$$

When

$$l=0, y=0, C_3 = -\frac{3}{\pi^2} \cdot \frac{l_0^2}{6R},$$

finally we obtain,

$$y = \frac{l_0^2}{6R} \left\{ \frac{3}{2} \left(\frac{l}{l_0} \right)^2 + \frac{3}{\pi^2} \left[\cos \pi \frac{l}{l_0} - 1 \right] \right\}$$

(3.41)

Take , the equation of transition spiral with rectangular coordinate will be

(3.42)

Transition spiral fulfilling all five requirements

Take the algebraic basic equation as

$$\frac{d^2 k}{dl^2} = Al \left(l - \frac{l_0}{2} \right) (l - l_0) = \frac{Al_0^3}{2} \left[2 \left(\frac{l}{l_0} \right)^3 - 3 \left(\frac{l}{l_0} \right)^2 + \left(\frac{l}{l_0} \right) \right]$$

(3.43)

in which A is an arbitrary constant, and boundary conditions to be fulfilled are

$$l=0, k''=0; l=l_0; k''=0; 0 < l < \frac{l_0}{2}, k'' > 0; \frac{l_0}{2} < l < l_0, k'' < 0.$$

From which we have,

$$k' = \int k'' dl = \frac{Al_0^2}{2} \left[\frac{1}{2} \left(\frac{l}{l_0} \right)^3 - \left(\frac{l}{l_0} \right)^3 + \frac{1}{2} \left(\frac{l}{l_0} \right)^2 \right] + C$$

When

$$l = 0, k' = 0, C = 0$$

$$k' = \frac{Al_0^2}{2} \left[\frac{1}{2} \left(\frac{l}{l_0} \right)^4 - \left(\frac{l}{l_0} \right)^3 + \frac{1}{2} \left(\frac{l}{l_0} \right)^2 \right]$$

$$k = \int k' dl = \frac{Al_0^3}{2} \left[\frac{1}{10} \left(\frac{l}{l_0} \right)^3 - \frac{1}{4} \left(\frac{l}{l_0} \right)^4 + \frac{1}{6} \left(\frac{l}{l_0} \right)^3 \right] + C_2$$

When

$$l = 0, k = 0, C_2 = 0; l = l_0; k = \frac{1}{R}, A = \frac{120}{Rl_0^3}.$$

$$k = \frac{1}{R} \left[6 \left(\frac{l}{l_0} \right)^3 - 15 \left(\frac{l}{l_0} \right)^4 + 10 \left(\frac{l}{l_0} \right)^3 \right]$$

$$\varphi = \int k dl = \frac{l_0}{2R} \left[2 \left(\frac{l}{l_0} \right)^6 - 6 \left(\frac{l}{l_0} \right)^5 + 5 \left(\frac{l}{l_0} \right)^4 \right] + C$$

When

$$l = 0, \varphi = 0, C = 0$$

$$\varphi = \frac{l_0}{2R} \left[2 \left(\frac{l}{l_0} \right)^6 - 6 \left(\frac{l}{l_0} \right)^5 + 5 \left(\frac{l}{l_0} \right)^4 \right]$$

$$y = \int \varphi dl = \frac{l_0^2}{6R} \left[\frac{6}{7} \left(\frac{l}{l_0} \right)^7 - 3 \left(\frac{l}{l_0} \right)^6 + 3 \left(\frac{l}{l_0} \right)^5 \right] + C$$

When

$$l=0, y=0, C=0,$$

finally we obtain

$$y = \frac{l_0^2}{6R} \left[\frac{6}{7} \left(\frac{l}{l_0} \right)^7 - 3 \left(\frac{l}{l_0} \right)^6 + 3 \left(\frac{l}{l_0} \right)^5 \right]$$

(3.44)

Take , the equation of transition spiral with rectangular coordinates will be,

(3.45)

Evidently, using the above method, we can draw conclusions from similar cases and derive equations for other transition spirals in accordance with the trigonometric or algebraic basic equations used to suit the different requirements.

3.2.4.4 Length of Transition Spiral

The length of transition spiral is influenced by many factors, among which the safety requirements of train operation and comfort requirement of passengers are the most important ones.

Safety Requirement

When the rolling stocks negotiate the curved tracks, neglecting the influences of the track elasticity and coil spring of cars, the two wheels at one of the bogies will be in contact with the rail surface, while at other end of the bogie, the outer wheel will be and the inner wheel will not be in contact with the rail surface. In order to ensure the operating safety of trains, the wheel flange should not climb over the inner rail surface (Fig. 3.17). Let i be the slope of the superelevation run-in, L_{max} be the maximum rigid wheel base of the bogie, then the gap between the inner wheel tread and the rail surface will be . In cases where this gap is greater than the minimum wheel flange height f_{min} , there will be a danger of derailment. Therefore, we must have

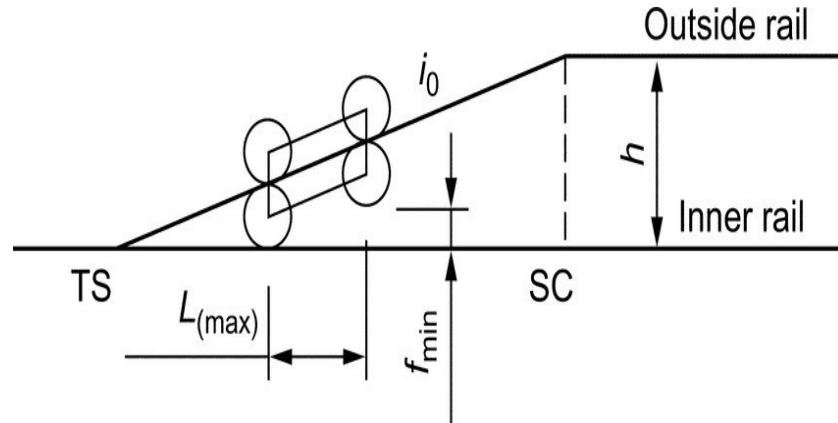


Fig. 3.17 Bogie on spiral.

$$i \cdot L_{\max} \leq f_{\min}$$

(3.46)

The length of spiral L_0 should be

(3.47)

where h_0 is the superelevation of the circular curve.

According to Chinese practice, in order to ensure the safety against derailment, the slope of the straight superelevation run-in should not exceed 2‰.

For transition spirals with curved superelevation run-in, its maximum slope must also fulfill the requirement of Eq. (3.47), and calculated by the following equation:

$$i = \frac{dh}{dl} = E \frac{dk}{dl}$$

where E or k . For curved superelevation run-in, this will be located at the middle of the transition spiral where $l = L_0/2$, therefore

$$i_{\max} = \left(\frac{dh}{dl} \right) = 11.8 V_0^2 \left(\frac{dk}{dl} \right)$$

For trigonometric spirals fulfilling the first four requirements,

(3.48)

Substituting into Eq. 3.48, we obtain

$$i_{\max} = \frac{11.8V_0^2\pi}{2Rl_0} = \frac{h_0\pi}{2l_0}$$

Let l_0, i_0 be the length and slope of the straight superelevation run-in of the cubic spiral, respectively. In order to ensure that $i_{\max}$ of the curved superelevation run-in will not exceed i_0 of the straight ones, we must have

$$\frac{h_0\pi}{2l_0} \leq \frac{h_0}{l_0}$$

Or

(3.49)

For algebraic spirals fulfilling all five requirements,

$$i_{\max} = \left(\frac{dh}{dl}\right) = 11.8V_0^2 \left(\frac{dk}{dl}\right) = 11.8V_0^2 \frac{1.875}{Rl_0} = \frac{1.875h_0}{l_0}$$

In order to ensure $i_{\max}$ not to exceed i_0 , we must have

$$\frac{1.875h_0}{l_0} \leq \frac{h_0}{l_0}$$

Or

(3.50)

It can be seen that, in order to ensure the maximum slope of the curved superelevation run-in does not exceed that of the straight ones, the length of the transition spiral must be lengthened appropriately.

According to Chinese practice, in order to ensure the safety against derailment, the slope of the straight superelevation run-in should not exceed 2‰, then length of transition spiral should be

$$l_{01} \geq h/2$$

Comfort Requirement

The rate of rise of the wheels on the outer rail is calculated as follows:

$$\mu = \frac{h_0 v_{\max}}{l_0} \quad (\text{mm/s})$$

where h_0 is the superelevation on circular curves, mm; $v_{\max}$ is the maximum train speed, m/s; and l_0 is the length of spiral, m.

In order to ensure the travelling comfort of the passengers, we must have

$$(3.51)$$

in which $V_{\max}$ is the maximum train speed, km/h;

1/3.6=conversion factor.

According to the long-term practice in China, we adapt . The Maintenance Regulations specify that while using Eq. (3.51) in calculating the length of the spiral for new lines, $V_{\max}$ will be the maximum train speed as projected. Under ordinary conditions, is used, while under difficult conditions, such as places adjacent to the bridges or tunnels or curves with very small radius, may be used instead. The calculated length of the spiral should be rounded to multiples of 10 m.

On existing lines, actual maximum train speed and superelevation are used as the basis of calculation. The Maintenance Regulations specify that under ordinary conditions, is used, while under extraordinarily difficult conditions, is used instead. Thus, under ordinary conditions, we use

$$(3.52)$$

Under extraordinarily difficult conditions, we use

(3.53)

The calculated length of the spiral should be also rounded to multiples of 10 m.

On existing lines, if the original length of the spiral is greater than that of the calculated value, the former is retained, otherwise it should be prolonged as appropriate.

In China, we also specify that, the length of the circular curve between two transition spirals should not be less than 20 m. While reconstructing or double tracking the existing lines, it is allowed that this should not be less than 14 m under difficult conditions.

3.2.4.5 Minimum Circular Arc Length Between Spiral

The lengths of the circular arc between two transition curves shall meet the conform and safety requirements, thus

(3.54)

where L_{cmin} is the minimum length of circular curve (m), it shall meet the value in Table 3.5.

Table 3.5

Minimum Allowable Length of Circular Curve

Speed (km/h)	350	300	250
Minimum allowable length of circular	280(210)	240(180)	200(150)

Note: Values in brackets are the minimum allowable values selected under difficult conditions.

When designing the plane, if the deflection angle is small, if the length of circular arc fails to meet the requirement, that is, Eq. (3.39) cannot be met, then we enlarge the radius, and lengthen the circular arc. If the condition is limited, the design of the plane should be changed.

For high speed railway, the minimum allowable lengths of the intermediate straight line between two adjacent curves and the circular curve between two transition curves shall be calculated with the following equation

Under general condition: $L \geq 0.8V$

(3.55)

Under difficult condition: $L \geq 0.6V$

(3.56)

where L indicates length of circular curve or intermediate straight line (m) and V indicates speed (km/h).

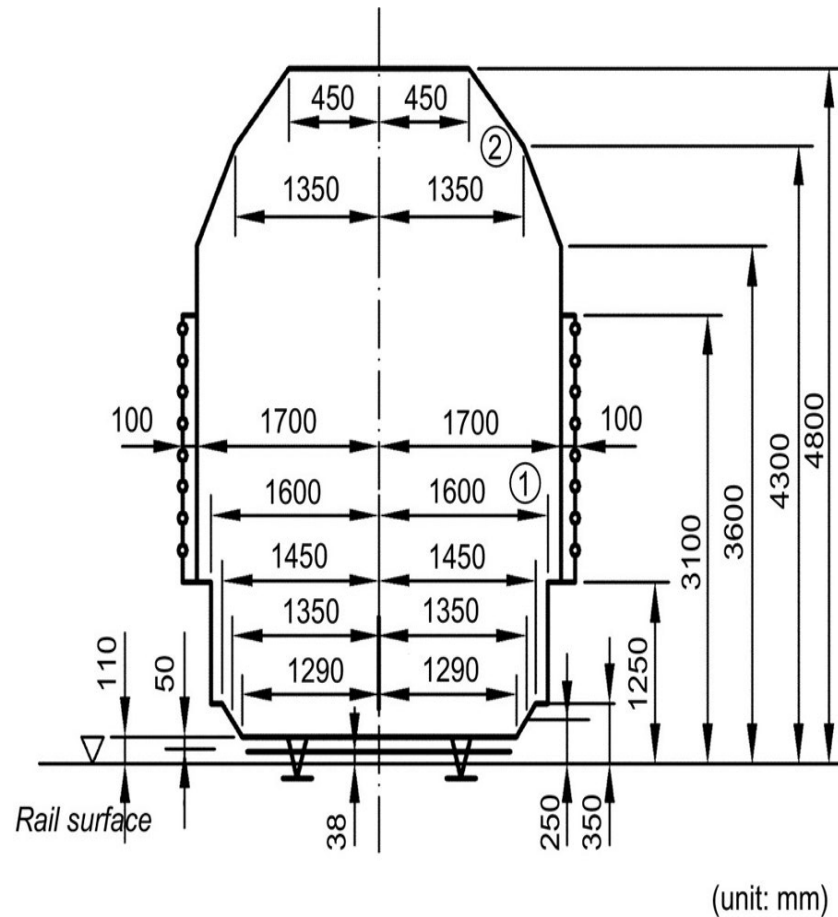
3.2.5 Distance Between Centers of Main Lines

When a railway is constructed with two or three main lines, the straight of the main line in section should be designed as a parallel double track with a constant distance between centers of lines, and the curves of the main line in section should be designed as concentric circles. The distance between centers of lines shall be determined to meet the safety requirements. In the curve area, sometimes, the distance should be widened. The influenced factors include railway clearance, aerodynamics, and wheel-rail contact geometrical relation.

3.2.5.1 Railway Clearance

Railway clearance is divided into rolling stock clearance limit, fundamental construction clearance of straight line, tunnel construction clearance, and bridge construction clearance.

Rolling stock clearance limit is the maximum overall size of rolling stock in width and height. In generally, rolling stock, both loaded car and empty car, shall not go beyond the bounds of rolling stock clearance. The rolling stock clearance of upper part can be found Fig. 3.18. In special cases, a train of out-of-gauge good, in which the loaded goods go beyond this clearance, shall be loaded to meet the relevant requirements.



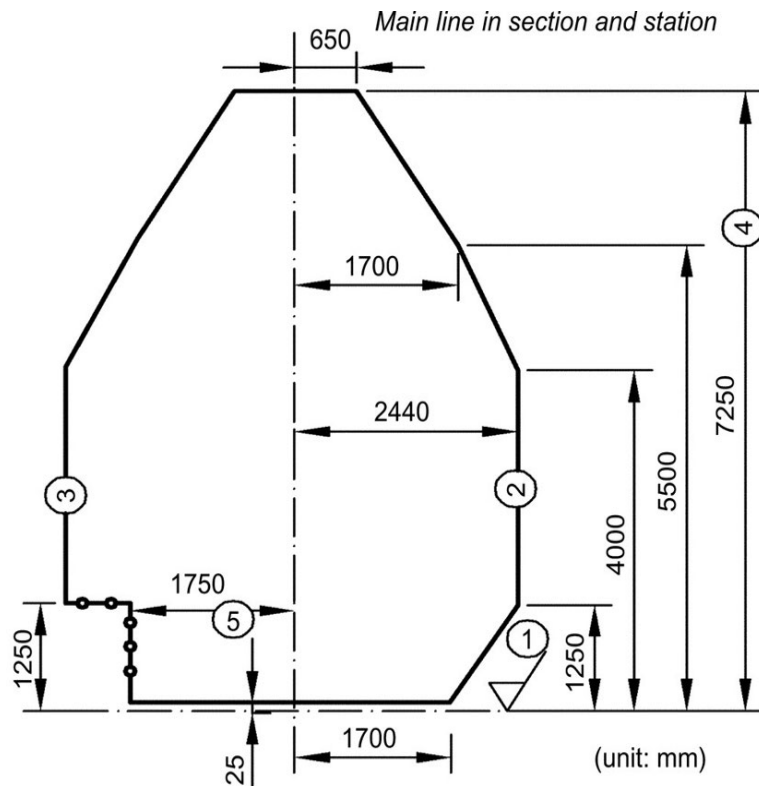
— Limit contour line of train signal

① For new electric locomotive, 1675 mm

② For new electric locomotive, 750 mm

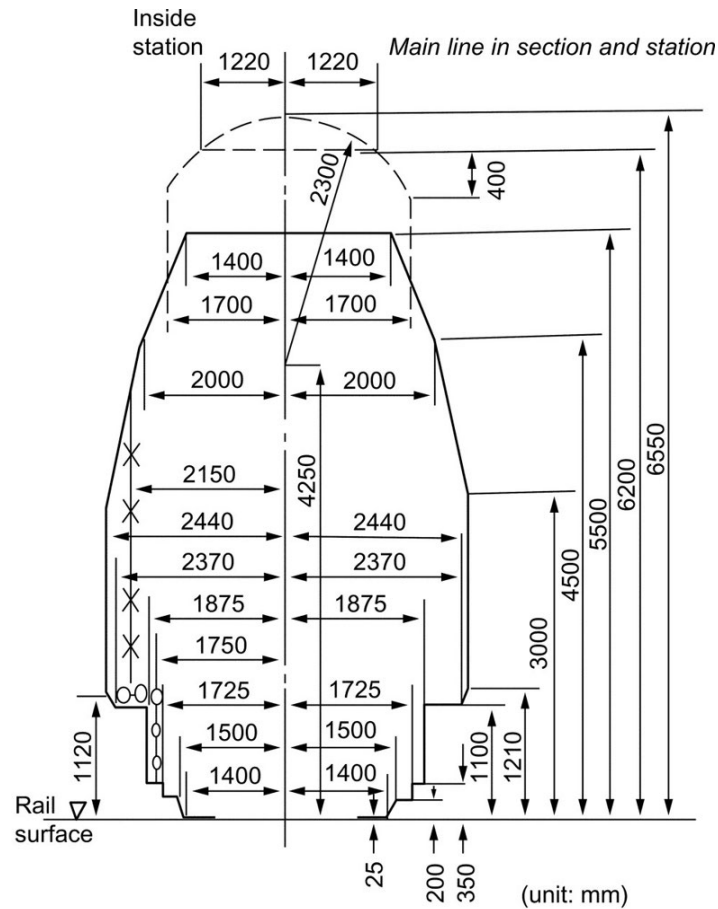
Fig. 3.18 Rolling stock clearance limit upper part.

The fundamental construction clearance is the overall contour line which cannot be surpassed by buildings and facilities in any cases (see Figs. 3.19 and 3.20).



- Construction clearance for platform (not suitable for main line)
- Fundamental construction clearance
- ① Elevation of rail surface
- ② Construction clearance for main line (no platform)
- ③ Construction by platform
- ④ Maximum height above rail surface
- ⑤ Width between center line of side track and edge of platform

Fig. 3.19 Construction clearance for line of passenger traffic.



- x—x— Construction clearance for signal (not suitable for main line)
- o—o Construction clearance for platform (not suitable for main line)
- Fundamental construction clearance
- Limit line for Overpass bridge, rain shed etc., in electric locomotive line

Fig. 3.20 Construction clearance for line of freight and passenger traffic.

For line of freight and passenger traffic with designed speed of 160 km/h, the height of construction clearance is 7.0 m.

3.2.5.2 Distance Between Centers of First Line and Second Line in Straight Line

The major influencing factor for distance between centers of main lines is pressure wave produced by two meeting trains. Big or small, the intensity of pressure wave is determined

by the designed speed of two meeting trains, streamlined car body, width and length of car, and distance between enter lines. In order to ensure the safety distance for the meeting of two trains, there must be enough distance between the center lines.

Distance Between First Line and Second Line

The minimum distance between first line and second line can be calculated as follows:

$$(3.57)$$

where $D_{min(1,2)}$ is the minimum distance between first line and second line (mm); B_1 , B_2 is the 1/2 maximum width of meeting cars (mm); For ordinary train, it is 1/2 width of rolling stock clearance limit plus width of train signal, that is $1700+100=1800$ (mm); for a high-speed train, it is 1/2 width of EMU. As the maximum width is 3.4 m for CRH series, hence, 1/2 maximum width is 1700 mm; and Y is the minimum safety distance for two meeting trains (mm) (the size is determined by running speed, structure of car, allowable pressure wave, etc.).

According to experiment data in China and several other countries, the maximum distance between two meeting trains are shown in Table 3.6. The distance between centers of main lines in section and station shall not be less than the standard values listed in Table 3.6.

Table 3.6

Distance Between Centers of Main Lines in Section and Station

Railway Type	Railway Line for Passenger Traffic	Railway for Mixed Pass
V_{max} (km/h)	350	300
Safety distance between rolling stocks (mm)	1600	1400
minimum distance between centers of lines (m)	5.0	4.8

For a line of passenger traffic, the distance between centers of tracks in parallel sections of main line with a connecting line or MU running line shall be determined comprehensively according to the train operation speed and its technical requirements of the adjacent line on one side and the subgrade level relationship of adjacent lines, as well as by taking related technical conditions of E&M equipment, subgrade drainage equipment, sound barrier, bridge and culvert, and working passage for ensuring the safety of technical operation staff etc. into consideration, and shall not be less than 5 m as a minimum.

On railway lines for mixed passenger and freight traffic with trains of out-of-gauge good passing, the distance between centers of lines shall meet the requirements: where the distance is larger than 350 mm, a train can run with ordinary speed without limit; in 300–350 mm, running speed cannot be higher than 30 km/h; and where the distance is smaller than 300 mm, no train is permitted to pass. Therefore, in a railway for mixed passenger and freight traffic with 4 m distance between center lines, if a train of I-grade out-of-gauge good (1/2 width of car is 1900 mm) is running in one line, an ordinary train (1/2 width of car is 1700 mm, width of train signal is 100 mm) is running on other line, then the net distance between cars of the two meeting trains is 300 mm. In this case, the two meeting trains can only run in speed of 30 km/h or lower. If a train of II-grade out-of-gauge (1/2 width is 1940 mm) or super-out-of-gauge is running in one line, no train is permitted to run on other line.

The distance between centers of two lines in double-tube tunnel shall be determined according to geological condition, tunnel structure and requirements of disaster prevention and relief after comprehensive analysis and study.

Distance Between Centers of the Second Line and the Third Line

As signals should be set between the second and third line, distance between centers of the second line and the third line shall meet the requirement of construction clearance. The maximum distance between centers shall comply with the following equation:

$$(3.58)$$

where $D_{min(2,3)}$ is the minimum distance between centers of the second line and the third line (mm); BZX is the 1/2 width of construction clearance (mm), take 2440 mm in China; and BX is the maximum width of signal (mm), take 410 mm in China.

Then the distance between centers is: $2440+410+2440=5290$ (mm), taking 5.3 m.

It is clear that the aerodynamic pressure produced by passing train is not the limited factor for determining the distance between centers of the second line and the third line. For

railway for mixed freight and passenger traffic, trains of out-of-gauge can run on the second line and third line at the same time once meet the requirements above.

The distance between line of high-speed passenger traffic and line of mixed freight and passenger traffic shall meet the requirement for distance between centers of the second line and the third line, that is, no less than 5.3 m.

The distance between centers of tracks in parallel sections of main lines with existing railway and mixed passenger and freight railway shall not be less than 5.3 m. The minimum distance between centers of tracks shall be determined comprehensively according to related technical conditions when the parallel lines are not in the same level or equipment is set up between tracks.

3.2.5.3 Distance Widening in Curve Sections

In curve sections, the construction clearance and distance between centers of line may be reduced as the change of geometric relation between car and track. In order to ensure the safety of operation, the distance between centers of line may need to be widened.

Reasons for Widening

1. Geometry deviation of car from center of track

When a car is negotiating the curved tracks, the middle part will protrude toward the inside of curve with W_1 , and the two end parts protrude toward outside with W_2 , as in Fig. 3.21A.

If the length of a car body is L , distance between bogie pivot centers is Z , according to the geometric relation of the curve, the protruded volume can be calculated as follows:

From

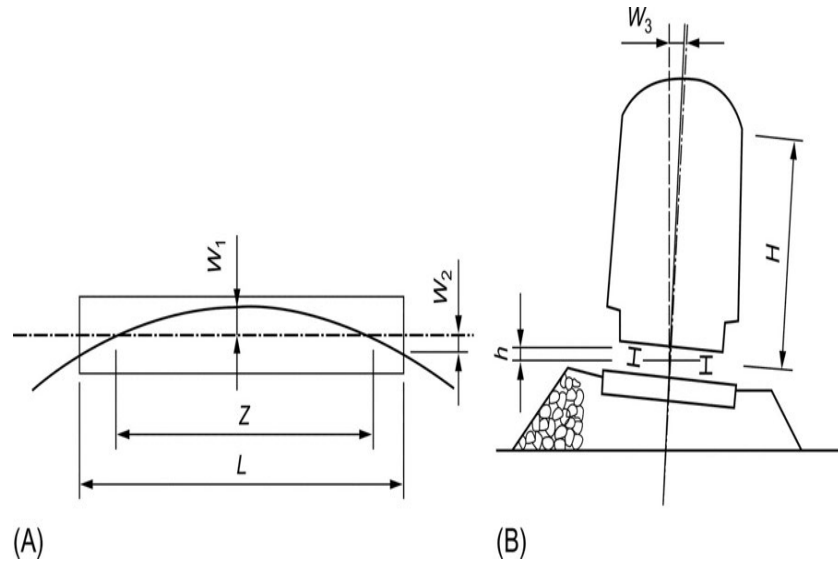


Fig. 3.21 Geometric relation between car and track on a curve section. (A) Geometry deviation of car (B) Deviation caused by superelevation.

$$(R - W_1)^2 + (Z/2)^2 = R^2$$

Then

$$R^2 - 2RW_1 + W_1^2 = R^2$$

From the above equation, and omitting the infinitesimal item with two times, we obtain

$$W_1 \approx \frac{Z^2}{8R}$$

where R is the radius of curve, m; L is the length of a car body; and Z is the distance between bogie pivot centers.

Similarly, W2 can be obtained using the following equation:

As

$$(L/2)^2 + [R - (W_1 + W_2)]^2 = R^2$$

Then

$$L^2/4 + \left[R^2 - 2R(W_1 + W_2) + (W_1 + W_2)^2 \right] = R^2$$

From the above equation, and omitting the infinitesimal item with 2 times, we obtain

$$W_2 \approx \frac{1}{8R}(L^2 - Z^2)$$

In China, the maximum length of car body $L=26$ m, distance between bogie pivot centers $Z=18$ m, then

(3.59)

$$W_2 = \frac{26^2 - 18^2}{8R} \times 1000 = \frac{44,000}{R} \text{ (mm)}$$

(3.60)

2. Deviation of car body caused by superelevation

When a car is negotiating the curved track with a superelevation of h , the body of car may have a deviation from the center line toward the curve center, as in Fig. 3.21B. At the point where the height of H is above the rail surface, the volume of inclination W_3 is as follows (distance between centers of rail is 1500 mm):

As

$$\frac{W_3}{H} = \frac{h}{1500}$$

Then

(3.61)

where h is the superelevation, mm, and H is the height of calculated point, $H=3850$ mm.

Value of Widening Calculation

1. Widening method for curve connected to straight lines with minimum distance between centers of line

① If superelevation of outer curve (h_w) is smaller than or equal to that of the inside curve h_N , the widening value of distance between centers of curve is shown as follows:

$$W = W_1 + W_2 = \frac{40,500}{R} + \frac{44,000}{R} = \frac{84,500}{R} \quad (\text{mm})$$

(3.62)

② If superelevation of outer curve (h_{outer}) is larger than that of the inside curve h_{inner} , the widening value of distance between centers of curve is as follows:

$$\begin{aligned} W &= W_1 + W_2 + W_3 = \frac{40,500}{R} + \frac{44,000}{R} + \frac{H}{1500}(h_{\text{outer}} - h_{\text{inner}}) \\ &= \frac{84,500}{R} + \frac{3850}{1500}(h_{\text{outer}} - h_{\text{inner}}) \quad (\text{mm}) \end{aligned}$$

(3.63)

The result shall be taken as the multiple of 5 mm.

2. Widening method for curve connected to straight lines with distance between centers of line being larger than the minimum one

In this case, curve widening can be determined as follows:

(3.64)

where W is the widening value of distance between centers of curve (mm); D_{min} is the minimum distance between centers of line in straight line (m); D is the distance between centers of straight line connected to curve (m); and W is the curve widening value when the distance between centers of line takes the minimum one (mm) (calculated with the method above).

Method to Widen the Distance Between Centers of Curves

For newly built double lines or the add-built second line or third line, curves in parallel sections should be designed as concentric circles, the distance between centers of curves can be widened by means of lengthening the transition spiral of inside curve, as in Fig. 3.22A. As we know, when a transition spiral is used, the major points TC and CT of circular curve would move toward the center of a circle with a spiral deflection of p . If a longer transition spiral is used in inside curve, we can get a larger spiral deflection, so that the distance between centers of curves will be widened.

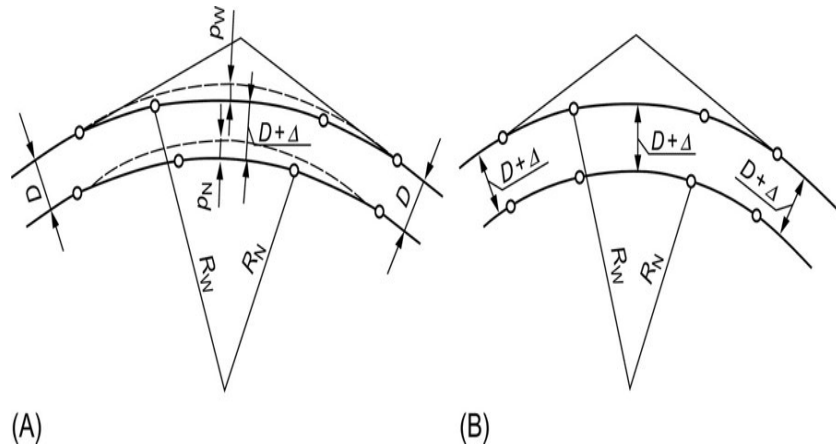


Fig. 3.22 Widening distance between centers of curves.

In order to widen the distance from D to $\Delta+D$, if the spiral deflection outside curve is (m) , the spiral of outside curve should be

$$p_{\text{inner}} = p_{\text{outer}} + W' \times 10^{-3} \quad (\text{m})$$

Hence the length of spiral inside should be

$$l_{\text{inner}} = \sqrt{24R_{\text{inner}} \times p_{\text{inner}}} = \sqrt{24R_{\text{inner}} (p_{\text{outer}} + W' \times 10^{-3})} \quad (\text{m})$$

in which

$$R_{\text{inner}} = R_{\text{outer}} - D - W' \times 10^{-3} (\text{m})$$

where D is the distance between centers of straight lines connected to curves (m).

In the sections where a curve is adjacent to a curve, if the intermediate straight line is too short, or the deflection angle is too small to meet the requirements for widening the distance of centers of curves by lengthening the spiral, it is necessary to widen the

distance of centers of lines D in straight line to ensure an enough distance between centers of curves, as in Fig. 3.22B.

Widened Conditions

1. For railways of mixed freight and passenger traffic

The distance between centers of curves shall be widened using the method discussed above.

2. For the sections of railway of passenger traffic without speed limits

The purpose to widen distance between centers of curves is to ensure that there is enough safety distance between two meeting trains. Nowadays, for railway with speed not lower than 200 km/h, the minimum safety distance between centers of line provided for by code have more than needed to meet the requirement of aerodynamics, in general, it is about 200 mm. According to the above method, the calculated widening value is no more than 150 mm. Hence, for railway of passenger traffic with speed larger than 200 km/h, it is not necessary to widen the distance between centers of curves. For railway line with speed of 200 km/h and lower, the distance shall be widened by means of the above methods.

3. For the sections of railway of passenger traffic with speed limits

In curve sections where speed of train is limited, in general, the train would negotiate a curve with a limited speed. In this case, the distance should be widened by using the method above.

3.2.5.4 Method to Calculate the Distance Between Centers of Curves in Sections With Changing of Distance

1. Method to determine the change of distance between centers of lines

1. The widening of distance between centers of lines in bridges or tunnels shall be completed in curves areas at the two ends of stations. In the case of difficult conditions, it can be completed on a straight line by using reverse curves.

2. For railway lines of mixed freight and passenger traffic, if the change of distance is realized with a pair of reverse curves, if the minimum distance is limited by the minimum length of circular arc, it is not necessary to lay out a spiral at the two ends of circular curve. However, in these cases, the radius should be no less than the corresponding value in Table 3.7.

Table 3.7

Minimum Radius With no Need to Lay Out Spiral

Designed Speed of Passenger Trains (km/h)	160	140	120	100	80
Minimum radius (m)	12,000	10,000	5000	4000	3000

3. For railway of mixed freight and passengers, if the change of distance is realized by using inverse curves, when the angle of deflection limit shall not meet the requirements of the maximum radius, the speed for passenger train is less than 100 km/h, and the minimum length of the spiral is 20 mm.

2. Calculation of distance between centers on sections with change of distance

1. In a straight track, according to the distance between centers of line, the change of curve can be calculated by using linear interpolation.

2. At curve sections with change of distance, the distance between two lines can be calculated with special plane curve calculation method, using trigonometric analysis.

3.3 Profile Design in Section

The railway profile is composed of grade sections which length and gradient is different from each other. The features of grade section are expressed in the length and gradient, as in Fig. 3.23. The length L_i is the level distance between both ends of a grade section, in meter. The value of gradient i is the ratio of H_i in meter (the height difference between both ends) to L_i in meter (the length of a grade section), in terms of one-thousandth (0.1 percentage), that is, taken as positive when ascending, negative when descending, and downward takes negative. Such as, a gradient of 10‰ means 10 m of elevation per kilometer.

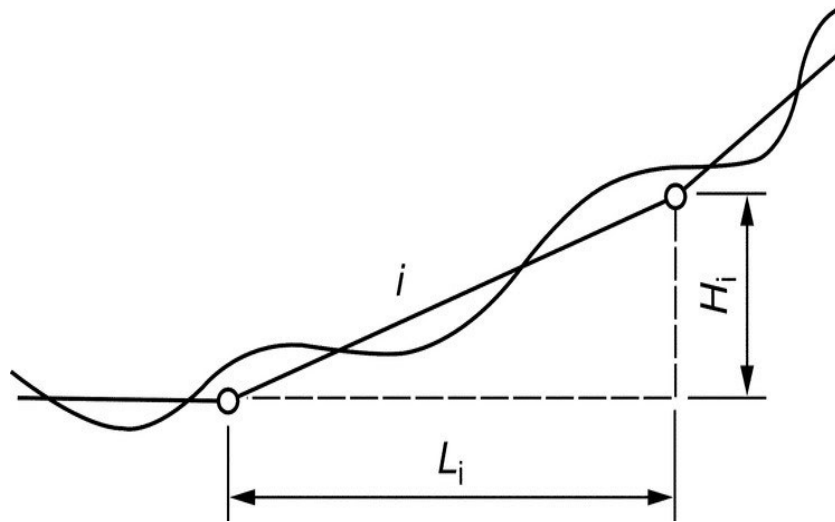


Fig. 3.23 Length and gradient.

The work of profile design includes determining the maximum gradient of grade, length of grade section, connection of point of gradient change, etc.

3.3.1 The Maximum Grade

For a newly built railway, maximum grade is the maximum value of gradient. In railway lines for mixed passenger and freight traffic, the maximum grade is determined by the traction mass of freight trains. In the section hauling by single locomotives, it is the ruling grade. In the section hauling by two or more locomotives, it is the pusher grade, in which the most common one is the double heading grade. In railway lines for passenger traffic, as motor cars use high power engines, light type cars, and fine-quality brake equipment, the

maximum gradient will not be limited by the traction mass of a passenger train. The maximum grade shall be determined after technical and economic comparisons in terms of engineering conditions and operation conditions.

3.3.1.1 Maximum Grade in Railway Line for Passenger Traffic

In high-speed railway lines for passenger traffic, the maximum grade shall be determined after technical and economic comparisons in terms of total power of EMU, topography along the railway, average running speed, and train combination, etc. For a newly built railway line for passenger traffic, a larger maximum gradient shall be selected to better fit the change of topography so that the railway is built with a lower construction cost.

Maximum Calculated Gradient

The maximum calculated gradient in railway line for passenger traffic is defined as the gradient value of the consecutive ascending grade on which a given multiple unit can run at the calculated speed.

For a definite EMU, the maximum gradient determined by motor car power can be calculated as follows:

$$i_{\max} = \frac{(\lambda_u F_c - R_0) \times 10^3}{M \times g} = f_i - r_0 (\text{‰})$$

(3.65)

or

$$(3.66)$$

where M is the total mass of MU (t); $i_{\max}$ is the maximum calculated gradient; Vmax is the maximum designed speed (km/h); r_0 is the unit basic resistance of EMU under the calculated speed (N/10t); F_c is the calculated tractive effort (kN); p_k is the average power per ton mass of MU (t); λ_u is the utilization coefficient of tractive effort; and g is the acceleration of gravity (m/s^2).

It is obvious that an increase in the speed of the MU train can be achieved by increasing the average unit power per mass ton of train.

For example, for a CRH3 EMU composed of three motors and three trailers, with 21.05 kW/t of average unit power per ton mass run ascending at speed of 300 km/h, the maximum gradient can be calculated as follows:

$$\begin{aligned} r_0 &= 0.66 + 0.00245V + 0.000132V^2 \\ &= 0.66 + 0.00245 \times 300 + 0.000132 \times 300^2 = 13.275 \text{ (N/10t)} \end{aligned}$$

Then

$$\begin{aligned} i_{\max} &= \frac{3600p_k - r_0 \times g \times V_{\max}}{V_{\max} \times g} = \frac{3600 \times 21.05 - 13.275 \times 9.81 \times 300}{9.81 \times 300} \\ &= 12.47(\text{‰}) \end{aligned}$$

The result indicated that under the given condition, a CRH3 EMU can run on a grade of 12‰ with speed of 300 km/h.

To add the number of motors can increase the total power of EMU so that the unit power per ton mass can be increased. On the other hand, reducingthe number of car in a unit can also attain the purpose to increase the unit power per ton mass. In this way, the maximum gradient in railway line for passenger traffic will not be limited by traction power.

The Adaptability Between Speed and Gradient

During the procedure that a train passes through a long grade section, the EMU’s power shall meet the requirement of starting acceleration and the surplus acceleration for maximum speed. Table 3.8 gives the relations among unit power, speed, basic resistance, surplus acceleration, and uniform speed gradient.

Table 3.8

Adaptability Analysis Between Speed and Gradient

Type of EMU/Maximum Speed (km/h)	Unit Power per Mass (kW/t)	Running Speed (km/h)	Basic Res
CRH3/350	19.67	350	17.76
300	13.33	25.75	12.42
250	9.56	30.9	21.34
CRH2C/300	19.68	300	13.37
280	11.90	25.79	13.89
250	9.87	28.89	19.02
200	6.93	36.11	29.18
CRH1/200	13.80	200	8.04
180	6.83	26.67	19.84
160	5.72	30.00	24.28
CRH2/200	13.34	200	6.93
180	5.91	27.19	21.28
160	4.99	30.60	25.61
CRH5/200	12.19	200	7.78
180	6.60	24.85	18.25
160	5.46	27.96	22.50

Note: Utilization coefficient of tractive effort takes 0.95.

Table 3.8 shows that for a surplus acceleration of 0.040 m/s², when a CRH3 train will run on level grade with the maximum speed of 350 km/h; 300 km/h on 12‰; a CRH with designed speed of 250 km/h will run on 21‰ with uniform speed of 200 km/h. Trains of CRH1, CRH2, and CRH5 will run on grades of 24‰, 25‰, and 22‰, respectively, at a uniform speed of 160 km/h, and run on 15‰, 17‰, and 14‰, respectively, at a uniform speed of 200 km/h.

Selection of Maximum Grade

For passenger traffic lines, the major influenced factors for determination of gradient are topography and height control points. With regard to topography, most newly built railway lines for passenger traffic will be constructed in plain or hilly land regions, the natural topographic gradient is small and the rise and fall is easy along the railway line. To overcome the height of topographical obstacles is not a major problem. In this way, it is necessary to use steep gradient. But on the other hand, passenger traffic line shall be built in totally enclosed overhead structures. Even in plains or hilly land regions, the maximum gradient shall be a larger one.

According to China's practice in the construction of passenger traffic, the suitable range of maximum gradient is 12–30‰. The maximum gradient of main line in sections should not be larger than 20‰, and under difficult conditions, should not be larger than 30‰ after technical and economic comparison.

The maximum gradient of MU running line shall not be larger than 35‰.

3.3.1.2 Ruling Grade

Definition

The ruling grade is defined here as the maximum gradient, over which a tonnage train can be hauled at a given speed by a given locomotive consist or horsepower. The tonnage capability varies from each class of locomotive, but in every case the maximum tonnage that can be pulled over the engine district by each locomotive at a given speed is set by the ruling grade. All lesser grades offer no obstacle to the movement of a train of that size. The ruling grade does not necessarily have the maximum gradient on the division. Momentum grades, pusher grades, or those that must regularly be doubled by tonnage train may be heavier.

Effects on Operations

The prime effect of a ruling grade is its limit on the utilization of locomotive capacity. A locomotive that moves a tonnage train over the ruling grade is often carrying unused power capacity over the rest of the line. The relation of this problem to that of ruling grade selection and the use of pusher grades will be considered shortly. Trains may be broken into smaller units to conform more readily to the profile. This, however, is a costly and time-consuming process requiring more locomotives and crews plus terminal time, facilities, and costs. Furthermore, passenger trains lack even this flexibility, since it is usually impractical to split them into two or more units. An important element in the problem is time. Tonnage trains especially may have their speed materially reduced on the ruling grade, with a consequent increase in terminal-to-terminal running time. Such speed reductions may not be serious if the grade is short and occurs only once on a division. On long grades or where the ruling grade occurs several times on the territory, the loss in time may become a major problem in scheduling. Other effects on operating will be discussed in the following paragraphs.

Calculation of Ruling Grade

The maximum ruling gradient of railway line is defined as the gradient value of the consecutive ascending grade on which a given locomotive can haul the train with specified weight at the calculated speed of locomotive constantly.

On railways for freight train and passenger train, for the train with traction mass of G_x , the maximum calculated gradient of the train is derived based on the principle that the resultant force acting on the train is zero when the general freight train runs on a consecutive ascending grade at the specified calculated speed of locomotive constantly. For a provided traction mass norm, the maximum calculated gradient at the section where the train is hauled by a single locomotive can be calculated as follows:

$$i_{cgmax} = \frac{\lambda_u F_c - (P \cdot r_0' + G_x \cdot r_0'') \cdot g}{(P + G_x) \cdot g} (\text{‰})$$

(3.67)

where G_x is the norm of traction mass (t); i_{cgmax} is the maximum calculated gradient; r_0' is the unit basic resistance of locomotive under the calculated speed (N/10t); r_0'' is the unit basic resistance of rolling stock under the calculated speed (N/10t); F_c is the calculated tractive effort (N); P is the locomotive mass (t); λ_u is the utilization coefficient of tractive effort; and g is the acceleration of gravity (m/s^2).

Example 3.1

In a railway line for mixed freight and passenger traffic, trains composed of cars with rolling bearing that is hauled by SS3 electric locomotive, if the tractive mass is 3500 tons, the calculated maximum gradient is: ($V_c=48$ km/h, $F_c=317,800$ N, $P=138$ t):

$$\begin{aligned}r_0' &= 1.25 + 0.019 \times 48 + 0.00032 \times 48^2 = 3.899 \text{ N/10t} \\r_0'' &= 0.92 + 0.0048 \times 48 + 0.000125 \times 48^2 = 1.4384 \text{ N/10t} \\i_{\text{rul}} &= \frac{0.9 \times 317800 - (138 \times 3.899 + 3500 \times 1.4384) \times 9.81}{(138 + 3500) \times 9.81} \\&= 6.48(\text{‰}), \text{ takes } i_{\text{rul}} = 6\text{‰}\end{aligned}$$

Choice of Ruling Grade

In some locations, the choice of ruling grade is almost self-evident, but it is seldom so simple. There are usually certain key spots—initial and final terminals, traffic centers, mountain passes, bridges, and river crossings—which must be held. Between these control points, there may be several route possibilities. A ruling grade should be selected for each route and the several possibilities compared. In doing so, the easiest possible route should be followed for the greatest possible distance and then use made of whatever means are necessary to overcome the remaining distance and elevation. Each leg of the route then contains a potential ruling grade that must be compared with others in the overall route for selection. The final choice is made only after the possibilities of still further revisions of the several proposed gradients have been explored. In addition to securing a 10 w gradient at minimum cost, the length of grade should be kept at a minimum for reasons already given. Furthermore, it is desirable to keep the ruling grades of adjacent divisions and districts as close to uniform as possible. This permits the same type of motive power to be used on each. With similar tonnage ratings, the number of motive power classes and units is thereby reduced, which permits a more flexible distribution of power. The need to rebuild trains to new tonnage ratings at division points is also reduced.

Ruling grades should be free of sidings, water and coaling stations, railroad crossings at grade, freight, and passenger stations, and any other cause for stops. Where these must be present, the gradient should be reduced to a rate on which a tonnage train can again be started easily.

Future line revisions and relocations should be kept in mind and a route selected should permit revision in the future without relocating a large portion of the line. A little forethought may permit a later improvement in gradient by introducing a minimum line change or construction of a readily accessible tunnel.

The nature of traffic is likely to have some influence. A road that operates a lightly loaded, fast, expedited service need not cause as much concern about the ruling grade as a road

with a preponderance of heavy drag freight, and tonnage train operation has cause for genuine concern over gradients.

The topography is one of the major factors influencing ruling grade. According to the absolute height, and the natural ground slope, the topography areas were classified by the Committee of Geomorphologic Classification, Chinese Academy of Sciences, in 1959, into plain regions, hilly regions, and mountain areas. Plain regions have no obvious rise and fall where the natural ground slope is less than 3°, and the relative elevation varies from 100 m to over 1000 m. In hilly regions, there are slight rises and falls. The natural ground slope is steeper than 20°. The relative elevations are lower than 100 m.

The mountain topography are these areas with complicated topography, such as the ridges of mountains, steep mountain slopes, overhanging cliffs, gorges, and deep ditches etc. In these regions, the change of terrain is very complicated, and the natural ground slope is steeper than 20°. According to the absolute height, the mountain areas were classified into extremely high mountains of over 5000 m, high mountains of 3500–5000 m, medium mountains of 1000–3500 m and low mountains of 500–1000 m. The relative elevation varies from 100 m to over 1000 m.

Ruling grade shall be selected according to railway class, topography conditions, and kind of traction, as shown in Table 3.9.

Table 3.9

The Maximum Ruling Grade (‰)

Railway Classification	I	II	III					
Topography Classification	Plain	Hilly	Mountain	Plain	Hilly	Mountain	Plain	Hilly
Kinds of traction	Electric	6.0	12.0	15.0	6.0	15.0	20.0	9.0
Diesel	6.0	9.0	12.0	6.0	9.0	15.0	8.0	12.0

Comparison of Grades

The prime economic problem of ruling grades is to determine the savings due to permitting the operation of fewer and heavier trains. The total net tonnage remains the same through the use of a lighter ruling gradient. The problem involves a comparison of train mile costs. This assumes that costs of train operation are more dependent on the number of trains, especially the costs of locomotive operation, rather than on the tonnage or number of cars in a train.

It should be self-evident from the discussion in Chapter 5 of fixed and variable costs that the expense of operating an additional train—for instance, 11 trains instead of 10 trains—is not going to be as great as the average cost of operating all the trains. Some elements of average train mile costs—traffic, most structures, miscellaneous operations—are not affected at all by the number of trains operated. Other cost elements, such as general expenses, yard operations, some structures, and maintenance items, vary to a small degree according to the number of trains operated. Another group, including fuel, wages of train and enginemen, locomotive repairs, and some forms of track maintenance, varies almost directly with the number of trains operated.

Optimizing Grade Selection

Implicit in the foregoing discussion is the economic desirability of lower grades to permit heavier and fewer trains. This assumption may not always lead to the greatest economic return. In addition to the construction versus operating expense aspects, there may be other factors that determine the optimum combination of gradient, speed, and train size.

Except for one, commodity unit trains, there can be excessive delays in accumulating tonnage to fill the higher ratings made possible by lower ruling grades. Such delays, while producing a high gross ton mile per train-hour figure, may also be producing dissatisfied patrons, who will turn to a competing railroad or mode that offers faster, more dependable service.

Customer satisfaction and other traffic requirements may necessitate faster trains and schedules rather than fewer, heavier trains. The end result may be the same—economy through a lower ruling grade that permits a higher speed on the grade and shorter terminal-to-terminal time. Speed can provide a competitive advantage.

The possibilities in lower construction costs for heavier grades, combined with shorter schedules for more but lighter trains, is an alternative worthy of examination. Computer programs that help select these several combinations to meet whatever needs are essential will assist in identifying alternative costs and revenues in selecting an optimum combination.

3.3.1.3 Balanced Profile

Balanced Profile Problems

In the preceding sections, consideration has, by implication, been given to grades designed for movement in one direction only. Actually trains run in both directions over the same profile (Fig. 3.24). In a few instances, on double track lines, the two tracks are on separate grades, and each has been designed for the prevailing movement of traffic without regard to the other. Normally both tracks occupy the same grade and have similar profiles.

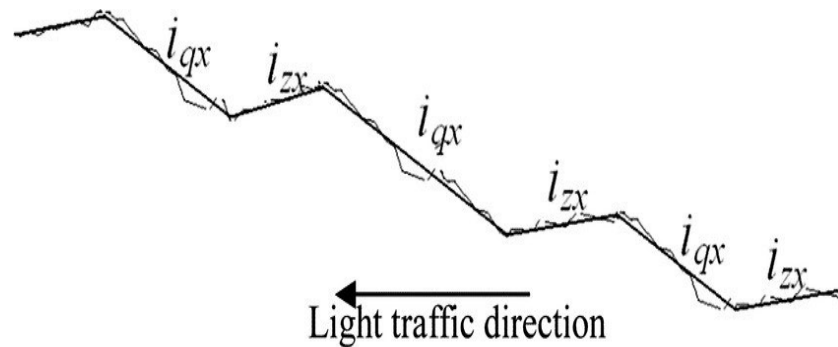


Fig. 3.24 Balanced profile.

It has been usual to have a prevailing tonnage movement in one direction only. Return-bound trains carry a high percentage of empties and can therefore be handled in fewer trains if these trains are heavily loaded. Locomotives must be returned as well as cars. This suggests double-heading very heavy return-bound trains. However, crews must also be returned. Since crews must be paid for double-heading, the crews and locomotive return will cost almost as much as operating a loaded train.

Advantage may be taken of this situation to return the cars and locomotives in lightly loaded trains that do not require as easy gradients as the loaded movement outbound. The money thus saved by reduced construction on return-bound grades may well be applied toward further improvement on tonnage grades.

Design of Balanced Profiles

To be exactly in balance, the return-bound ruling grade need be no flatter than that necessary to permit the same number of empty cars with less total resistance to be handled as are taken loaded in the opposite direction. Thus, if a locomotive of a 318 kN-drawbar pull on a 10‰ grade can haul 3500-ton cars at 48 km/h, the same locomotive can

haul the same number of empty (1100-ton) cars at the same speed on a 25‰ gradient, taking into account the greater unit resistance per ton of car weight for empty cars.

Actually, the problem is not as simple as this. The difficulty lies mainly in determining just what percentage of theoretical balance should have. Where a line is devoted to a one-way, one-commodity-movement—coal or iron ore in unit trains, a goodly tonnage may move in the opposite direction. (Passenger trains almost always have a balanced flow.) There is difficulty in predicting the ratio between prevailing and counter traffic flow. The changing pattern of industrial location and population centers are tending to even the balance between east-west and north-south flows. The data from traffic surveys and projections can aid the engineer in designing this phase of location.

Calculation of Ruling Grade in Light Goods Flow Direction

On consideration of ratio of goods flow in two direction, suppose the train pairs is the same and the number of cars is the same, the traction mass in light goods flow direction GL can be obtained as follows:

$$i_{RL} \leq \frac{\lambda_u F_c - (P \cdot r'_0 + G_R \cdot r''_{0(a)}) \cdot g}{(P + G_L)g} (\text{‰})$$

(3.68)

where GL is the traction mass in light goods flow direction (t); iRL is the maximum ruling gradient in light goods flow direction; r'0 is the unit basic resistance of locomotive under the calculated speed (N/10t); r''0(a) is the average unit basic resistance of empty cars under the calculated speed (N/10t); Fc is the calculated tractive effort (N); P is the locomotive mass (t); λu is the utilization coefficient of tractive effort; and g is the acceleration of gravity (m/s²).

Traction mass in light traffic direction and basic resistance can be calculated as:

$$G_L = n(\lambda_{LH} \times w_{load} + w_{car})$$

$$r''_{0(a)} = \frac{\lambda_{LH}(w_{load} + w_{car}) \times r''_{0h} + (1 - \lambda_{LH}) \times w_{car} \times r''_{0L}}{\lambda_{Nh} \times w + w_{car}}$$

(3.69)

where n is the number of cars in a definite train (equal to that in heavy traffic direction); λLH is the ratio of freight volume in light direction and heavy direction; wload is the the

average weight of net load per car (t); w_{car} is the average weight of freight car (t); and r'_{0h} , r'_{0L} is the basic unit resistance for loaded car and empty car (N/10t).

If the calculated result is larger than that in the heavy direction, the number of trains in light traffic will be more than that in the heavy direction. This case is not reasonable for practice. Therefore, the ruling grade in light traffic direction shall not be larger than triple of that in the heavy direction.

3.3.1.4 Helper Grades

Trains of a given tonnage should be operated intact between major terminals. An intermediate breaking up of trains to overcome heavy grades is a wasteful operation. It is equally wasteful of engine capacity to operate a locomotive over most of the line with a tonnage well below its capabilities for that territory merely to enable it to haul the train without stopping over an excessively steep ruling grade. When a reasonable balance cannot be reached between a proposed ruling grade and the rest of the line, it may be more economical to select a new and lower ruling grade and permit the excessive gradient to be operated with a helper engine service. This use of helper grades is also in conformance with the principle of penetrating an area as far as possible, as easily as possible, and then bunching the gradient at one point and overcoming it there by whatever means are expedient.

Operation of Helper Grades

The simplest helper grade operation is that of an engine spotted in a pocket track at the foot of the helper grade. When a tonnage train arrives, the helper couples on behind. After pushing the train over the crest of the grade, the helper cuts off, and drops back to the foot of the grade to await another train. If traffic is heavy or the grade is long, more than one helper may be necessary. Passing sidings or even an entire second main may be necessary to aid the helper in returning or to avoid delay to passenger and dispatch trains. The operation is further complicated and delay introduced when the helper engines are placed in front to double-head or are cut in between the train and the caboose (as required by law and the safety rules of the railroad). A relatively long delay may be occasioned both at the base and at the summit of the grade. Excessive delays occur when helpers must also be cut into the middle of the train.

The Maximum Helper Grade

The maximum value of helper grade is determined in terms of the operation conditions for a train on steep slope, including safety of braking system, energy consumption, technology work at station, etc.

The maximum helper gradient shall be determined in terms of the tonnage of freight train, number of locomotives, and mode of helper tractive:

$$i''_{\text{helper}} = \frac{\lambda_u \sum \lambda \times F_c - \left(\sum P \times r_0' + G \times r_0'' \right) \times g}{\left(\sum P + G \right) \times g}$$

(3.70)

where G is the traction mass with single locomotive on ruling grade (t); r'0, r"0 is the unit basic resistance of locomotive and car under the calculated speed (N/10t); and λ is the coefficient of tractive mode, determined in terms of the kind of tractive, operating mode.

The meanings of other symbols are the same as above.

Dual-locomotive traction is a kind of helper grade used commonly. In general, the two locomotives shall employ the same type, the mode of helper, double-headed or pushing, should be determined in the allowable stress strength of coupler. The maximum helper grade iSJ for dual-locomotive traction can be calculated using the following equation:

$$i'''_{\text{helper}} = \frac{(1 + \lambda) \lambda_u \times F_c - (2P \times r_0' + G \times r_0'') \times g}{(2P + G) \times g} (\text{‰})$$

(3.71)

For helper tractive using the same type of locomotive, the maximum helper grade corresponding to ruling grades are given in Table 3.10.

Table 3.10

Maximum Helper Grades of Electric and Diesel Locomotive (‰)

Ruling Grade		Dual-Locomotive Helper Grade		Triple-Locomotive Helper Grade	
Electric	Diesel			Electric	Diesel

4.0	9.0	8.5	14.0	13.0
5.0	11.0	10.5	16.5	15.5
6.0	13.0	12.5	19.0	18.5
7.0	14.5	14.5	21.5	21.0
8.0	16.5	16.0	24.0	23.5
9.0	18.5	18.0	26.5	25.0
10.0	20.0	20.0	29.0	
11.0	22.0	21.5	30.0	
12.0	24.0	23.5		
13.0	25.5	25.0		
14.0	27.5			
15.0	29.0			
16.0	30.0			

Design of Helper Grades

Theoretically, the tractive effort that two or more locomotives can exert together should be the sum of their drawbar pulls. Actually only about 90% of each can be realized because of the difficulties in securing perfect coordination between the two. Thus, if each of two locomotives can haul 2000 tons over a gradient, the two combined can haul not 4000 tons but 3600 tons. Keeping this factor in mind, one sees a relation between the design of the ruling grade and that of helper grades. There is nothing to be gained by constructing a helper grade that permits two locomotives to handle 8000 tons when the ruling grade limits the train size to 5000 tons. Ideally the helper grade should be such as just permit handling of the ruling grade tonnage and no more. (An exception might be made where heavier power or a future additional grade reduction is contemplated.) On the other hand, if topography permits the construction of a helper grade good for 8000 tons without additional expense, consideration should be given to selecting a ruling grade that coordinates the operation of such tonnages. Thus the full possibilities of both are utilized.

Economics of Helper Grades

In making an economic study of the desirability of helper grade operation, the cost of helper grade construction and operation is balanced against the alternative costs of smaller and more numerous trains operating over the steeper grade or against the costs of reducing the gradient. All cost elements attributable to a helper service must be included in estimating the helper grade costs, including the terminal and running expenses of the helper engine, delays to trains picking up and dropping the helper engines, and any extra trackage and signaling the service may require. Locomotive running expenses are a function of locomotive mileage. Each location should be subject to an individual cost study. If a figure is lacking for locomotive mile expense, the fuel, water, lubricant, and repair figures used in determining train mile costs may be substituted, plus whatever engine crew wages are involved. In some instances, economies may be made by assigning the locomotive other switching duties (Brotherhood agreements permitting) when helper duty occurs infrequently. The lower construction cost of a steeper grade is also an offsetting factor.

Modern Alternatives

The need for helpers and helper grades has been greatly reduced by the ability to combine several diesel-electric units into one locomotive consist controlled from the lead unit and also by the overload capability of diesel-electrics. The number of units in a consist is limited by the amount of drawbar pull the couplers can withstand. High-strength couplers on modern equipment (such as 13# coupler) are designed for up to 562,500 N of pull, but

those on older cars are usually limited to about 250,000 N or less. Even the high-strength designs experience wear and may develop in time hairline cracks or become nicked or gouged.

To meet this problem and to provide smoother tractive and braking action, slave or drone units are spotted in the train, usually at the one-third and/or two-thirds points. Control may be exercised from the lead unit in the train by radio or instruments on the drones that respond to the train action-pull, buff, slack action, or brake pipe pressure.

3.3.2 Connection of Grade Section

3.3.2.1 Algebraic Difference Between Adjacent Gradients

A profile of railway line is composed of grade sections, some ascending, some descending, and the others are level. As a grade is taken as positive when ascending, negative when descending, the algebraic difference between adjacent gradients shall be expressed in absolute value of the algebraic difference Δi . Such as, if the gradient of the first grade section i_1 is 6‰ descending, and that of the second grade section i_2 is 4‰ ascending, then the algebraic difference of gradient is

$$\Delta i = |i_1 - i_2| = |(-6\text{‰}) - (+4\text{‰})| = 10\text{‰}$$

Limited Condition

An allowable algebraic difference between adjacent gradients shall be designed to ensure no coupler breaking when a train passes through it. In railway lines for mixed freight traffic and passenger traffic, the allowable algebraic difference is limited by coupler condition of freight trains. In railway lines for passenger traffic, as the weight of train is light, and tight-lock coupler is used, algebraic difference between adjacent gradients is not limited by the breaking-coupler condition.

The following discussion will be only aimed at railway lines for mixed freight traffic and passenger traffic.

In the 1980s, China's railway authorities stipulated that the maximum algebraic difference between adjacent gradients cannot be larger than ruling grade of heavy traffic direction. In the mid-1990s, in order to revise the code, researchers made an investigation aimed at the breaking-coupler at point of gradient change. The investigation revealed that although there were many points of gradient change where the algebraic differences were larger than the ruling grade, there was no coupler broken down where trains running over there. A new researcher has found following regulations:

- ① The value of longitudinal force of train at the point of gradient change will increase with algebraic difference of gradients.
- ② At summits formation, pull will increase and push decrease, but at the sag, it is the opposite.
- ③ The value of longitudinal force of a train is determined in terms of tonnage ratings, length of train, locomotive working condition, and the profile formation, etc.

According to the simulation calculation of track-train interaction, to ensure the longitudinal force of train will not larger than the allowable strength when a train is passing through the point of gradient change with maximum algebraic difference, that is no coupler broken down, if all trains use the number 2 coupler, the maximum algebraic difference can be double of ruling grade. But on consideration of the increasing of tonnage rating, the maximum algebraic difference should leave some surplus.

The Maximum Allowable Algebraic Difference of Adjacent Gradients

Simulation calculation of train running shows that the traction mass exerts a major influence on the longitudinal force of train. As the long-term traction mass is determined by the available length arrival-departure track, the relation between traction mass and algebraic difference of adjacent grading can be expressed in the long-term available length of available-departure track. In this case, the maximum algebraic difference of adjacent gradients can be selected from Table 3.11 in terms of the available length of arrival-departure track.

Table 3.11

Maximum Algebraic Difference of Adjacent Gradients

Long-Term Effective Length of Reception-Departure Track (m)	1050	850	750	650
Algebraic difference of adjacent gradients (‰)	General conditions	8	10	12
Difficult conditions	10	12	15	18

3.3.2.2 Vertical Curves

For smooth riding (and good appearance), vertical curves provide a gradual transition from one grade to another. The curve should be as long as practicable. The circular or parabola is usually used in railway design.

Radius of Vertical Curves

The radius shall be determined according to designed safety and ride comfort.

Radius to Ensure the Ride Comfort

When a train negotiates a vertical curve section, the train body will be exerted a centrifugal acceleration. The centrifugal acceleration is:

$$\alpha_v = \frac{v^2}{R_V} \text{ (m/s}^2\text{)}$$

where v is the speed in meter per second, and R_V is the radius of the vertical curve in meters.

To convert these terms to common usage, v in meter per second is expressed as V in kilometer per hour, thereby

$$\alpha_v = \frac{V^2}{3.6^2 R_V}$$

where V is the train speed in kilometer per hour.

When a train negotiates a vertical curve section, the centrifugal acceleration should not exceed the allowable riding comfort. For a railway line with designed speed of $V_{\max}$, the minimum vertical radius to ensure the riding comfort is:

$$R_V = \frac{V_{\max}^2}{3.6^2 \times \alpha_v} \text{ (m)}$$

According to the practice, the allowable centrifugal acceleration a_v generally takes 0.15–0.6 m/s^2 .

For the design of passenger traffic line, a_v generally takes 0.15 m/s^2 and 0.2 m/s^2 , the radius to meet the riding comfort shall comply with the following relation:

$$(3.72)$$

According to above equation, if the maximum designed speed of passenger train $V_{\max}=160 \text{ km/h}$, $R_v=12,800 \text{ m}$ and $10,200 \text{ m}$; for $V_{\max}=140 \text{ km/h}$, $R_v=9800 \text{ m}$ and 7800 m .

In high-speed railway line for passenger traffic, a_v generally takes 0.4 m/s^2 in general condition, and 0.5 m/s^2 in difficult condition, so that vertical radius should comply with the following relation:

$$(3.73)$$

Radius to Ensure No Derailment

When a train negotiates a summit (Fig. 3.25), the train body will exert a centrifugal force upward. The centrifugal force is

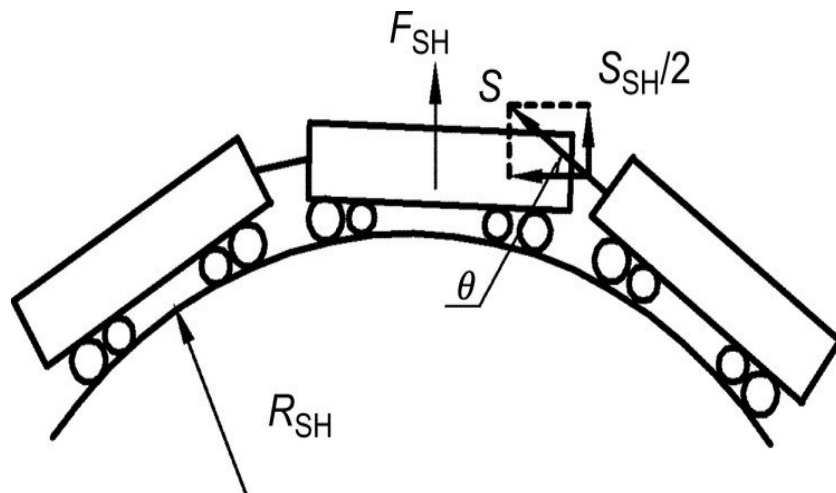


Fig. 3.25 A train on the summit vertical curve.

$$F_v = m \times \alpha_v = \frac{mV_{\max}^2}{3.6^2 R_v}$$

where α_v is the vertical acceleration (m/s^2); F_v is the vertical centrifugal force (N); $V_{\max}$ is the maximum designed speed (km/h); R_v is the radius of vertical curve (m); and m is the mass of car (kg).

This centrifugal force will cause a tendency to float upward and impact the running safety.

On other hand, when a train round a summit vertical curve, the braking force of a train will exert a vertical component upward S_v . On considering the most unfavorable conditions, assume that a train is in emergency braking, the longitudinal push force caused by braking is S , its' vertical component is $S_v/2$, thus,

$$S_v = 2S \sin \theta = \frac{l}{R_v} \times S$$

The resultant of a vertical centrifugal force and vertical component of braking ΔW cause a train wheel load reduction. The resultant can be calculated as follows:

$$\Delta W = F_v + S_v = \frac{1}{R_v} \left(\frac{mV^2}{3.6^2} + l \times S \right)$$

The rate of wheel load reduction is then

$$\frac{\Delta W}{W} = \frac{1}{mgR_v} \left[m \times \frac{V^2}{3.6^2} + l \times S \right]$$

where W is the weight of car (N), $W = m \times g$; g is the acceleration due to gravity, 9.81 m/s^2 ; and l is the distance of coupler knuckle of car (m).

According to the experience of Japanese railways, on consideration of safety, the rate of wheel load reduction caused by the vertical resultant force cannot be larger than 10%, that means $\Delta W/W \leq 0.1$, so that the vertical radius shall meet

(3.74)

This requirement is not a major condition for mixed freight traffic and passenger traffic.

According to the above equation, we can obtain the relations between vertical curve and speed as Table 3.12.

Table 3.12

Radius of Vertical Curves to Ensure no Derailment

vmax	100	200	250	300	350
Rv	800	3200	5000	7200	9800

Radius to Ensure No Coupler Separation

On a line for mixed freight traffic and passenger traffic, when a train runs through a point of gradient change and the connection of adjacent cars is nearby the point of gradient change, the coupler will stagger a slack up and down; see Fig. 3.26. If the stagger slack is larger than the allowable value, the coupler will separate. Fig. 3.26 shows that the stagger slack will increase with the radius decrease. A radius to ensure safety on considering the coupler separation should meet the following equation:

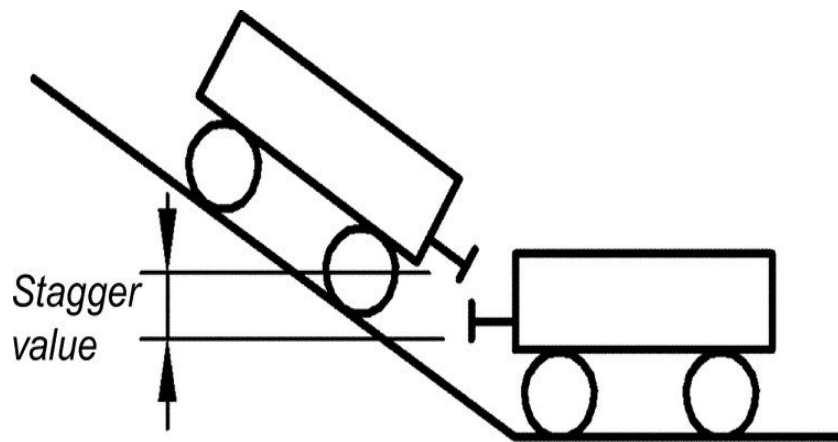


Fig. 3.26 Couple stagger.

(3.75)

where R_v is the vertical radius (m); L is the distance between bogie pivot centers (m); d is the distance between bogie pivot center and coupler center (m); f_R is the allowable displacement of coupler center, freight takes 11 mm, passenger takes 16 mm.

China standard GB146.1-83 for railway clearance stipulates that distance between bogie pivot centers is taken as 9.35 m for freight cars, and 18 m for passenger cars. Distance between bogie pivot center and coupler center include two parts: that are 1/2 rigid wheel base and the length of the coupler. The maximum rigid wheel base is 4.8 m, and the length of coupler is 469 mm. Substitute these dates into Eq. (3.75), the corresponding vertical radii are 3229.5 m for freight train and 3788.13 m for passenger train separately.

Radius to Meet the Requirement of Track Maintenance

A larger radius vertical curve will provide a gradual transition from one grade to another. However, it is not always a case of the larger the better. When the radius is larger than a definite value, it become difficult to meet the requirements of maintenance. According to practice in railway line, the maximum of vertical curve is 40,000 m.

Selection of Vertical Curve Radius

When the gradient difference of adjacent grade section on main line is larger than or equal to a definite value, vertical curve in circular arc shall be used for connection. The minimum allowable vertical curve radius shall be selected from Table 3.13 according to the long-time designed speed of the section; the maximum vertical curve radius shall not be larger than 30,000 m. The minimum allowable length of vertical curve must not be shorter than 25 m.

Table 3.13

Minimum Vertical Radius

Railway Type	For Passenger Traffic		For Mixed Traffic				
Designed speed (km/h)	350	300	250	200	200,160		≤
Rv (m)	25,000	20,000	15,000	15,000	10,000		

Geometry Elements of Vertical Curve

1. Tangent length T_v

[Fig. 3.27 shows that:](#)

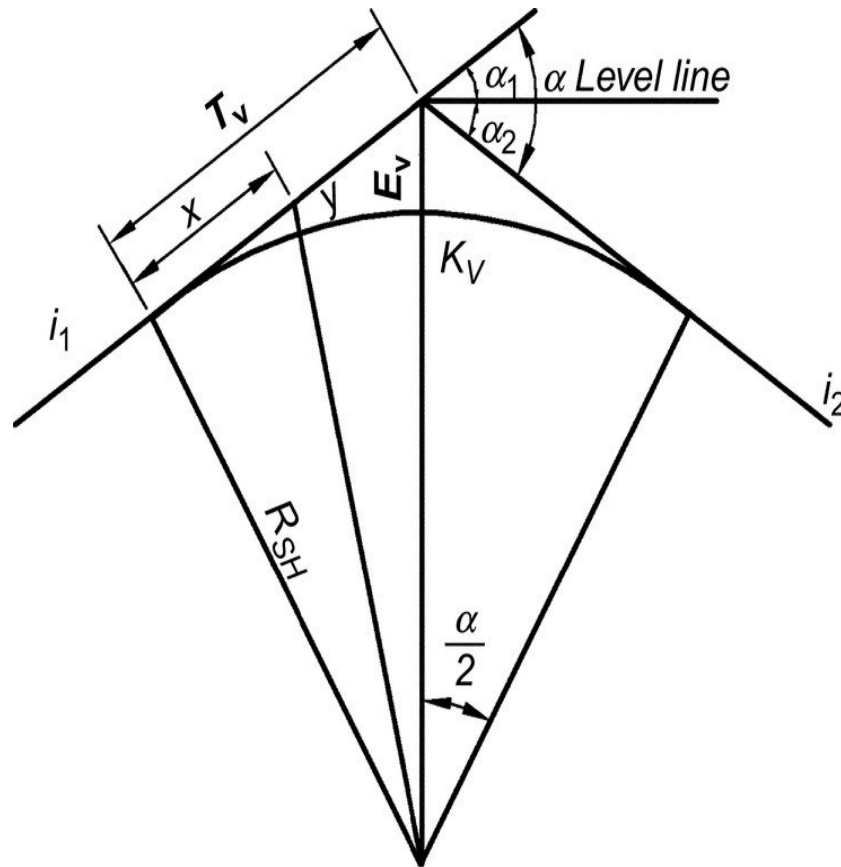


Fig. 3.27 Vertical curve.

$$\begin{aligned}
 T_v &= R_v \times \tan \frac{\alpha}{2} \approx \frac{R_v}{2} \tan \alpha = \frac{R_v}{2} \times \tan |\alpha_1 - \alpha_2| \\
 &= \frac{R_v}{2} \left| \frac{\tan \alpha_1 - \tan \alpha_2}{1 + \tan \alpha_1 \times \tan \alpha_2} \right| \approx \frac{R_v}{2} |\tan \alpha_1 - \tan \alpha_2| \\
 &= \frac{R_v}{2} \left| \frac{i_1}{1000} - \frac{i_2}{1000} \right| \\
 &= \frac{R_v \times \Delta i}{2000}
 \end{aligned}$$

(3.76)

where α is the deflection angle of vertical angle ($^\circ$); α_1, α_2 are the two included angle between grade line and level lines ($^\circ$), taken as positive when ascending, negative when descending; i_1, i_2 are the two intersecting grades ($\%$), taken as positive when ascending, negative when descending; and Δi is the algebraic difference between adjacent gradients ($\%$).

2. Length of vertical curve K_v

$$(3.77)$$

3. Vertical distance y

As

$$(R_v + y)^2 = x^2$$

$$2R_v \times y = x^2 - y^2$$

As the value of y^2 is very small, it can be omitted, so that

$$(3.78)$$

where x is the distance from the calculated point to the start point of vertical curve in meters.

The vertical distance at the point of gradient change is called external secant E_v , which can be calculated as follows:

$$(3.79)$$

The height for construction at point of gradient change equals design height minus (at summit) or plus (at sag) the external secant. The height of cutting or filling of subgrade shall be calculated in terms of the height for construction.

Example 3.2

An I-grade railway line for mixed freight traffic and passenger traffic. A is a point of gradient change. Its height from the ground is 476.50 m, and design height is 472.36 m, R_v is 10,000 m; the values of two adjacent grades are $i_1=6\%$, $i_2=-2\%$, which is the cutting height of point A.

Solution

Algebraic gradient difference of point A:

The tangent length of vertical curve of point A = 40(m)

External secant of A is: (m)

Height for construction of A is: $472.36 - 0.08 = 472.28$ (m)

The cutting height of A is: $476.50 - 472.28 = 4.22$ (m)

Parabola Vertical Curve

Sometimes, a parabola arc is used to provide a gradual transition from one grade to another.

Fundamental Characteristics

A parabola of the form $y=kx^2$ is customary, where x is taken in the direction of the grade or tangent and y is in a radial direction. From this equation, we can state the following:

1. The offsets from the tangent vary with the square of the distance along the tangent.
2. The external distance is equal to the mid-ordinate.
3. The second differences between y values for equal tangential (x) increments are equal.

The rate of change is the algebraic difference in grade per 20 m along the curve:

$$(3.80)$$

where r is the rate of change in grade in percent per 20 m; i_1 and i_2 are the two intersecting grades, taken as positive when ascending, negative when descending; and L is the curve length in 20 m stations.

For main line operations, the values recommended by the China Railway are $r = 0.10$ for summits and 0.05 for sags. Values twice as great may be obtained on secondary tracks. On classification yard hump the rate of change must not exceed that which permits long cars to cross the hump crest without dragging on the rails. The use of 20 m stations simplifies the computational and field procedures. If, from the choice of grades and r values, an odd value is computed for L , the next highest even value of L should be adopted and a revised r value computed.

Conditions for Designing Vertical Curves

The minimum algebraic difference of gradients for designing vertical curve

① To ensure no derailment

At a point of gradient change with no vertical curves, the grade section is connected as a broken line. When a train runs through the gradient change point, the vibration and acceleration will occur and increase abruptly, and riding comfort level will be reduced. If the front part of a locomotive or car goes ahead to the second grade section, but the weight center of a locomotive or car is also at the first grade section before the gradient change point, the front wheel of locomotive will be in a suspended state. If the suspension height is larger than the flange height, the wheels will derail.

In order to smooth the gradient change point, vertical curves are employed to provide a gradual transition from one grade to another. The maximum algebraic difference of gradients to ensure no derailment should satisfy the following relation:

$$(3.81)$$

where LZ is the distance from center of gravity for car loaded to the center of first wheel of bogie (m) and d_{min} is the flange height (m).

If we take the distance from center of gravity for car loaded to the center of first wheel of bogie as 5.6 m, flange height as 0.025 m, then the algebraic difference of adjacent gradients is 4.5%.

② The smooth capacity by track structure

The track skeleton is fixed on track bed by fastenings. Practice has proved that, for ordinary tracks, when the external secant at the point of gradient change is less than 10 mm, a curve will form on the top surface of rail curve naturally from fastening rails to sleepers where it is not necessary to construct a curve formation on top of sub-rail foundation. For this reason, only at these points of gradient change where the external secant is larger than 10 mm, vertical curves shall be provided to smooth the gradient

changes. If the external secant is given in 10 mm, for different vertical curve radius, the corresponding algebraic difference of adjacent grades are listed in Table 3.14.

China’s railways regulate that the connections between grade sections shall comply with the following rules: for lines where the designed speed is 160 km/h and over, when the gradient difference of adjacent grade section on main line is larger than or equal to 1‰, a vertical curve in circular arc shall be used for connection. For lines where the designed speed is lower than 160 km/h, when the gradient difference between adjacent grades is more than 3‰ for I-grade, II-grade, and 4‰ for III-grade, that means that it is necessary to set up vertical curves on the top of the subgrade.

In order to meet the requirements, the minimum allowable length of vertical curve must not be shorter than 25 m.

Table 3.14

Relation of Vertical Radius and Algebraic Difference of Adjacent Grades

RV (m)	25,000	20,000	15,000	10,000
Δimin (‰)	1.8	2.0	2.3	2.8

Other Requirements

① The vertical curve (or gradient change point) must not be located in the same region with transition curve, turnout, and expansion rail joint. For these reasons, the point of gradient change should leave the starting and ending points of transition curves, turnouts, and expansion rail joints at least a length of vertical curve (see Fig. 3.28A).

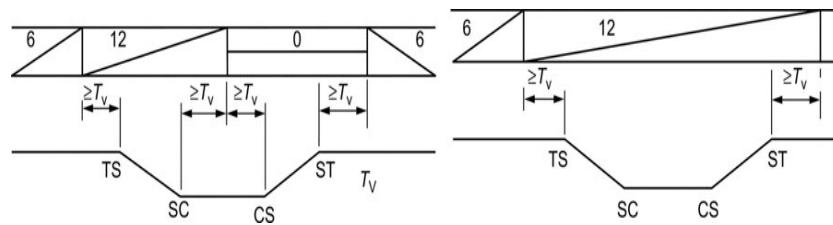


Fig. 3.28 Relation between point of grade change and curve.

② The vertical curve should not be located in the same region with the plane circular curve, see Fig. 3.28B, and under difficult conditions, the value of vertical curve shall not be smaller than the values in Table 3.15.

Table 3.15

Minimum Allowable Curve Radius When Vertical Curve and Plane Circular Curve are Located in Same Region

Speed (km/h)	350	300	250	
Min. allowable plane circular curve (m)	Ballast track	7000	5000	3500
Ballastless track	6000	4500	3000	
Min. allowable vertical curve radius (m)	25,000	25,000	20,000	

In lines for passenger traffic, when the gradient difference between adjacent grades of MU running line more than 3‰, the grades shall be connected with vertical circular arc. The radius of vertical curve is 5000 m under general condition and 3000 m under difficult condition.

3.3.3 Length of Grade Section

The length of grade section is the level distance between two points of adjacent grade sections.

From the point of engineering, short length of grade section is much easy to fit the rise and fall of topography, reduce the work volume of subgrade, bridges and tunnels, as in Fig. 3.29. But from the point of train operation, longer length of grade section is much easy to meet the requirements of safety and riding comfort. Therefore, the length of grade section shall be determined after technical and economic comparisons in terms of engineering and operation conditions synthetically.



Fig. 3.29 Profiles with different lengths of grade section.

3.3.3.1 The Minimum Length of Grade Section

The length of grade section shall be determined to comply with the requirements of safety and riding comfort.

The Minimum Length Determined by the Coupler Strength

For ordinary railway lines, when a train negotiates a point of gradient change, as the operating resistance is different in front and behind of the point of gradient change and there is a clearance between couplers, some cars of the train will suffer additional

acceleration so that the train running smooth will be worsened. At the same time, the impact and longitudinal force will increase at the point of gradient change.

On consideration of these reasons, the length of grade section shall be designed long enough to ensure that a coupler breaking will never occur at any gradient change point. According to the coupler strength of freight car, the allowable longitudinal force is taken as 980 kN for pull force and 1960 kN for push force. The results of simulation calculation show that even under the most unfavorable conditions, the maximum longitudinal force will not exceed the coupler strength.

The coupler pressure determined by the length of grade section will change with the tonnage mass directly. Simulating calculation for a train with 6500 tons show that one-third of a train length is a reasonable length of grade section.

The minimum length determined by the coupler strength shall meet the values in Table 3.16.

Table 3.16

Minimum Length of Grade Section Determined by the Coupler Strength

Classification of Railway	Lines for Passenger and Freight Trains		
Design speed (km/h)	200	160	≤140
Effective length of arrival and departure track (m)	1050	1050	1050
Minimum length of grade section (m)	600(400)	400	400

In railway lines for passenger traffic, as EMU adopts tight-lock couplers, the length of grade section is not limited by the coupler strength.

Length Determined by the Smooth and Steady Requirement of Train Running

From the point of smooth and steady of train running, the length of grade section shall be designed to ensure not only that the two vertical curves at adjacent points will not overlap at the middle of grade section, but also the vibration ensured by vertical curve will disappear at the straight section. From this point, the length of grade section shall be designed as in Fig. 3.30.

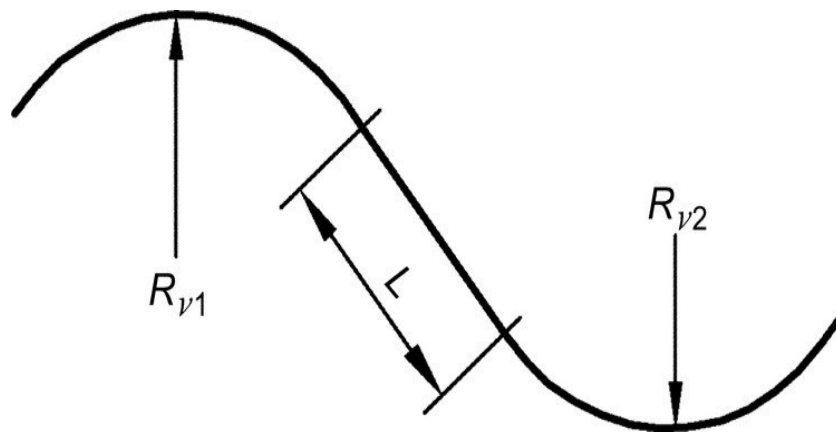


Fig. 3.30 Minimum length between vertical curves.

Practices in German and Japanese railways have proved that the minimum straight between adjacent vertical curves is about 0.4 times of the maximum designed speed, which means the minimum length of grade section should be

$$l_{\min} = 2 \times \left(\frac{R_v \times \Delta i_{\max}}{2000} \right) + 0.4V_{\max} \quad (\text{m})$$

(3.82)

where $l_{\min}$ is the minimum length of grade section (m); $\Delta i_{\max}$ is the algebraic difference of adjacent grades (‰); and R_v is the radius of vertical curve (m).

From what has been discussed above, the length of grade determined by the smooth and steady of train running shall meet the values in Table 3.17.

Table 3.17

Length of Grade Determined by the Smooth and Steady of Train Running (m)

Design Speed (km/h)	350	300	250	200	160	140	120	
Rv (m)	25,000	25,000	20,000	15,000	15,000	10,000	10,000	
Δimax	30	30	30	30	18	18	18	
LJmin (m)	General	122.5	105	87.5	70	56	49	42
Difficult	157.5	135	112.5	90	72	63	54	
	12.5Δi	12.5Δi	10Δi	7.5Δi	7.5Δi	5Δi	5Δi	
lmin (m)	General	497.5	480	387.5	191	191	139	132
Difficult	532.5	510	412.5	225	207	153	144	

Note: $l_{\min}$ is the minimum length of intermediate straight between two adjacent vertical curves.

Ensure a Train not Running Through Two Adjacent Gradient Change Points at the Same Time

To improve the smoothness and stability of passenger train, the grade section should be long enough to ensure that a train will not round two adjacent gradient change points at the same time. From this requirement, the length of grade section should be larger than the length of long-term passenger trains.

On considering the development of railways in China, the length of a grade section should be selected based on the matching principle of high-speed trains and crossing-line trains, and should consider the compatibility of mixed operation of different speeds on the same track. On consideration of a long passenger train with 16 cars, and reserving a safety distance of 15 m, the minimum length of grade section should be 450 m.

3.3.3.2 The Minimum Length of Grade Section

Standards

From what has been discussed above, the length of grade section is composed of two parts: the tangent length of vertical curve and the intermediate straight line between vertical curves. As the radius of vertical curve will not be a constant value, and there are no limits for the maximum algebraic difference of gradients in a high-speed railway, it is difficult to assign a uniform standard. For a high-speed railway, a scientific and reasonable method is to assign the intermediate straight grade section between vertical curves. Thus, for a high-speed railway line, the length of grade section should be computed using the following equation:

$$l_{\min} \geq \frac{R_{v1} \bullet \Delta i_{\max}}{2000} + \frac{R_{v2} \bullet \Delta i_{\max}}{2000} + l_{j\min} \quad (\text{m})$$

The intermediate straight grade section between vertical curves shall be computed using the following equation or taken from Table 3.18.

Table 3.18

The Intermediate Straight Grade Section Between Vertical Curves (m)

Design Speed (km/h)	350	300	200<v≤250	200	
Construction conditions	General	175	150	125	100
Difficult	140	120	100	80	

(3.83)

On consideration of safety, riding comfort level, engineering, and operation, etc. synthetically, main lines should be designed as long grade sections whose minimum allowable length shall comply with the values given in Table 3.19. The minimum length of grade section should not be used continuously under general conditions, and should not be used continuously under difficult conditions.

Table 3.19

Minimum Allowable Length of Grade Section

Railway Type	High-Speed Railway	Mixed Freight and Passenger Traffic
Design speed (km/h)	350	300
Available length Arrival and departure line (m)		
Minimum length of grade section (m)	General	$12.5\Delta i + L_{jmin}$

Conditions Used 200 m Length of Grade Section

In railway lines for freight traffic and passenger traffic, in order to save land and reduce amount of engineering, the length of grade section can be shortened to 200 m at the following places:

1. The length of a level stretch between opposite sign gradient set at the summit for easing up the difference of gradients, can be 200 m long (see Fig. 3.31A). But at the sag, the length of a level stretch between opposite sign gradient should also meet the minimum length in Table 3.19, such as in Fig. 3.31B.

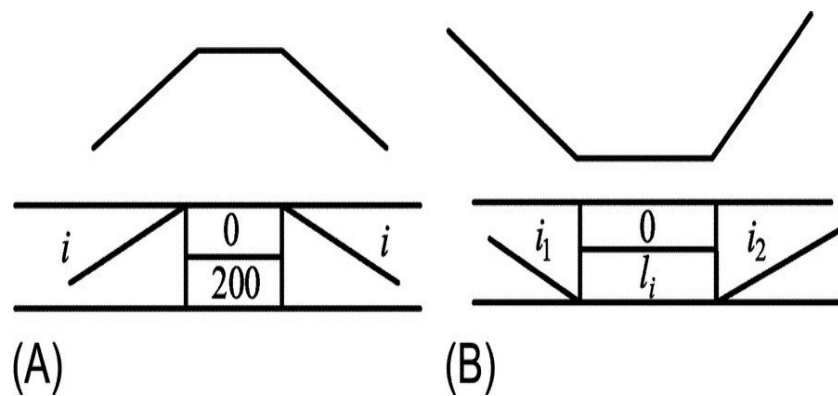


Fig. 3.31 Length of level stretch between opposite sign gradient.

2. For grade section formed by gradient reduction, see Fig. 3.32A, the length of grade section can be shortened to 200 m.

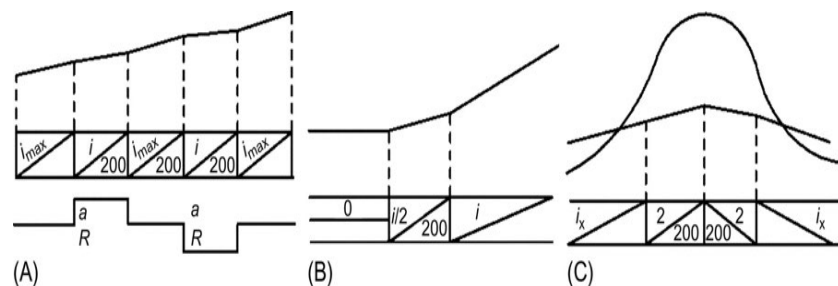


Fig. 3.32 200 m Grade sections.

3. Easy gradient for acceleration between two grades with same direction for easing the difference of gradients can use a 200 m grade section (see Fig. 3.32B).
4. The length of a double spur grade at the summit of long road cutting to set for drainage can be shortened to 200 m. The minimum gradient of double spur grade should be no smaller than 2‰ to ensure good drainage.
5. In untwining lines in terminals, as the speed is generally slow and the grade sections are ascending or descending fast. The length of grade section can be shortened to 200 m (Fig. 3.32C).

3.3.3.3 The Maximum Length of Grade Section

Railway Line for Mixed of Freight Traffic and Passenger Traffic

On railway lines for freight traffic and passenger traffic, when a freight train is running towards the station near the long-steep descending grade section, the locomotive brake gear should do overall test in a given time continuously so that the train working time at station will be longer. For this reason, profile design should use long steep grades as little as possible. According to the requirements of brake technology, the long steep grades are grade sections where the gradient is larger than 6‰ and the length is longer than 8 km for mixed freight and passenger traffic; the gradient is larger than 12‰ and the length is 5 km for passenger traffic, or the grade is 20‰ and the length is 2 km or more.

Railway Line for Passenger Traffic

In high-speed passenger lines, in order to avoid traction motor being super heated, the length of grade sections should be limited where the maximum gradient is used.

Practice and Test

Based on the fact that the temperature rise in main traction motor cannot be higher than 120°C, Japan's Shinkansen stipulates that the maximum length can be 7 km for a 15‰ maximum grade; for a grade section shorter than 2.5 km, the maximum gradient is 18‰; and for a grade section shorter than 1 km, the maximum grade can use 20‰. Japan's Shinkansen also stipulates that, in a 10 km section, the average gradient should not be larger than 12‰ in general. In difficult conditions, the maximum gradient is 15‰.

France's railway regulations stipulate that: for grade sections shorter than 3 km, the gradient cannot exceed 18‰; for grade sections with length of 3–15 km, the maximum grade is 15‰. For grade sections where the gradient is larger than 25‰, the maximum length is 4 km.

International Union of Rail ways (UIC) provide that for grade sections shorter than 10 km, the gradient shall not be larger than 25‰; for 6 km length, the maximum gradient is 35‰. A 40‰ gradient shall be handled specially.

Simulation and Analysis

On considering a train can running on a maximum grade at 90% of design speed, the wheel-rail dynamics can ensure the safety and ride comfort. Based on this requirement, suppose that a 350 km/h EMU runs ascending 15‰ grade, 20‰ grade, and 30‰ grade, the simulation result show that the train running speed can reach the design speed on 15–30‰ grades.

Maximum Length of a Grade Section With a Maximum Grade

The code for design of high-speed railway (rail) stipulates that for grade sections with gradients no larger than 12‰, it is not necessary to limited the maximum length. For grade sections with gradients larger than 15‰, the length should not be longer than 9 km; for 20‰ ones, the maximum length of grade sections should not be longer than 5 km.

3.3.4 Compensation of Maximum Grade

In railway lines for mixed freight and passenger traffic, when a train rounds a curve or passes through a tunnel of 400 m long and over, a train is subject to some additional resistances. At long and steep sections where grades should be designed as the maximum gradient, if the sum of the designed gradient and curve or tunnel equivalent grade exceeds the given maximum grade, a train with tonnage rating determined by ruling grade will run at a speed less than calculated speed. If so, the train will run more and more slowly, at least it can cause a delay to the train running. In order to ensure the resistance under a train not to exceed the equivalent grade of ruling grade, grade design should take some reduction of maximum grade section at curves or tunnels. Expressing curve resistance and tunnel air resistance as that of an equivalent grade is useful in solving problems in the design of grades, upon which curves or tunnels are superimposed.

3.3.4.1 Compensation for Curvature

Equivalent Curve Grades

It is frequently convenient to express curve resistance in terms of the equivalent grade that would offer the same resistance. Thus curve resistance of 1 newton per 10 tons equals the resistance offered by a 1‰ grade. In other words, the unit resistance of a 1 newton per 10 tons is the same as the resistance that a 1‰ grade would offer. One can convert curve resistance to the equivalent grade, add that to the profile grade, and compute the combined effects in one operation. However handled, curve resistance should not be overlooked. That is

$$i_c = r_c \quad (‰)$$

Experience and tests have shown a marked reduction in curve resistance arising from the use of rail and flange lubricators. These devices, now available in several commercial models, apply a graphite lubricant to the flanges of passing wheels under the repetitive passing of those wheels.

The actuating device is usually a form of ramp or trip adjacent to the rail head that depresses as the wheel passes over it, causing a pumping action within the lubricant supply line. The Supply line terminates at the gage side of the rail head. where lubricant is delivered in small quantities to the wheel flanges. Lubricant is distributed from the wheel flanges to the gage side of the rail heads. Traces of lubricant have been noted several miles from the source. Lubricators are properly located at the approaches to long, sharp curves, before a series of closely spaced, short, sharp curves, or at the approach to a series of turnouts, as on a yard lead. When the curve series include reverse curves, lubricators are required on both rails.

Where the coincidence of grade and curvature controls tonnage ratings, an increase in tonnage rating may be expected from the use of lubricators although the percentage of possible saving becomes less as gradient increases. The current manual of the tractive effort calculation in China railway recommends a full $600/R(N/10t)$ in curve resistance was noted, that is, a reduction in equivalent gradient $600/R‰$, or a saving of $500/R$ meter of equivalent elevation in 1000 meters of curve length.

Train length versus curve length affects total curve resistance. A 100-car train on a curve 60 car lengths long is not experiencing curve resistance throughout the train but only on 60% of its length. Total curve resistance rises from a minimum value as the train enters the curve to a maximum and continues so until less than 60 cars remain on the curve. The resistance then decreases to zero as the last car leaves the curve. With compensated curves there is no increase in effective resistance.

The Theory of Compensation

Expressing curve resistance as that of an equivalent grade is useful in solving problems in the design of grades upon which curves are super-imposed.

Suppose a locomotive was just capable of hauling a train of G tons up a $i_{\max}$ gradient without stalling. If an R curve is superimposed on this gradient, the total effective gradient that the locomotive must overcome is the actual gradient of $i_{\max}$ plus the equivalent gradient for a R curve of Δi_r , or $i_{\max} + \Delta i_r$. The train will stall. In order to convert this effective gradient of $i_{\max} + \Delta i_r$ into an effective gradient of $i\%$ that the locomotive can negotiate, the actual gradient must be reduced by Δi_r , the design grade i should be:

$$(3.84)$$

where $i_{\max}$ is the maximum gradient (‰) and Δi_r is the equivalent gradient of curve resistance (‰).

For example, if a locomotive was just capable of hauling a train of 3000 tons up a 6.0‰ gradient without stalling. If a curve of 500 m radius is superimposed on this gradient, the total effective gradient that the locomotive must overcome is the actual gradient of 6.0‰ plus the equivalent gradient for a 500 m radius curve of 1.2‰ ($600/500$), or 7.2‰. The train will stall. In order to convert this effective gradient of 7.2‰ into an effective gradient of 6.0‰ that the locomotive can negotiate, the actual gradient must be reduced by 4.8‰ (see Fig. 3.33).

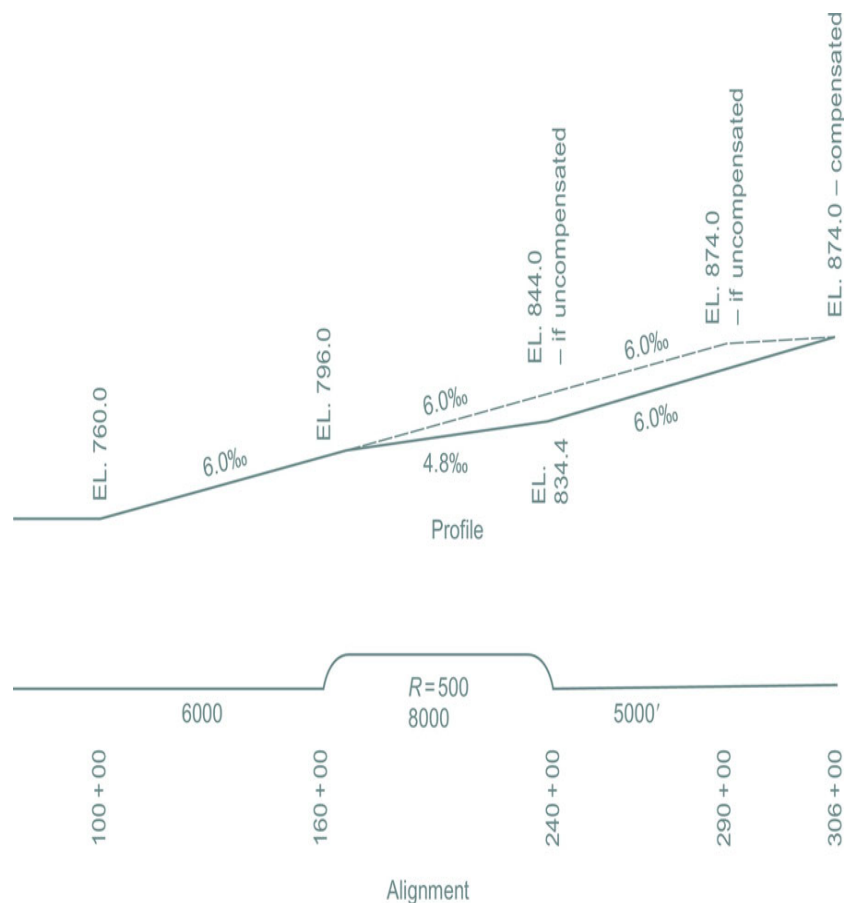


Fig. 3.33 Example: compensation for curvature.

Rules for compensation of curve resistance

Compensation is desirable but not always required. When curvature occurs on a ruling grade, it has a limiting effect, and compensation is then a necessity. Introducing compensation sometimes taxes the ingenuity of the locating engineer. By reducing the actual gradient throughout the length of curve, more distance is required to attain the desired elevation. This must often be achieved through the process of development, which in turn may introduce more curvature, with the necessity for additional compensation and modification.

Compensation of a curve should comply with the following rules:

- ① When curvature occurs on a slight grade, it has no limiting effect, and compensation is not necessary.
- ② Grade design should ensure enough compensation of curve resistance, and avoid too much compensation with more distance to attain the desired elevation.
- ③ The length of curve used in compensation formula is the length of simple circular curve without spiral; the length of freight train is the short-term one. As the length of a short-term train is shorter than that of a long-term train, compensation in terms of a short-term train can meet the requirements of a long-term train.
- ④ The length of the compensated grade shall not be short and close to the length of circular curve. The length of grade section should not be shorter than 200 m, and can be divided exactly by 50 m. In general, the length of grade section should be no longer than the length of a short-term freight train.
- ⑤ The precision of design gradient by curve compensation is taken as 0.1.

Method of Curvature Compensation

1. The straight line longer than 200 m between two adjacent curves can be designed as a grade section without compensation. Its gradient takes as the maximum grade.
2. A curve longer than a freight train can be designed as a grade section, the value of compensation of curve is

$$(3.85)$$

3. A curve shorter than a freight train can be designed as a grade section, the value of compensation of curve is

$$\Delta i_R = \left(\frac{600}{R} \times \frac{L_c}{L_i} \right) = \frac{600}{R} \cdot \frac{\pi R \alpha}{180 L_i} = \frac{10.5 \alpha}{L_i} (\text{‰})$$

(3.86)

where α is the deflection angle of curve ($^\circ$); L_c is the length of curve (m); R is the radius of curve (m); and L_i is the length of design grade section (m), if it is longer than the length of freight train, its value takes as the length of freight train.

4. If curves and intermediate straight lines are all shorter than 200 m, a section with two short curves can be designed as two grades by dividing intermediate straight line into two parts. Compensation of curve is shown in Eq. (3.86). It can also be designed as a grade; the value of compensation of curve is

(3.87)

where is total angle degree of all curves in the compensated section.

5. Sometimes, a curve will occur on two grades, the compensation of curve should be calculated in assign part of deflected angle on each grade.

Example 3.3

A newly electric traction railway line for mixed freight and passenger traffic, ruling grade is 12‰, the length of short-term freight train is 550 m, design speed is 100 km/h. a part of plane is shown as Fig. 3.34. This section occurs on a long-steep area. Design ascending with maximum grades.

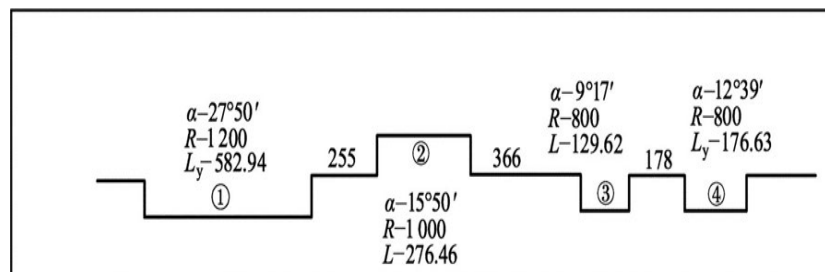


Fig. 3.34 Compensation for curvature.

Solution

Design the profile as follows:

1. The two straight lines front and behind curve ② are longer than 200 m, which can be designed as a grade section without compensation. The length of grades is 200 m and 350 m respectively; gradient takes as the ruling grade of 12‰.

2. Curve ① which is longer than a short-term freight train can be designed as a compensated grade. Takes the length of grade just longer than the length of curve in 600 m, and the design gradient is:

$$i_{\text{rul}} - \frac{600}{R} = 12 - \frac{600}{1200} = 11.5 \text{ (‰)}, \text{ takes it as } 11.5\text{‰}$$

3. Design curve ② which is shorter than a short-term freight train as a compensated grade. Takes the length of grade just longer than the length of curve in 300 m, and the design gradient is

$$i = i_{\text{rul}} - \frac{10.5\alpha}{L_i} = 12 - \frac{10.5 \times 15.83}{300} = 11.45 \text{ (‰)}$$

which takes it as 11.4‰.

4. Curve ③, curve ④ and the intermediate straight line between them are all shorter than 200 m. They can be designed as two grade sections by divided the intermediate straight line into two parts. The length of grade section is 250 m, and the gradient can be designed using the following equation:

$$i = i_{\text{rul}} - \frac{10.5\alpha}{L_i} = 12 - \frac{10.5 \times 9.28}{250} = 11.61 \text{ (‰)},$$

takes it as 11.6‰

$$i = i_{\text{rul}} - \frac{10.5\alpha}{L_i} = 12 - \frac{10.5 \times 12.65}{250} = 11.47 \text{ (‰)}$$

takes it as 11.4‰

This section can also design a grade with 500 m long and 11.5‰ gradient.

The design result is shown in Fig. 3.35.

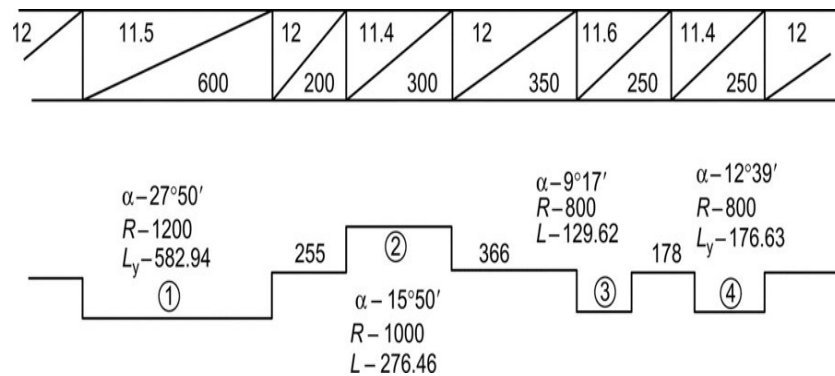


Fig. 3.35 Diagram of solution of Example 3.3.

3.3.4.2 Compensation of a Gradient in Tunnel

In railway lines for mixed freight and passenger traffic, at the location where the maximum gradient is fully used, when train passes through the tunnel which length is more than 400 m, its additional resistance increases but adhesion coefficient reduces, leading to the design gradient of profile plus the equivalent gradient of additional aerodynamic drag in tunnel greater than the maximum gradient. Therefore, in the profile design, it is necessary to compensate the maximum gradient to ensure the general freight train to pass through this location with speed no less than the stipulated. The Code for Design of Railway Line (hereinafter referred to as the Line Specification) offers us the maximum gradient compensation coefficients of the corresponding tunnels.

Sources of Tunnel Resistance

Tunnel resistance is the added resistance or “drag” on a train that must be overcome by the tractive effort in passing through a tunnel longer than 400 m. Resistance is usually measured in newtons per ton of train weight. The difference between resistance in a tunnel and that on an open level track divided by the length of tunnel gives the curve resistance in newtons per ton per meter.

In one form or another, tunnel resistance represents the work expended in overcoming air pressure, air drag, and air friction along train. The exact reasons for the occurrence of tunnel resistance are complex and difficult to determine. Theories differ chiefly in details regarding the action of a car truck in going through a tunnel.

At the section where the maximum gradient is fully used, if the equivalent gradient of profile exceeds the maximum gradient, the freight train will eventually run at a speed less

than calculated speed on the consecutive ascending grade, which will result in accidents due to the slow speed, even causing suspension on the way. Hence, the design gradient of profile plus the equivalent gradient of additional resistance in tunnel should be not greater than the maximum gradient. Therefore, for profile design, we need to reduce the maximum gradient to ensure the freight train passing through this section with speed no less than calculated speed or stipulated speed.

Method of Tunnel Compensation

At the tunnel section where the maximum gradient is fully used, when the train goes through the tunnel, if the calculated gradient of locomotive approaches the ruling gradient of the design line, the gradient equivalent to additional resistance should be deducted to ensure the train passing through this tunnel with speed no less than the calculated speed of the locomotive.

Only additional aerodynamic drag in tunnel affects the compensation of maximum gradient for the tunnel when using electric traction. For diesel-traction, however, not only additional tunnel aerodynamic drag but also the speed of train through the tunnel influences the compensation of maximum gradient.

Let the compensation of maximum gradient in tunnel be Δi_s . Then the maximum design gradient of tunnel, i , is

$$i = i_{\max} - \Delta i_T \text{ ‰}$$

In order to simplify the calculation, the maximum gradient compensation value for the tunnel, Δi_s , can be converted to maximum gradient coefficient β_T . The relationship of β_T with design grade i is as follows:

$$i = i_{\max} - \Delta i_T = \left(1 - \frac{\Delta i_T}{i_{\max}}\right) \cdot i_{\max} = \beta_T \cdot i_{\max} (\text{‰})$$

For electric traction:

$$\beta_T = \begin{cases} 1 - \frac{r_T - (i_c - i_{\max})}{i_{\max}} = \frac{i_c - r_0}{i_{\max}} & i_c - i_{\max} \leq r_T \\ 1 & i_c - i_{\max} > r_T \end{cases}$$

For diesel-traction:

$$\beta_T = \begin{cases} 1 - \frac{r_T - (i_v - i_{\max})}{i_{\max}} = \frac{i_v - r_T}{i_{\max}} & i_v - i_{\max} \leq r_T \\ 1 & i_v - i_{\max} > r_T \end{cases}$$

where r_T is the additional unit resistance in tunnel (N/10t); $i_{\max}$ is the maximum gradient of design line (‰); i_c is the calculated gradient of locomotive, namely gradient value when the train runs at a constant speed; for the freight train, it refers to the equilibrium gradient when the locomotive runs at a minimum calculated speed (‰); and i_v is the equilibrium gradient under the train speed through the tunnel. It equals the unit resultant force value under the train speed through the tunnel, i.e., i_v (‰) = $f - r_0$ (N/10t), where f is the unit traction force and r_0 is the unit basic resistance.

According to research results, we can get maximum tunnel gradient coefficient β_T in Table 3.20.

Table 3.20

Electric and Diesel Tunnel Gradient Coefficient β_T

Tractive effort type Length of Tunnel (m)	Electric	Diesel
400 < LT ≤ 1000	0.95	0.90
1000 < LT ≤ 4000	0.90	0.80
LT > 4000	0.85	0.75

3.3.4.3 Range Compensation

The major factor for compensation of gradient in tunnel are air additional resistance and the requirement of lowest speed for going through the tunnel. Although the pressure at the head of train will occur abruptly when a train enter a tunnel, the frictional force around will increase with the part of train entering the tunnel. The friction force reaches its peak value after the whole train entering the tunnel. On the other hand, the attraction force at the tail of a train occurs only when the whole train enter a tunnel. For simplifying the calculation, the compensation range is limited in the length of tunnel, and the compensation grade section can be divided exactly by 50.

For diesel traction, the result of compensation should be checked the requirement of passing tunnel speed. In order to ensure that a freight train can go through a tunnel with speed no lower than the calculated speed, it is necessary to set an easy gradient for acceleration outside the tunnel portal of an ascending grade.

3.3.4.4 Design of an Easy Gradient for Acceleration

For diesel traction, if the required speed is higher than the calculated speed, an easy gradient for acceleration should be provided outside the tunnel portal at the ascending end. The length of an easy gradient for acceleration L_{eg} (see Fig. 3.36) can be calculated as follows:

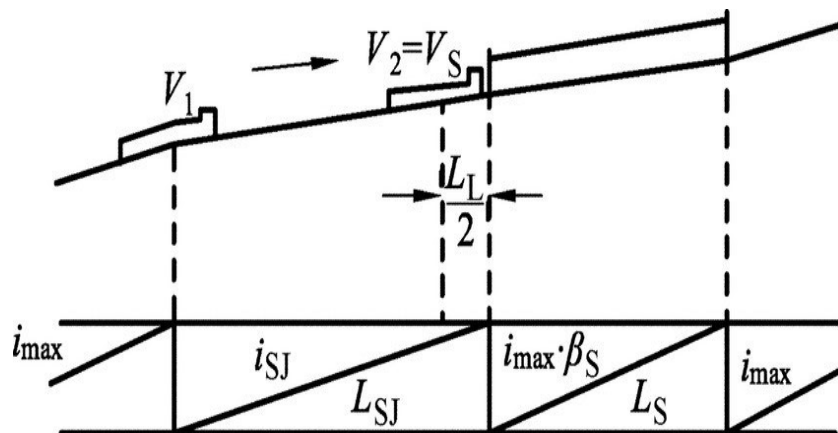


Fig. 3.36 An easy gradient for acceleration.

$$L_{eg} = \sum \frac{4.17(V_2^2 - V_1^2)}{f - r_0 - i_{eg}} + \frac{L_{train}}{2} (m)$$

(3.88)

where V_1 is the running speed at the starting point of an easy gradient for acceleration (km/h), on the maximum grade takes as locomotive calculated speed V_{ca} ; V_2 is the running speed when the head of locomotive come to tunnel portal (km/h), that is, the minimum tunnel passing speed V_s . If the difference of V_1 and V_2 is too large, it is necessary to divide the difference into smaller interval of speed that would not be larger than 5 km/h; $f - r_0$ is the unit resultant force calculated with average speed of , (N/10t); i_{eg} is the grade of easy gradient for acceleration(‰), generally, it takes the same gradient as inside of the tunnel; if a curve occurs in an easy gradient for acceleration, then i_{SJ} should be an equivalent gradient; and L_{train} is the length of freight train (m).

The length of an easy gradient for acceleration should take the result in round numbers of 50 m, and no shorter than 200 m.

Example 3.5

A railway line for mixed freight and passenger traffic use diesel traction, ruling grade is 6‰, type of locomotive is DF4B, the length of freight train is 493 m, the length of tunnel is 1300 m, the profile is shown in Fig. 3.37. This section should be designed in maximum grade ascending.


$$L_{\text{eg}} = \sum \frac{4.17(V_2^2 - V_1^2)}{f - r_0 - i_{\text{eg}}} + \frac{L_{\text{train}}}{2}$$

$$= \frac{4.17(26.8^2 - 21.8^2)}{f|_{v=24.3} - r_0|_{v=24.3} - 4.8} + \frac{493}{2} = \frac{4.17(26.8^2 - 21.8^2)}{7.58 - 1.61 - 4.8} + 247 = 1113.1 \text{ (m)}$$

Take Leg=1150 m, and divide it into two grade sections; one is 500 m in straight line, and the other is 650 m in curve.

ieg is equivalent gradient, it takes as 4.8‰ in a straight, and in a curve, it is:

$$i = 4.8 - \frac{600}{800} = 4.8 - 0.75 = 4.05(\text{‰})$$

which takes 4.0‰.

3.3.5 Effect of a grade section on operating expenses

3.3.5.1 Effect of a Gradient on Operating Expenses

For a design line, when the types of locomotive and maximum grade are given, the mass of train and maximum continuous speed will be determined. For upward grades, the greater the design grade is, the more fuel and power consumption per kilometer will be. For downward grades, the lower the restriction speed, the more grievous the wear will be, so that the operating expense will increase. Fig. 3.38 give the relation between maximum grade and operating expenses, in which ruling grade is 12‰, locomotives are SS1, DF4 and QJ separately. Fig. 3.38 shows that operating expenses per kilometer increase as the grade increases.

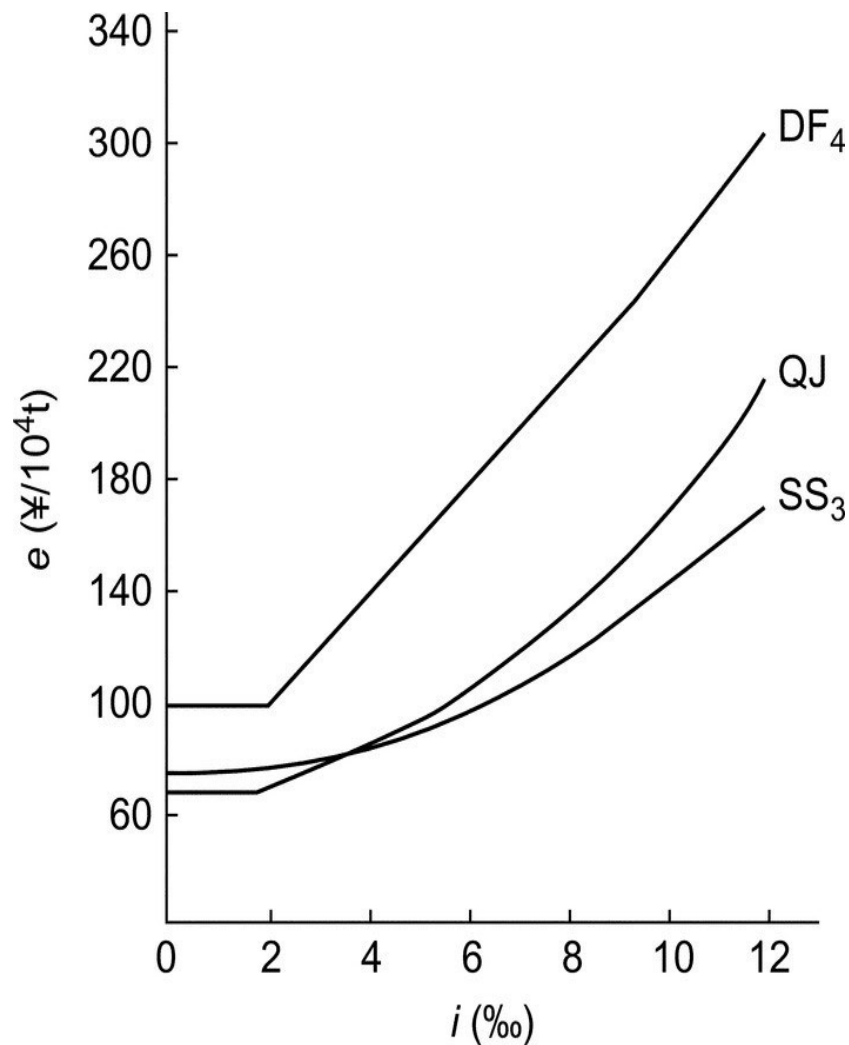


Fig. 3.38 Relation between grade.

Fig. 3.39 shows the effect of different composition of grade section on energy consumption. The lengths and gradients of grades in (a) and (b) are all the same, but ascending or descending conditions entering station and leaving station are different. The profile in (b), a train running on a downward grade to leave station, is beneficial to acceleration. A descending grade at the exiting end of station is beneficial to acceleration and reducing energy consumption; and an ascending grade at the entering end of station is beneficial to train deceleration and reducing the braking wear. Profile (a) is inversed. On consideration of energy consumption, train operating expenses on profile (a) will be higher than that in (b). It is obviously that a summit position of profile for a station is better than a sag position.

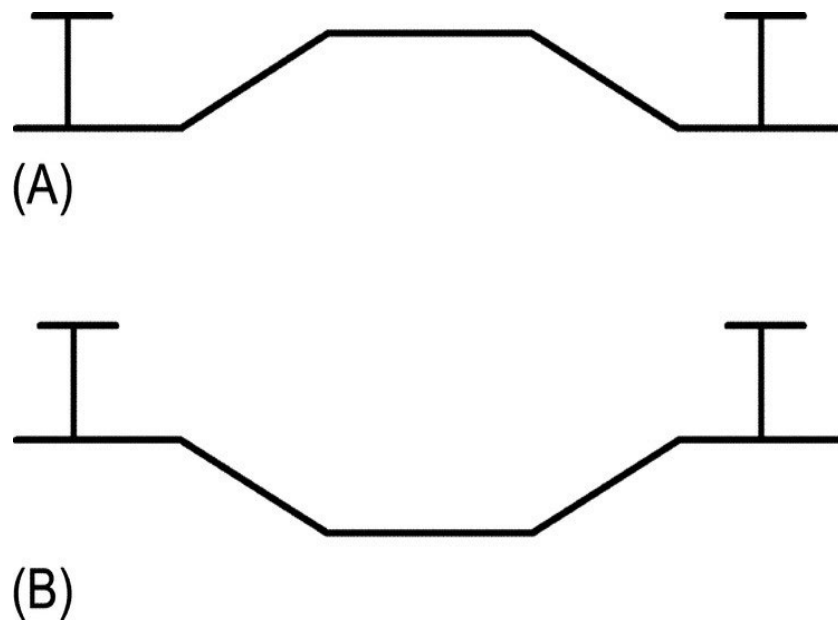


Fig. 3.39 Summit profile, sag profile and operating expenses.

3.3.5.2 Segments of Severe Grade and Easy Grade

When running downgrade, the trains can coast under gravity without the traction of locomotive. The steeper and longer the grade is, the faster the trains can slide finally. However, limited by the braking condition, the speed cannot be too high; besides, it shall be braked when reaching the limit. On such grade segment, the train may produce certain potential energy at the slope top that cannot be fully consumed by braking. Besides, the travel costs will increase due to the easily worn brake shoe under the braking effect. Such a segment is defined as the segment of severe grade.

If the downgrade is easy or it is steep and short, the trains can coast under gravity within the limiting speed. Thus, no braking is required. On such grade segment, the potential energy of trains can be fully consumed, the brake shoe will not wear, so the travel costs will not increase. Such a segment is defined as the segment of easy grade.

The necessity of braking operation is related to grade, length of grade segment, and initial speed of the trains in such a grade segment, which can be depicted by a speed-distance curve. In Fig. 3.40, segment a-b represents the severe grade segment where braking is needed and other segments are easy grade segments without the braking operation.

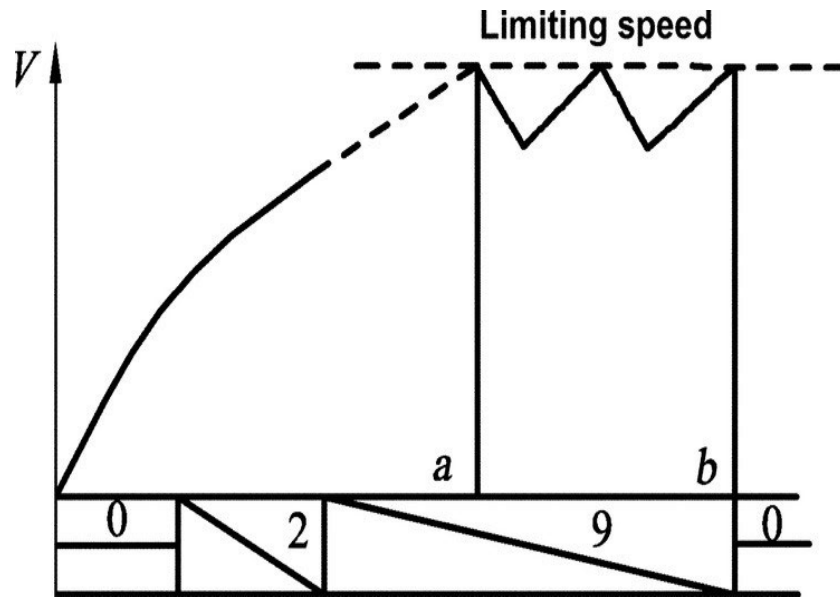


Fig. 3.40 Determination of severe grade segment.

If the trains, despite the length of grade, can coast downgrade and finally run at a constant limiting speed without braking, such a grade is referred to as the maximum easy grade $i_{eg(max)}$, calculated according to the following equations:

Since

$$P \times r'_0 + G \times r''_0 = i_{eg(max)} \times (P + G)$$

then

$$(3.89)$$

where r_0' is the Unit basic resistance of locomotives at limiting speed, N/10t; r_0'' is the Unit basic resistance of vehicles at limiting speed, N/10t; and r_0 is the average unit basic resistance of trains at limiting speed, N/10t.

The maximum easy grade is generally about 2.5‰ for heavy freight trains and 4‰ for empty freight trains according to the equation above and the braking limiting speed, locomotives, vehicles, and traction capacities of mixed passenger and freight lines in China.

In general, the grade segment with grade greater than 4‰ and height difference exceeding 10 m is roughly determined as the severe grade segment during the profile design of mixed passenger and freight line. The severe grade segments shall be eliminated if the topographic conditions permit.

3.3.5.3 Lifting Height

The lifting height of line refers to the rising height in upgrade direction. The lifting height shall be calculated in both up and down directions (see Fig. 3.41). The total lifting height in both up and down directions between a and b are expressed respectively as:

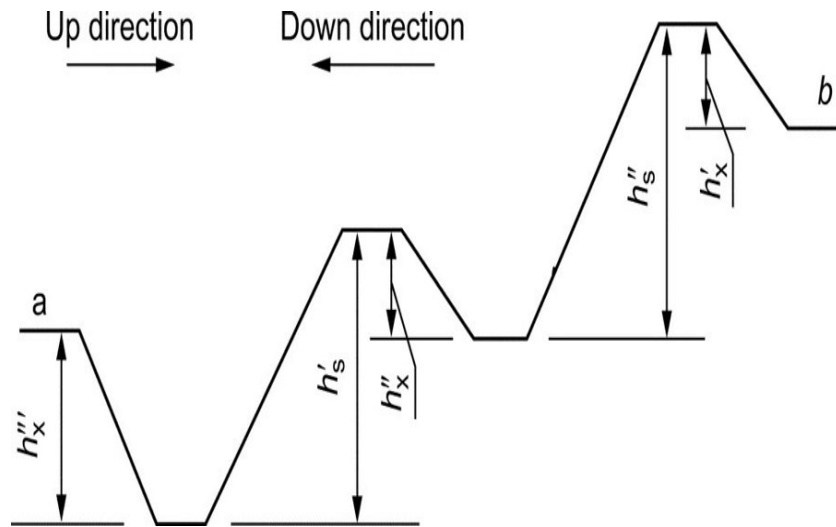


Fig. 3.41 Lifting height.

$$\sum h_U = h'_U + h''_U \quad (\text{m})$$

$$\sum h_D = h'_D + h''_D + h'''_D \quad (\text{m})$$

The train energy consumption and running speed are affected by the lifting height. Under constant line length, a greater lifting height may result in more fuel or electricity

consumption, longer running time, and thus a higher driving cost. Thus, the lifting height shall be used as one of the technical indicators in an alternative comparison.

The profile design shall adapt to the topographic relief. In addition, the lifting height shall be minimized. In Fig. 3.42, the running speed can be improved with travel costs reduced by simply reducing the design elevation of profile top and lifting height and changing the grade segment into a dotted line grade segment.

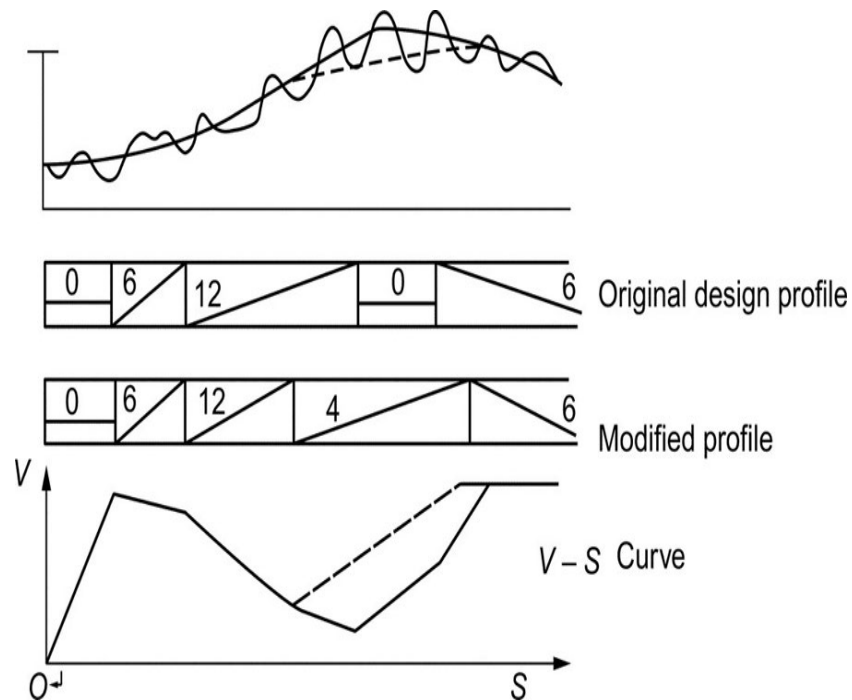


Fig. 3.42 Reduction of lifting height.

3.4 Plane and Profile Design at Bridge, Culvert, Tunnel and Subgrade

3.4.1 Bridge and Culvert Zones

The bridges can be divided into super-long bridges (>500 m), long bridges (101-500 m), medium bridges (21-100 m), and small bridges (≤ 20 m) by length. The culvert aperture is generally 0.75-6.0 m.

3.4.1.1 Plane Design

There are no special requirements on line planes at small bridges and culverts.

The super-long bridges, long bridges, continuous beam bridges, steel beam bridges, and large span bridges should be set in a straight line. Exceptionally, in certain inevitable difficult conditions, they should be set in a large radius curve. If the bridge is set in a curve, it is difficult to design and construct the bridge structure, replace rails, and adjust the curve. The line location is easy to deform, resulting in excessive eccentricity to adversely affect pier and abutment stress. The swing of the running vehicles in the curve is detrimental to the bridge stress and riding safety.

Open deck bridges should be set in a straight line. If the open deck bridges are set in curve, it is hard to determine the line location on a ballastless deck. The track gauge is difficult to keep, affecting the running safety. The superelevation of the high rail must be adjusted with bridge sleepers which are difficult to pave and replace. An open deck bridge with span greater than 40 m or length over 100 m can be set in the curve with a radius less than 1000 m, providing it is economically and technically viable.

The open deck bridges cannot be set in a reverse curve, or the intense vibration will occur during the passage of trains, which will affect the safety of the operation. In addition, the line cannot be kept in place properly during maintenance. Bridge eccentricity will occur, jeopardizing the bridge stress, especially for open deck bridges. Therefore, only the ballasted deck bridges can be set in a reverse curve under difficult conditions. In such cases, the longer intermediate straight line shall be adopted.

The curve radius on the bridges shall not restrict the rational selection of a bridge span. The minimum allowable curve radii for commonly used standard beams are listed in Table 3.21.

Table 3.21

Type of Beam	Reinforced Concrete Beam	Pre-stress Reinforced Concrete Beam
Common	Lower Height	
Span (m)	≤4	20
Minimum allowable curve radius (m)	Typical	350
Exceptional	250	300

The bridge approach connecting the long bridges shall follow the plane standard of bridges. During the curve design, the radius shall not be less than the minimum curve radius of the zone. In addition, the requirement on curve radius of bridge approach shall be considered when the beams are erected with the girder-erecting machine.

3.4.1.2 Profile Design

The culverts and ballasted deck bridges can be set on a grade with any profile.

The profiles of continuous beam bridges, steel beam bridges, and large span bridges shall be designed in accordance with the technical requirements of bridge design.

Open deck bridges should set on the near-level grade. If the bridges are set on a grade, it is hard to determine the line location due to the rail creeping. The track gauge is difficult to keep, causing difficulties in line maintenance and affecting the running safety. If the bridges must be set on a grade, the grade should not exceed 4‰ to avoid increasing the rail creeping when the trains run downgrade and brake on the bridge. The open deck bridge with the span exceeding 40 m or the length exceeding 100 m is set on the grade greater than 4‰, providing the sufficient technical and economic bases are ensured.

The vertical curve shall not be set on an open deck bridge to avoid paving and maintenance difficulties due to the adjustment of rail top elevation. Thus the distance from the grade change point to two ends of the open deck bridge shall not be less than the vertical curve tangent during the profile design, as shown in Fig. 3.43.

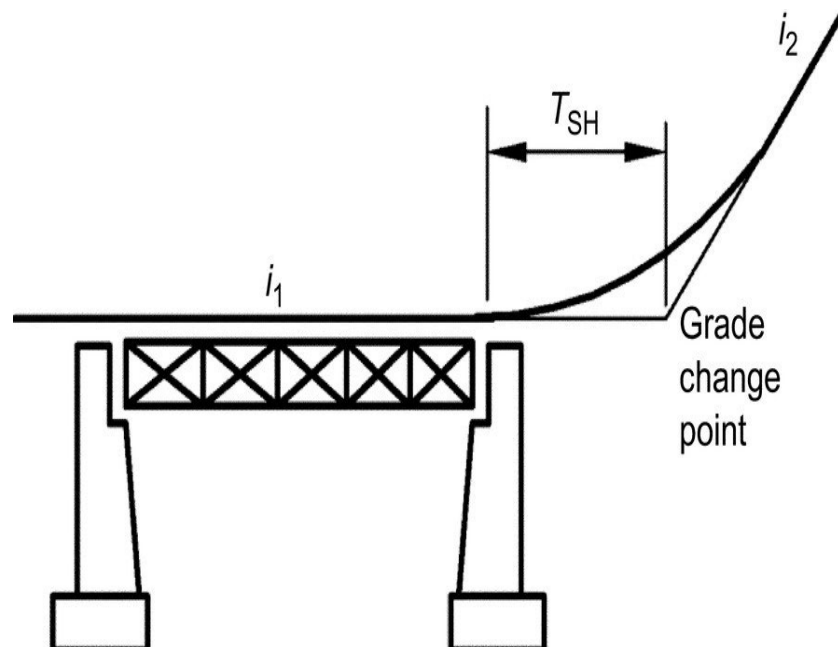


Fig. 3.43 Distance from grade change point to an open deck bridge.

For the designed formation level, it shall not be less than the minimum height at the culverts as required by hydrological and construction conditions. It shall not be less than the minimum height at the bridges as required by hydrological conditions and the clearance height under bridge. To ensure necessary navigation clearance under large bridges on riverways in flat areas, the bridge approach elevations on both ends can be reduced. In addition, the convex profile can be set on the bridge.

When a PDL crosses other railways and highways (roads), the profile design elevation shall meet its clearance height; the clearance height under the overpass crossing PDL shall not be less than 7.25 m. When a PDL passes underneath the existing overpass, the lower clearance height can be adopted through the technical and economic comparison.

In addition to meeting the hydrologic conditions and bridge structure, the profile design for bridges that cross river shall conform to the navigation clearance requirements.

For elevated lines for crossing roads or zone with poor geological conditions, the bridges mainly adopt the simply supported beams with span not greater than 32 m or continuous box beam with equal spans generally not greater than 15 m.

3.4.2 Tunnel Zones

3.4.2.1 Line Plane

The tunnel has poor measurement, construction, operation, ventilation, and maintenance conditions compared to the empty zone, especially the curve tunnels, so the tunnels should be set in a straight line. If the tunnels must be set in a curve limited by the topographical and geological conditions, the curve should set near the tunnel portal with a large curve radius.

The tunnel should not be set in a reverse curve. If the tunnel must be set in a reverse curve, the length of the intermediate straight line should not be less than 44 m, in order to avoid the overlapping due to the curve widening at two ends so as to simplify the construction.

When the curve outside the straight tunnel is close to the portal, the distance from TS (tangent to spiral) or ST (spiral to tangent) to the portal shall not be less than 25 m, to avoid widening the portal and portal lining.

3.4.2.2 Line Profile

The line profile in a tunnel can be set in single surface slope or inverted V-shaped slope. The single surface slope ensures possible height and is benefit for the operation ventilation of long tunnel, while the inverted V-shaped slope is benefit for the drainage and deslagging during the construction.

To obtain the possible height, the tunnel in the zone with maximum grade shall be provided with a single surface slope.

The long tunnel with developed groundwater shall be provided with an inverted V-shaped slope. As the long tunnel with an inverted V-shaped slope has poor ventilation, the waste gases and oil-smoke exhausted by the bidirectional upgrade trains during the diesel traction will pollute the tunnel to deteriorate the operating and maintenance conditions. The artificial ventilation shall be used if necessary.

The grade in the tunnel should not be less than 3‰ for drainage. The grade of the tunnel with developed groundwater in severely cold areas can be properly increased to reduce the impact on drainage of ice accumulation of in winter.

3.4.2.3 Requirements of Subgrade on Line Profile

The designed formation level for subgrade of bridge approach of super-long bridge, long and medium bridges crossing flood-relief channel, reservoir area and waterfront, flood way district and flood retarding basin and low-lying areas shall not be less than design level+height of swell+wave invasion height+0.5 m and shall conform to related requirements of state flood control standard design.

The designed formation level for subgrade near the small bridge and culverts shall not be less than design level+height of swell+0.5 m.

The design grade in long cut should not be less than 2‰ for drainage of side ditch. When the cut of mixed passenger and freight railway is over 400 m and located on slope top of convex profile, it can be set in inverted V-shaped slope with a grade not less than 2‰ and a slope length not less than 200 m.

The division altitude for subgrade and bridges shall be comprehensively determined through techno-economic comparison according to embankment foundation conditions, packing properties and source, local land resources, and urban traffic requirement.

3.5 Plane and Profile Design at Station Site

3.5.1 Length of Station Site

The length of station site (LSS) is decided by the effective length of long-term arrival-departure track (L_{ad}) and the length of throat at both ends of turnout (L_{th}), as shown in Fig. 3.44. The tangent length of the vertical curve at both ends of station site is not included in the length of station site.

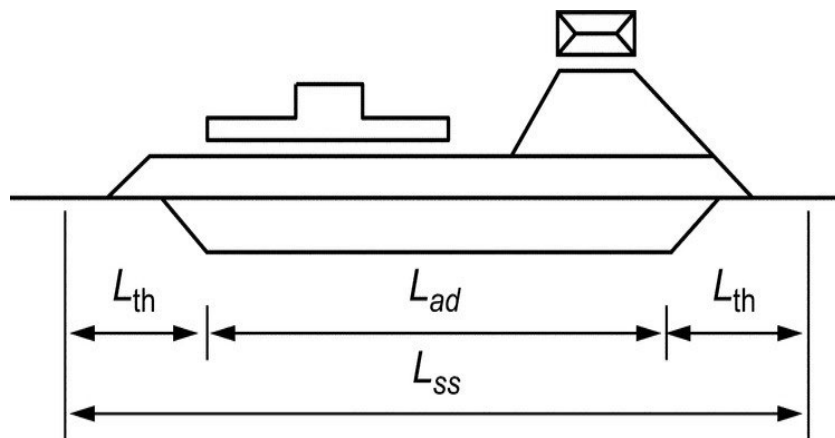


Fig. 3.44 Length of station site.

3.5.1.1 Mixed Passenger and Freight Line

The length of station site in mixed passenger and freight line is determined by the number of main lines, station type, station track layout form and effective length of long-term arrival-departure track. The length of the throat at both ends of station site may vary with station type and the number of tracks. Middle zone length of station site is determined by track layout form and effective length of arrival-departure track. Table 3.22 provides the minimum values of the length of station site in mixed passenger and freight line.

Table 3.22

Station Type	Station Layout Form	Effective Length of Long Term Arrival-Departure
1050	850	750
Single-line	Double-line	Single-line
Passing station, overtaking station	Traversal type	1450
Intermediate station	Traversal type	1600
District station	Traversal type	2000
Vertical type	3500	4000

The length of the vertical curve at both ends of station site is not included in the length of station site listed in Table 3.22. When the grade differences of grade change point at both ends of station site are more than 3‰ (Levels I and II railways) and 4‰ (Level III railways), the grade change point shall be set beyond the length of vertical curve tangent outside the ends of station site.

As for the length of station site listed in Table 3.22, the length of both ends of overtaking station and double-line intermediate station sites is determined by the length of one set of No.18 single crossover turnout laid at both ends; whereas other turnouts in main line are determined as per No.12 turnout. In other conditions, the length of the station site shall be determined as per the calculation.

Values listed in Table 3.22 are calculated per ordinary stations. If other railway connects in the station, the length of the station site shall be determined as per the calculation. The length of the station site of a complicated intermediate station and district station can be calculated and determined as the actual conditions.

Values listed in the table are the length of station site of single-locomotive traction. As for double-locomotive traction or multiple-locomotive traction, the effective length and the length of station site shall be increased as the number of added locomotives and their length accordingly.

3.5.1.2 Passenger Dedicated Line (PDL)

Length of PDL station site shall be calculated as the effective length of arrival-departure track, long term station layout form and turnout type, as shown in Fig. 3.45. Length of station throat and the length of station site may vary with PDL station layout form, the provision of diverging line of comprehensive maintenance section, and the number and direction of inter-station crossovers, as shown in Table 3.23.

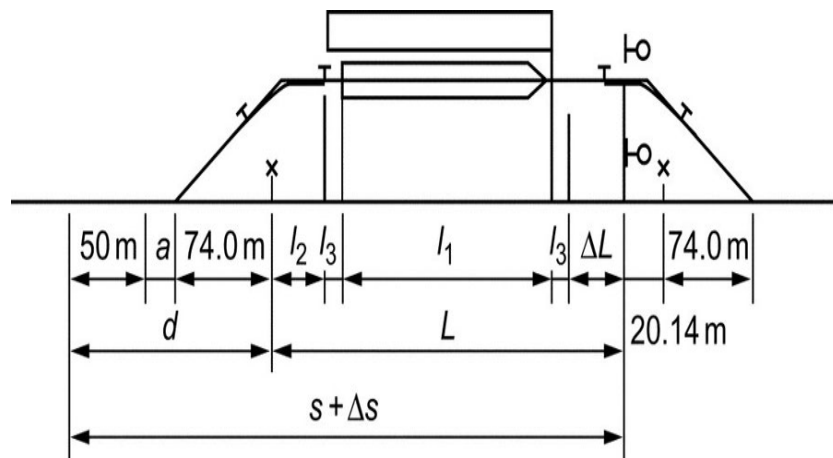


Fig. 3.45 Length of station site.

Table 3.23

Length of Intermediate Station Site in PDL

Without Diverging Line		With Diverging Line	
Figure	Length of Station Site (m)	Figure	Length of Station Site (m)
	2200		2320
	1800		
	1800		1920
	1350		

-
1. The effective length of arrival-departure track will not increase with the two-way receiving-departure condition. For any track, the reverse departure signal turns off when a train departs from the same track. The distance between home signal and basic rail joint of the first turnout is 50 m, and that between home signal and the first fouling post beside the main line is 50 m.
 2. The length of a station site is defined as the distance between the home signal and the signal at the other end or the rail joint in the stock rail of the outmost turnout, excluding the straight-line distance between the joint in the stock rail of the outmost turnout and the origin of curve (ST) as well as the main line vertical curve.

3.5.2 Line Plane

3.5.2.1 Plane Standard of Station Main Line

Station site shall be set in the straight line for the safety and convenience of technical operation in the station. However, under special and difficult conditions, such as restriction of terrain, setting the station in straight line may cause extra engineering work, in this case the station site may set in the curve, but the curve radius shall meet the requirements of minimum radius value as the corresponding technical conditions.

Such a curve option has the following operational disadvantages:

1. Bad visibility in the station perplexes the train receiving and departure, shunting and train examination operation conditions, hence increasing the time and reducing the efficiency of signal transmission, causing signal error and affecting the safety of the operation.
2. Additional curve resistance is increased when the train starts. The larger the scale of station, the greater the operation, and the more serious the influence.

Mixed Passenger and Freight Line

Station plane design shall meet the requirements of design running speed of passenger train in the section. If the station is set in the curve, the minimum curve radius shall meet the following provisions:

- ① As for the 200 km/h line, curve radius in the station should meet the standard of section main line. Under difficult conditions, curve radius can be determined as the train speed, which should not be less than 1000 m. A smaller deflection angle should be adopted in the station curve.

② A district station shall be set in the straight line. Under the special and difficult conditions, if the station can be set in the curve based on the sufficient reasons, its curve radius shall be no less than the values listed in Table 3.24.

Table 3.24

Minimum Plane Circular Curve Radius of Station Site

Design Running Speed of Passenger Train in the Section (km/h)	160	140	120	100	8
District station	1600	1200	800		
Intermediate station, passing station, overtaking station	Typical	2000	1600	1200	
Difficult	1600	1200	800	600	

③ Intermediate station, passing station and overtaking station should be set in a straight line. Under difficult conditions, if the station should be set in the curve, smaller curve intersection angle and larger curve radius shall be adopted. The minimum circular curve radius shall be no less than the values required in Table 3.24 to ensure that the long-term passenger train can pass the station at the design speed.

PDL

The station shall be set in the straight line. Under the difficult conditions, the station can be set in the curve after alternative comparison technically and economically, but the minimum curve radius of main line in the station shall be reasonably determined according to the design speed. As for the station where all trains stop, the minimum curve radius shall be no less than 1000 m. Setting the station in the curve shall meet the following requirements:

- ① A smaller curve deflection angle and length should be adopted.
- ② Crossover and cross-track passenger train connecting lines and other zones linking the turnouts, the straight length between the transition curve of main line and the joint in front and rear of the turnout shall meet the requirements in Table 3.25.

Table 3.25

Minimum Straight Length Between Transition Curve Within Station Site and Joint in Front and Rear of Turnout

Maximum Design Running Speed (km/h)	350	300	250	200	
Straight length (m)	Typical	210	180	150	120
Difficult	140	120	100	80	

3.5.2.2 Provision on Station Site Setting in Reverse Curve

Traversal type stations in mixed passenger and freight line shall not be set in the reverse curve to avoid worse visibility, lower efficiency, and degraded operation safety. If a vertical type station is set in the reverse curve, the reverse curve should not exist within the effective length of arrival-departure track in all operation directions.

PDL stations shall not be set in the reverse curve.

3.5.2.3 Plane Requirements at Station Throat

There are lots of turnouts in the station throat. Setting the turnout in the curve may have the following problems: for example, switch rail is not closed with serious wear; transition lead curve and straight line of turnout are not easy to connect; complex track gauge perplexes maintenance; trains badly shake and are prone to derailment; curve turnout shall be specially designed and manufactured. Therefore, the main line of a station throat shall be set in a straight line.

3.5.3 Line Profile

3.5.3.1 Grade of Station Site

The station site shall be set on the near-level grade to ensure the convenience and safety of station operation. However, if the natural longitudinal grade is steep, the station site may be set in the grade to save work or maximize line height, but the design grade shall meet the requirements on station operation and running safety.

Restrictions of Station Site Grade

1. The maximum grade preventing runaway of vehicles parking in the station

In the case of gale, vibration, or collision, vehicles equipped with rolling bearings may run away when being parked in the station site whose grade exceeds that prevents runaway. Tests of China Academy of Railway Sciences (TRAINS) show that the grade preventing runaway of the freight train parking in the station is about 1.6‰. However, the operation practice shows that runaway exists in coupling vehicle in the existing station with the grade of 1.5‰ of station site. Therefore, the grade preventing runaway of passenger train shall be smaller than that of freight train due to the lighter weight and smaller inertia force.

Therefore, the grade preventing runaway of vehicles shall be no more than 1‰.

2. Maximum allowed grade preventing runaway of stopping trains

The train is under braking when parking in the station. Sliding force and braking forces act on a train when it stops in the grade under braking. The grade preventing runaway of the train is then

$$i \leq (B + M \times r_0 \times g) / (M \times g) = b + r_0 (\text{‰})$$

(3.90)

where B is the braking force of train (kN); M is the weight of train (t); r0 is the unit basic resistance of train (N/10t); and b is the unit braking force of train (N/10t).

- No runaway condition of high speed train

Service braking shall be considered when a high-speed train stops in the station, and the corresponding adhesion coefficient is 0.02-0.06. See Table 3.26 for the maximum grade preventing runaway of trains under the different braking adhesion coefficients after analysis and calculation.

Therefore, trains can safely stop on the steep grade due to the high braking performance of high-speed EMUs.

Table 3.26

Maximum Grade Preventing Runaway of a High-Speed Train

Adhesion Coefficient	0.02	0.03	0.04	0.05
imax (‰)	25	35	45	55

- No runaway condition of ordinary medium-speed train

An ordinary medium-speed train implements air braking when stopping in the station with the braking force of . Hence the corresponding maximum no runaway speed is

$$i \leq \frac{1000 \sum K\phi + (P \cdot r'_0 + G i''_0) \times g}{(P + G) \times g} = \frac{1000 \sum K\phi}{10 \times (P + G)} = r_0$$

(3.91)

where P, G is the weight of locomotive and train (t); r_0 is the conversion brake shoe pressure of locomotives (kN); r'_0 is the unit basic resistance of train in coasting (N/10t); and ϕ is the conversion friction coefficient between wheel and brake shoe.

If a 104 type braking system is adopted, the braking force is 330 kN, w_0 is 1.8 at 5 km/h, and conversion friction coefficient is 0.25. As for the axle weight of ordinary medium-speed passenger train, if the locomotive is 20t and vehicles is 17t, then i_{max} is 7.7‰.

The Code for Design of Railway Line suggests that the grade preventing runaway is 6‰ based on comprehensive consideration of various factors.

3. Shunting operation conditions in the station

Many intermediate stations in mixed passenger and freight line involve shunting, uncoupling and coupling operation. According to operation practice in China, station operation safety cannot be ensured in the station on the grade of 6‰, while that can be ensured in a station on the grade of 2.5‰.

4. Station site conditions in railways of other countries

The station site grade is no more than 1.5‰ and no more than 2.5‰ under difficult conditions in the former Soviet Union; 2.5‰ and 10‰ under rare conditions in Germany and the former Czech Republic; and 2.5‰ and 6‰ under rare conditions in Japan. Sweden considers vehicles equipped with rolling bearing, the maximum station site grade is 1.25‰, and grade of 2.5‰ may be adopted under rare conditions.

Design of Station Site Grade

Considering various factors, and according to relevant specifications in China, the design of station site grade shall meet the following requirements.

The station site should be arranged on the near-level grade; otherwise when it has to be arranged on the grade under difficult conditions, generally, the grade should be no more than 1.0‰, to guarantee the safety and convenience of shunting in the station.

Under extremely difficult conditions, the intermediate station in a PDL is allowed to be arranged on the grade with gradient no more than 2.5‰. If it is technically and economically viable, the overtaking station can be arranged on the grade with a gradient no more than 6‰. The passing station and overtaking station in mixed passenger and freight line can be arranged on the grade with a gradient no more than 6‰ to facilitate downgrade parking and upgrade starting. However, the consecutive grades with a gradient of more than 6‰ shall not be arranged for the adjacent two stations. Taking the constant development of industry and agriculture along the line into consideration, the coupling and uncoupling operation may be available at one of these two adjacent stations at least for the convenience of local transport in future.

The station site grade in railways in Taiwan is generally no more than 2‰, and no more than 3‰ at most.

The stations set on grade in the mixed passenger and freight line shall be subject to startup check according to the locomotive type and tonnage rating to determine the grade for starting.

Starting Grade

For the mixed passenger and freight lines, given the train locomotive type and tonnage rating, the maximum starting grade is(max) may be defined as

$$(3.92)$$

where F_s is the starting traction of locomotive (N); r_s is the unit starting resistance of locomotive, taking as 50 N/t for electric and diesel locomotives; and r'_s is the unit starting resistance of freight train, calculated according to Eqs. (2.50) and (2.51).

If there are curves within the starting scope of trains, the conversion grade within the train length which includes curve additional resistance shall be no greater than the maximum starting grade.

If two grade segments are designed in the starting scope of the train, it shall be considered that the average conversion grade within the train length shall be no greater than the maximum starting grade when the train is located at most unfavorable position.

Example 3.6

For the mixed passenger and freight line: $i_{rul}=6‰$, DF4B-type locomotive selected, ($F_s=442.2$ kN, $P=138$ t, $L_{Loc}=21.2$ m), $G=3870$ t, train length=700 m. The plane and profile of a certain passing station are shown in Fig. 3.46. It should be checked whether the freight train installed with rolling bearing can be smoothly started when it is located at the most unfavorable position.

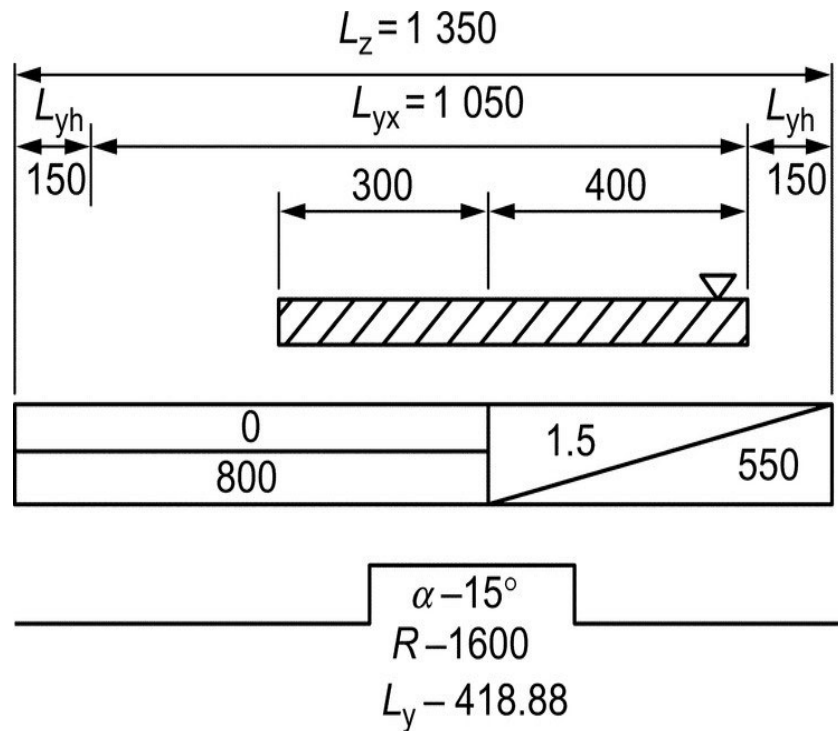


Fig. 3.46 Calculation of starting grade.

Solution

Maximum starting grade $i_q(\max)$ is calculated according to Eq. (3.92):

$$\begin{aligned}
 i_s &= \frac{\lambda_u F_s - (P \times r'_s + G \times r''_s) \times g}{(P + G) \times g} \\
 &= \frac{442200 \times 0.9 - (138 \times 5 - 3870 \times 3.5) \times 10}{(138 + 3870) \times 10} = 6.57(\text{‰})
 \end{aligned}$$

When the train is at the most unfavorable position, the average conversion grade i_j :

$$i_j = \frac{1.5 \times 400}{700} + \frac{10.5 \times 15}{700} = 1.08(\text{‰})$$

As the average conversion grade is less than the maximum starting grade, the train can be started successfully.

3.5.3.2 Grade Segment of Station Site

In general, one grade segment is designed in the scope of station site. In order to reduce the work quantities, the station site may be designed on the different grade segments.

The grade of main line in the turnout at station throat should be equal to the grade of station site. Under extremely difficult conditions, the throat may be arranged on the grade with gradient 2‰ less than limiting grade, this is because the turnout additional resistance at throat is about 2.0 N/kN. However, the grade of district station and passenger station shall be no more than 2.5‰, and that of the intermediate station, passing station and overtaking station shall be no more than 10‰.

3.5.3.3 Passenger Stopping Point

The passenger stopping point in the mixed passenger and freight line are allowed to be arranged on the grade where the passenger train can be started, but the grade shall be no greater than 8‰. Under extremely difficult conditions, the passenger stopping point may be arranged on the grade with a gradient greater than 8‰ if the sufficient technical and economic basis is available.

3.5.4 Plane and Profile Design at Both Ends of Station Site

3.5.4.1 Design Standards

The design standards for the main line at both ends of station in the mixed passenger and freight lines shall refer to the design standards of section line. In special conditions, the station in passenger dedicated lines can be designed as follows:

1. The speed acceleration/deceleration zones at both ends of stations where all high-speed trains dwell may refer to the technical standards corresponding to the running speed.
2. The design speed at both ends of stations where some high-speed trains dwell and pass shall be determined according to landform along the line, environmental protection requirements, parking proportion of high-speed trains in this station and through comprehensively technical and economical comparison, and designed according to relevant speed standards.

3.5.4.2 Setting of Vertical Curve and Transition Curve

The vertical curve shall not be extended into the station site in profile. The distance between the end point of station site and grade change point outside the station site shall be no less than the length of the tangent line of vertical line (TV), as shown in the right part of Fig. 3.47.

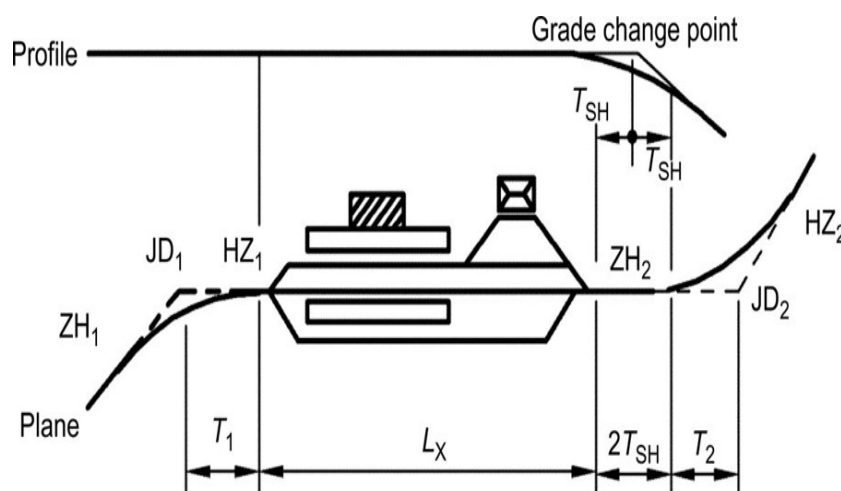


Fig. 3.47 Plane and profile at both ends of station site.

The transition curve shall not be extended into the station site in plane. The distance between the end point of station site and curve intersection point outside the station site shall be no less than the length of the tangent line of curve (T1), as shown in the left part of Fig. 3.47. If the lines at both ends of the station site have curves in plane and vertical curves in profile, it shall be considered that the vertical curve shall not overlap the transition curve, as shown in the right part of Fig. 3.47. The distance between the curve intersection point and the end point of station site shall be no less than $2TV+T2$.

The length of the straight line between the transition curve and the joint in front and rear of turnout in a PDL shall meet the following requirements:

1. Crossover and crossover passenger train connecting lines and other zones linking the turnouts shall meet the requirements in Table 3.25.
2. For the speed-limit zones, such as deceleration/acceleration zones at both end of large stations and the existing railways, the distance between the end points of station site and curve intersection outside the station site shall be less than:

(3.94)

where L is the length of straight line between the starting point of transition curve outside the station and joint in front/rear of turnouts (m); and V is the designed speed in the zone (km/h).

3.5.4.3 Inbound Easy Grade for Starting in Mixed Passenger and Freight Line

As a result of unpunctual arrival, delayed operation in the station, temporary fault of station equipment, busy lines and occupation of throat, the incoming trains are always temporarily parked before the home signal. In order to make the incoming train starts upgrade smoothly after parking, generally, the easy grade for starting will be arranged in front of the home signal. The calculation results show that: the train can be started on the limiting grade in the case of electric traction; while the train is difficult to start on the easy limiting grade in the case of diesel traction. Therefore, as stipulated in the Code for Design of Railway Line, for diesel traction railways whose limiting grade is less than or equal to 6‰, if the grade in front of the home signal of marshaling station, district station, and junction station cannot guarantee the smooth starting of freight train, an easy grade for starting should also be arranged. Except for the stations with complex landform, other stations shall also follow the rule.

The grade of easy grade for starting may be calculated using Eq. (3.92), and its length shall be no shorter than the effective length of long-term arrival and departure track. The home signal is normally arranged at least 50 m to actual point of switch rail of inbound turnout, and the easy grade for starting is located in front of the home signal.

3.5.4.4 Outbound Accelerating Easy Grade in Mixed Passenger and Freight Lines

If there is a long steep grade in front of the station, an easy grade may be designed on the upgrade segment outside the station site in order to facilitate acceleration and shorten the running time, if the landform condition is favorable, and the easy grade is called outbound accelerating easy grade. If the landform is unfavorable, the speed-distance curve shall be plotted to judge whether it reaches the calculated speed when the train tail enters the limiting grade. If it fails, an accelerating grade shall be built to avoid the difficult operation of the train.

Through calculation, the starting traction of diesel locomotive is large, and its calculated speed is relatively lower, generally, it is able to reach the calculated speed of diesel locomotive within the station site, so the accelerating grade is unnecessary. The calculated

speed of power locomotive is high, so the accelerating grade is generally arranged on the limiting grade in front of the station.

3.5.4.5 Coordination of Station Site and Section Profiles

If possible, the station site shall be arranged on the top of convex profile with a gentle grade at both sides as much as possible, for the convenience of inbound deceleration and outbound acceleration. The station site located at the concave profile is not conducive to inbound deceleration and outbound acceleration, or to the operation of the train.

3.6 Line Plans and Profile Details

The line plans and profile are the basic documents in railway design. The line plans comprehensively and clearly reflect the railway plane position and the terrain and its features of the places along the line; the profiles reflect the spatial location and relief of the line. They represent the important design idea of the designers, and play an important role in providing department approval, expert review, construction guidance, and track maintenance for the railway construction projects.

Line plans and profiles with different requirements and uses shall be prepared at different stages of the railway life cycle. To meet course needs, the basic requirements for line plans and profile details, and the data calculation methods in the figures will be introduced in this section.

3.6.1 Classification and Scale

At different stages of the railway life cycle, plans and profiles with different requirements and uses shall be prepared based on different requirements for scale, specific content, and level of specificity.

The line plan and profile miniature map, line scheme plan, line plan and profile shall be prepared for pre-feasibility study and feasibility study. The line scheme plan miniature

map, line scheme plan, and the line plan and profile of the options and major alternatives shall be prepared for the feasibility study of newly built railway. In addition, the line plan and profile of relevant lines such as connecting line and EMU running track shall be prepared for a PDL. The line scheme plan, line plan, and profile details shall be prepared at the preliminary design stage. The line plan, profile details, and layout of modified road and grade crossing (separation) are prepared at the construction drawings design stage.

The line plan and profile miniature map schematically depicts the basic line alignment. The typical scale of a plan is: 1:50,000–1:500,000. The typical scale of a profile is: lateral: 1:50,000–1:500,000; vertical: 1:1000, 1:2000, and 1:5000.

The options and alternatives for important lines, main geological structural lines, and adverse geological range are drawn in the line scheme plan miniature map with a scale of 1:50,000.

The main adverse geology and environmental sensitive areas controlling the line alignment shall be marked in the line scheme plan for pre-feasibility study. The options, schemes for important lines, local line schemes, main geological structural lines and adverse geological range shall be drawn for a feasibility study, and the requirements of water conservancy, city, traffic, and special environmental protection areas on line design shall be marked. The scale of the plan is generally 1:10,000–1:50,000.

The line plan is the major result of line design with different requirements for scale, specific content, and level of specificity at different stages. The options and main

alternatives shall be drawn; the main adverse geology and environmental sensitive areas controlling the line alignment or line scheme shall be marked; the adverse geological range and property shall be given. The plan shall be coherent with stations and hubs. The scale of the plan for pre-feasibility study is 1:10,000–1:50,000, and scales for preliminary design and construction drawings design are 1:2000 or 1:5000.

The profiles of the options and main alternatives shall be prepared for a pre-feasibility study and feasibility study, and the scales of lateral and vertical types are 1:10,000–1:50,000 and 1:500–1:1000, respectively.

The profile details of the design line shall be prepared for preliminary design and construction drawings design; the scale of the lateral type is 1:10,000 and the scale of the vertical type is 1:500 or 1:1000.

3.6.2 Line Plan

A line plan refers to a plan with line plan and relevant data based on a large-scale strip topographic map with preliminary traverse and plane rectangular coordinate (see Fig. 3.48).

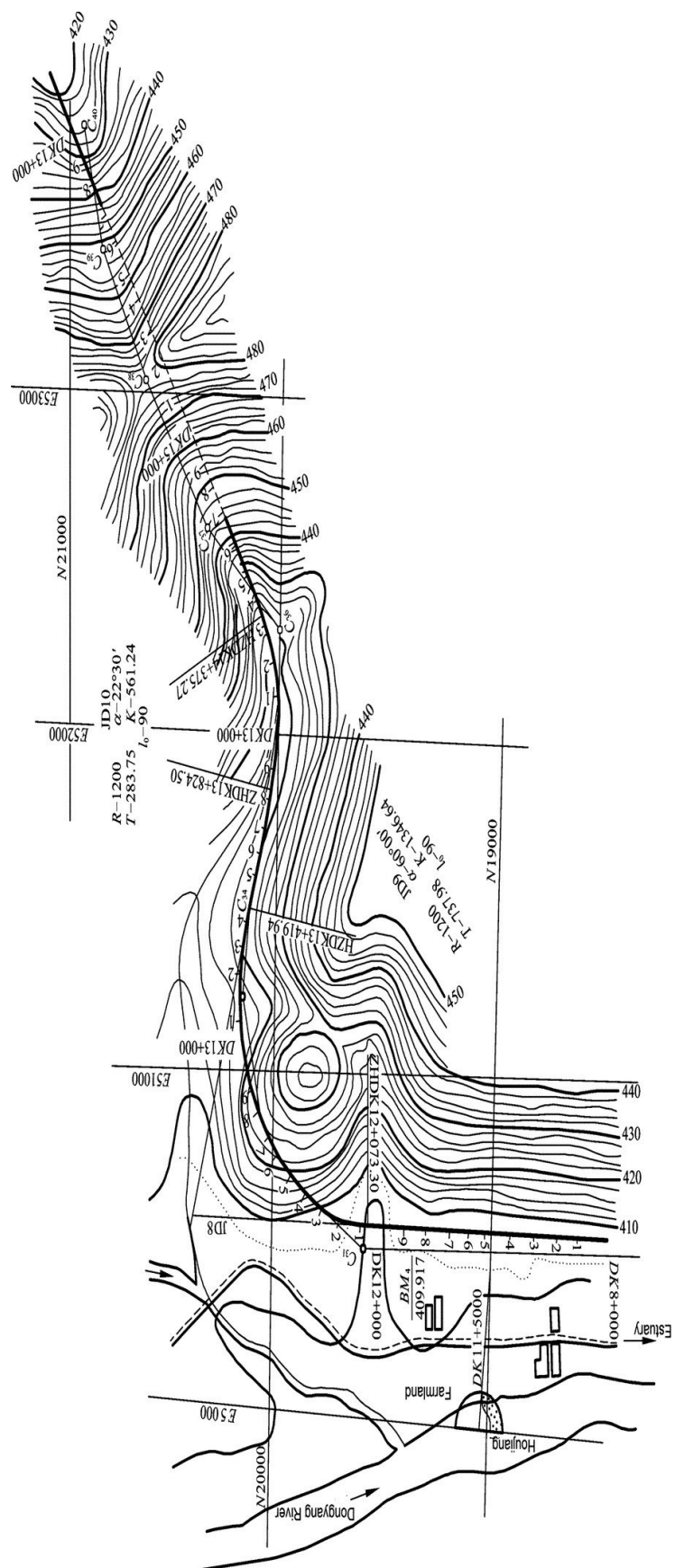


Fig. 3.48 Line plan graph.

3.6.2.1 Plotting of Center Lines

The center lines of the options and main alternatives shall be plotted in the line plan, and preferably on the same drawing. The chainages of the design origin and destination, scheme names, and connection relationship shall be indicated in the drawing. The kilometer posts of the line shall be marked at integer kilometers, the hectometer posts shall be marked between kilometer posts, and the chainage stake numbers shall be marked on the short lines perpendicular to the line. When the chainage increases from left to right or vice versa, the numbers always face towards the left side of the drawing. The codes of different design stages shall be indicated at kilometer posts. A feasibility study is denoted by AK, a preliminary survey CK, and a location survey DK. The kilometers of the remaining stake numbers can be omitted. The relations of broken chainage and broken height at the joint part of two schemes or survey teams shall be indicated in the drawing.

The change in letter orientation of the helical line and switch-back curve shall be still towards the left side of the drawing after the line is developed.

Left and right lines shall be drawn for the new double tracks; the chainage of left line shall be marked, and the relation of origin and destination chainage of the right detouring line, chainage of the detouring line, paragraph numbers and

broken chainage shall be indicated. The distance between centers of design lines shall be marked at change position of distance between track centerlines.

3.6.2.2 Curve Elements and Chainage of Curve Origin and Destination

When the scale of the paper location of line is greater than or equal to 1:10,000, the curve intersection shall be drawn and numbers of intersection point shall be marked. During location survey and setting out, the curve control stakes (origin and destination of the curve) shall be drawn and then numbered. They shall be marked vertically to the center line with symbols and chainage.

The curve elements of new single track shall be marked on the inner side of the curve.

The curve elements of the new double track or reserved second line shall be marked on the left and right lines, respectively. The left line is marked on the left side and the right line is marked on the proper position on the right. Internal broken chainage shall be marked below the curve elements.

The number of a curve shall be indicated at the intersection of curves, and footnotes L or R shall be attached to curve intersection angle, representing left and right intersection angles, respectively. The curve elements shall be marked on the inner side of the curve, parallel to the line. The chainage of the origin TS and destination ST of a curve shall be

marked on the inner side of the curve, perpendicular to the line.

3.6.2.3 Main Buildings Along the Line

Buildings such as stations, large and medium bridges, tunnels, grade crossings, and separation crossings shall be indicated with stipulated legends with chainage, type, and size. In the case of road and riverway diversions, the center lines shall be drawn.

3.6.2.4 Preliminary Traverse and Bench Mark

A preliminary traverse shall be drawn in the plan with traverse point number, chainage, height, and the azimuth angle or direction angle of traverse, shown as the continuous broken line in Fig. 3.48. The traverse point is denoted by C and footnoted by the number. The location, number, and height of bench mark also shall be drawn in the plan.

3.6.3 Profile Details

3.6.3.1 Contents of Profile Details

In the profile details, horizontal direction represents the line length and the vertical direction represents the elevation.

The major technical standards, chainage of the design origin and destinations, chainage of the origin, and destination of the first construction section and the second roundabout section, connection relationship and broken chainage shall be marked on the figure. Height scale shall be drawn at the origin of profile and broken height. Drawings shall be created in the upper part of the figure and the profile bar shall be drawn in the bottom (see Fig. 3.49). The relations of broken chainage and the number, height, and location of benchmark shall be indicated in the figure. Geological graphic symbols shall be better drawn in the profile details.

Major technical standards	
Line level	Level 1
Mainline number	Single line
Limiting grade	6‰
Minimum radius of curve	1200 m
Type of traction	Diesel traction
Type of locomotive	Dongfeng
Effective length of receiving-departure track	650 m
Block mode	Semi-automation

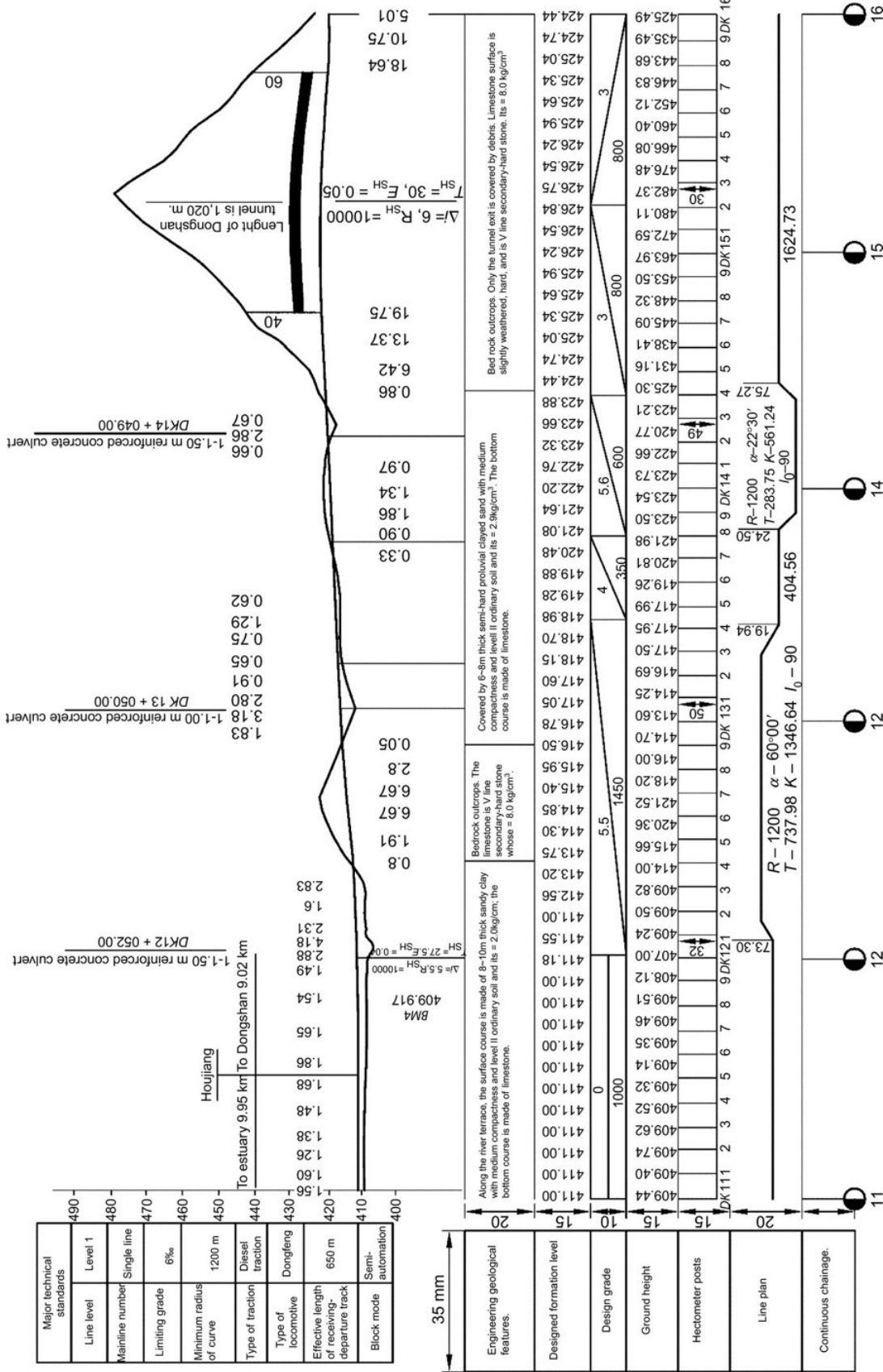


Fig. 3.49 Profile graph.

Profiles of the new double track and new second line shall be drawn in a row from the left line. Profile of the reserved second line shall be drawn in a row from the first line. An auxiliary profile shall be drawn for the roundabout section and the section of unequal height of the two paralleled lines.

3.6.3.2 Profile Column

The contents, formats, and sizes of the profile column shall be determined by the classification of construction projects and design stages. The contents shall be shown at the bottom of the profile, organized from bottom to top as follows:

1. Continuous chainage. The center line of passenger station building in the starting station of the line is usually taken as 0, and the chainage is indicated at integer kilometers.
2. Line plan. This is the schematic diagram of line plane. A line plane curve shall be drawn by convex or concave broken line. Convexness represents a right-turning curve while concaveness represents a left-turning curve. The turning points of convexness and concaveness are, in order, TS, SC, CS, and ST. The distances from the last hectometer post shall be indicated with TS and ST. The curve elements shall be marked on the inner side of the curve. The

horizontal line between two adjacent curves is a straight line, the length of which shall be indicated.

3. Hectometer post and additional post. The hectometer post shall be set after each integer hundred meters, and the distance from the last hectometer post shall be indicated at an additional post.

4. Ground height. This shall be marked at each hectometer post and additional post. The reading of the height on the topographic map shall be accurate to one-tenth of a contour interval. The measured field height shall be accurate to 0.01 m.

5. Design grade. The upward or downward oblique lines represent upgrade or downgrade, and the horizontal line represents level line. The figures above the line represent the value of grade (‰), while those under the line represent the grade segment length (m).

6. Designed formation level. The designed formation level at grade change points, hectometer posts, and additional posts shall be marked in the diagram, with an accuracy of 0.01 m.

7. Engineering geological features. The conditions will briefly be filled in along the line such as serious adverse geological phenomena, main stratum, lithologic features, and hydrogeology.

3.6.3.3 Profile Drawings

The drawing is drawn above the figure, indicating the general picture of the longitudinal profile and the features of buildings along the line. The design grade line and ground line shall be drawn in the drawing (see Fig. 3.49). In the figure, a fine line represents the ground line, while a bold line represents the design grade line.

At the left side of the diagram, the main technical standards of the line shall be indicated.

The distances from the front and rear stations as well as the round trip running time in front and rear sections shall be indicated beside the station symbols.

The names, chain-ages, types, and sizes of main buildings along the line, as well as the locations and data of the broken chain-age posts and benchmark posts, shall be indicated above the design grade line.

Chapter 4

Railway Location

Abstract

In this chapter, the basic principles of railway location are first discussed, followed by line strike. Selection of basic strike of railway lines is the fundamental problem in railway line design. The rationalization of line strike not only directly influences the engineering investment and transport efficiency of the railway project, but also affects the role of designed lines in a railway network. Topographic conditions, especially the average natural ground slopes, exert a tremendous influence on alignment positions and methods for railway location. Engineering geological conditions are also an important basis to decide a line strike and location which determine the stability and economic rationality of the railway buildings. Generally, super major bridges and long tunnels often have influence on partial strike-off alignment of route, while general bridges, culverts, and tunnels which enjoy a large quantity will be laid out according to route. Various environmentally sensitive problems need to be avoided and solved at the early stage of railway survey and design. Finally, adoption of computer-aided railway location and alignment design obviously benefits design quality improvement, manpower and capital saving, and design speed acceleration.

Keywords

Selection of stations; Line strike; Geological conditions;
Computer-aided railway location; Alignment design

The work of railway location is to select the line strike in directions and determine the spatial location of railway lines on the contour map or ground field. Through railway location, the distribution and type of relevant equipment and buildings (e.g., subgrades, bridges, culverts, tunnels, stations, and locomotive depots) can be determined. The reasonableness of alternative route locations will determine highly the capital, material, labor, and land occupation for constructing these equipment and buildings.

4.1 Basic Principles of Railway Location

4.1.1 Natural Conditions Affecting Location of Railway Lines

Natural conditions affecting railway location mainly include the topography, climate, hydrogeology, engineering geology, soil, plants, etc. along the line.

Topography is one of the major factors regarding railway route locations, and also largely affects the mainly technical standards of railway. According to topographic form, relative elevation difference, ground slope, and smoothness along railway line, the terrain can be classified into plains, hills, and mountain regions.

(1) Plain

Plain region features flat terrain without obvious rolling, and natural ground slope is generally within three degrees. Rivers in plain area are straight and wide, and have continuous and wider flat terraces along them. Alignments in plain area are of gently longitudinal gradient or slightly rolling.

(2) Hilly region

Hilly regions are divided into rolling terrain and hilly terrain. Rolling terrain is relatively flat, with natural ground slope less than 20 degrees and relative elevation difference below 100 m. The alternative route locations of designed line are generally not limited by terrain conditions.

Severe-hilly terrain refers to the continuous, undulating hills with deep valleys and high watershed. Natural ground longitudinal slope is generally above 20 degrees. Determinations of plan and profile of the lines are generally limited by terrain conditions.

(3) Mountain terrain

Mountain terrain refers to ridges, steep mountain slopes, cliffs, gorges, canyons, deep gullies, etc. In these areas, landforms are complex and natural ground slopes are mostly above 20 degrees. Most parameters of plans, profiles, and cross-sections would be limited by terrain conditions.

Deep erosion gullies in plateau area, continuous highlands with obvious watershed and the areas with natural ground longitudinal slope more than 20 degrees also fall within the scope of mountains terrain.

Climatic conditions directly or indirectly affect the amount of surface water, underground water level, amount, strength and form of atmospheric precipitation, subgrade water temperature, sludgy period, snow cover in winter, and extended frost period. These conditions restrict construction periods and conditions to some extent.

Hydrologic conditions affect the design of quantity and size of drainage structures. Hydrogeological conditions determine the thickness and location of aquifers, and affect

the possibility for collapse of subgrade or subgrade rock strata.

Geological structure determines the rock stability nearby foundation and subgrade affect the analysis of the possibility for any sliding, falling and collapse. It also affects the degree of difficulty in construction of earth-rock work and the quality of road materials.

Soil is the basic material in subgrade construction, which would affect the shape and size of subgrade as well as structure types.

Vegetation coverage on ground affects storm runoff, degree of soil erosion, and to some extent the hydro-physical and thermo-physical properties of subgrade soil.

All the above natural conditions contact with each other and restrict each other, and are under the process of interaction and changing frequently. Therefore, railway location requires detailed investigations and site surveys, full considerations of natural condition, and future changes of natural conditions and effects of completed railway to ensure solidity and stability of railway lines and smooth traffic in complex natural conditions.

4.1.2 General Principles of Railway Location

The permanent way is the skeleton of a railway; its quality would affect the railway functions and its significance in the railway network. Railway location should involve

comprehensive consideration of politics, economy, and natural conditions, and handle various relationships properly. The route location should be technically feasible, economically rational, and in harmony with the environment.

(1) Coordinate with overall plan of urban, local traffic, farmland and water conservancy and other relevant engineering constructions to make proper arrangements.

(2) In every design stage, it is necessary to study all of the possible alternative route locations deeply and in detail by using various advanced methods, and to optimize location schemes based on multi-scheme demonstration and comparison methods.

(3) The plan and profile should be designed not only to guarantee safe, smooth, and comfortable running, but also to achieve small work quantities, low cost, low operation expenses, and good benefits, and to be advantageous to construction and maintenance of buildings. If there is a small increase in work quantities, higher technical indexes should be used to the greatest extent. Do not use any limiting index or place undue emphasis on high index regardless of project size.

(4) Railway location should be coordinated with farmland capital construction so that the right of way should occupy less fertile farmland and try not to occupy high-yield fields, commercial crop fields, or pass through economic wooden land.

(5) For railways passing through scenic spots, landscape and historical sites, the location should be chosen so as to protect the original natural state. Railway structures should be designed in harmony with the surrounding environment

and landscape, and important historical heritage sites should be treated well.

(6) For a railway location, it is necessary to conduct an in-depth investigation in engineering geology and hydrogeology to make clear their effects on railway engineering. For seriously unfavorable geological road sections such as landslide, collapse, debris flow, karst, and mire, as well as special areas like desert and permafrost, alternative route locations should be studied carefully, and generally these regions should be detoured around. If the lines must pass through such regions, the route should pass through at a proper position, with the passing-through area narrowed and necessary reinforcement engineering measures taken.

(7) The railway location should attach importance to environmental protection, reducing the environment impact and pollution resulting from railway construction and operation.

The above principles apply to the location of all classes of railways. However, in specific implementation, different emphasis should be placed on different classes of railways. For example, high-speed passenger railway lines provide direct and fast traffic service for start, end points and middle important control points, so the following rules should be taken into consideration during location:

(1) For passengers' convenience and trip attraction, the lines should not deviate far from the main direction, and cover major cities along the railway; connecting with secondary towns along the line should use link lines; for railways based on local traffic, within a reasonable range, route location should connect more towns as far as possible.

(2) The location should detour around all unfavorable geologic bodies as required. As for unfavorable geologic bodies that are difficult to detour around, engineering improvement measures shall be taken based on a geological exploration in order to ensure operation safety.

(3) The location and overall design shall consider side slope protection, waterproofing, and drainage in a system-engineering way, in order to optimize the plane and profile of the track and determine the best engineering scheme after comparison.

(4) The subgrade construction shall avoid high filling and deep or long cutting. As for special ground and bad geologic areas, the cutting and filling height of the subgrade shall be strictly limited.

(5) Passenger railway lines shall detour around areas such as those greatly affected by flood or under serious river erosion, or areas with high rainfall, high rainfall intensity, and long rainfall duration. If this is not possible, these areas should be passed through with viaducts or any other proper engineering measures.

4.1.3 Steps and Methods of Railway Location

The railway location is essential in the whole railway survey and design. The location procedure should divide into several stages and complete step by step. Prior to each decision or coordinate decisions, exhaustive comparisons and selection of alternative schemes have to be carried out.

The number of stages of railway location depends on the complicatedness of the natural condition, the availability of information materials, and the local peculiarities. The necessity of working by steps is according to the designed railway. Studying problems shall range from rough to detailed and from the whole to parts. Location work process shall be from large range to narrow strip, then to line, until the specific alignment is determined. Every working step is preceded by and based on full investigations and surveys. These characteristics decide the relationship of field work and office work during railway location: data obtained in field survey and investigation is the basis of office paper location, while the office paper location maps serves as the guide to the field survey work in next stage. After several replications, the route will finally be laid on the ground. Railway location procedures are generally arranged into strike selection, route selection in narrow strip area, and alignments design of the selected route.

(1) Line strike selection

Line strike selection is to determine basic route linking initial and final terminals and major intermediate traffic centers. First, find out various possible alternative route proposals from a larger area on a small scale (1:25000–1:100000) topographical map, by means of collecting relevant data of all possible alternatives, and making preliminary comparing and determining several better route proposals that are valuable to study in detail in next stage. Then, on the basis of thorough field investigations, find out the best route from good proposals by using multiple comparisons and decisions. If the terrain is complex or the study region is very large, location can be carried out by using aerial reconnaissance, photogrammetry or remote sensing data.

(2) Location in strip of land

Once the general location for a route has been determined by fixing the initial and final terminals and any intermediate traffic centers, the detailed study of location is taken up between these control points based principally on a reconnaissance survey. Reconnaissance consists of a rapid study of the location possibilities within a strip of land between the control points. Consideration of a specific route is at first avoided. The strip varying in width from several hundred meters to several kilometers and having the general direction of lines connecting the control points is studied as a whole. Additional control points in the form of mountain passes, ridges, river crossings, minor traffic centers, and valley openings are found. A study of the intervening areas reveals several possible routes. These several routes are then made the subject of an economic study using all the principles and tools that have been stated for location design; a tentative selection is made for a preliminary survey. Railway location in strip of land is generally carried out on a topographical contour map with 1:1000–1:5000 scale. In cases where the duties of the projected line is clear, the natural condition is not complicated and enough detailed maps and materials of information are available, the general route of all possible alternatives can readily be compared and the adopted route may be selected. Otherwise, more than one scheme will be presented for further investigation or left to be decided in the next step, the preliminary design.

(3) Final location

Once a particular route has been selected, the line is designed in detail. The major work is to the plan, profile, and cross-section in detail to determine the alignment according to main technical standards and selected route. In this stage, curves are staked and cross-sections are taken from which earthwork yardages are computed. The

intersection points and the beginning and ending of curves should be carefully referenced so that these can be reestablished during construction.

This chapter introduces in detail the selection of line strike, station distribution, and railway location methods.

4.2 Selection of Line Strike

Selection of basic strike of railway lines is the fundamental problem in railway line design. The rationalization of line strike not only directly influences the engineering investment and transport efficiency of the railway project, but also affects the role of designed line in railway network, that is, the satisfaction with national political, economic, and national defense requirements and long-term projects.

Between the initial and final terminals of designed line, due to differences of city location, resource distribution, distribution of industry and agriculture and natural conditions, there are lots of alternative important cities and towns or traffic centers where the designed lines must pass through, which are called “economic agglomeration points,” “major control points,” or “traffic center points.” A series of tangent lines by linking these control points are alternative line strikes for the designed railway. The series of tangent lines linking the control points determined by railway network planning and national economic planning generally forms the basic line strike. Due to natural conditions, there are different route schemes between two economic agglomeration points. As shown in Fig. 4.1, if linking the initial and final terminals points with cities A, B, and C which must be passed through directly, as the route must go across several large rivers and pass through higher mountains and unfavorable geological sections, the selected scheme would cause more investment, poor quality, and large risk in construction and operation. In order to reduce engineering cost, save operation expenditure and remove hidden troubles, the route should go by favorable locations of

natural conditions, such as sites D and E suitable for constructing super-large bridge or complex bridge, F and G detouring unfavorable geological area and bealocks H and I.

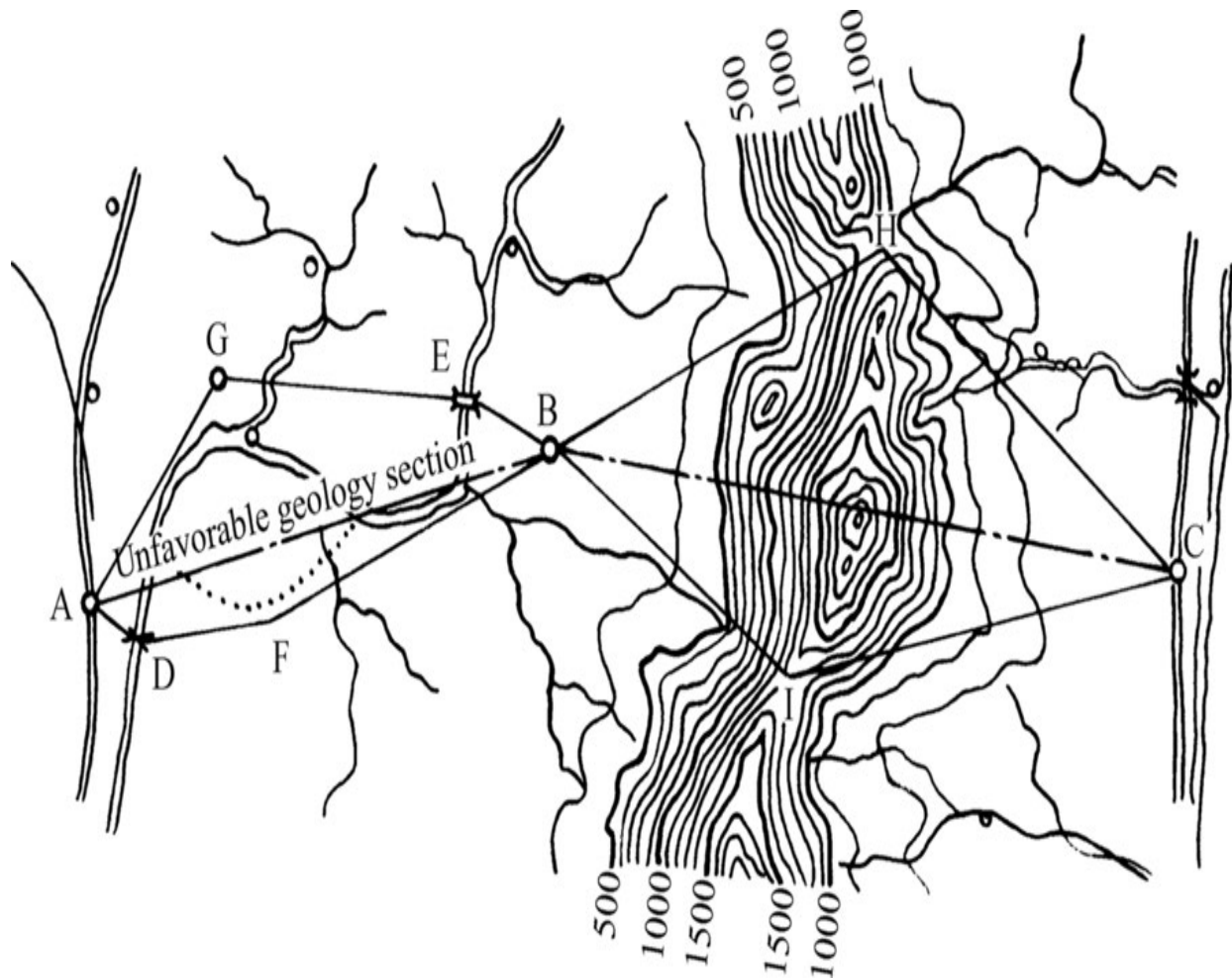


Fig. 4.1 Development of a route.

These points are called minor control points. Hence, there are two alternative routes between major points A and B, namely ADFB and AGE B; also there are two alternative routes between strongpoints B and C, namely BHC and BIC. These routes formed by tangent lines are alternative strike

schemes. One of the basic tasks of railway location is to find out the best route from the alternatives as the basis for further design in the next stage.

4.2.1 Governing Factors in Strike Selection

There are many factors affecting line strike. These are summarized as follows:

(1) Significance of projected railway and cooperation with other construction projects in the traffic catchment areas along the line

The strike of trunk railway shall be laid straight in order to shorten the distance and time of through passenger and freight transportation. The railway connecting the capital city or the economically developed prefecture-level cities should be laid near towns and industrial and mining areas in order to meet requirements for local passenger and freight transportation. The selection of strike shall also coordinate with railroad network planning and other construction projects in traffic catchment areas along the line. According to passenger and freight flow direction, junction stations shall be selected to strive to reduce roundabout transportation; be favorable for introduction of other trunk line and branch lines under planning. The selection of strike should have reasonable connection with other traffic systems in the area, and meet national defense requirements. If the line passes through bigger cities, line strike and stations must be located in harmony with city planning.

(2) Economic benefit and traffic volume requirements of the designed line

The line strike should be selected to provide service for more industrial and mining bases and economic centers. From this point, the railway construction can not only accelerate regional national economic development, but also expand the traffic volume of railways, increase transportation revenue, and obtain higher economic benefits.

(3) Natural conditions

Natural conditions such as terrain, geology, hydrology, and weather decide engineering difficulty and operation quality of railway and have direct influence on selection of line strike. The line strike should manage to detour these areas with bad natural barriers such as seriously unfavorable geological section, water-deficient areas, high-intensity earthquake areas, lofty mountains, and unfavorable gorges.

(4) Main technical standards and construction conditions

The main technical standards of the designed line would influence the selection of strike to a certain extent. If high-power locomotives are used for one transportation task, the profile could employ a bigger maximum gradient to make the line possible to be laid closer to short straight transport direction.

In difficult mountainous areas, construction period and construction technological level have a significant impact on selection of strike, and sometimes even is a governing factors. For example, due to limited construction period and lack of construction technology and experience in extra-long tunnels, the selection of Shamulada tunnel scheme of Chengdu-Kunming Railway had no choice but to construct a

short tunnel and abandon other long-tunnel alternatives with better technical-economic indicators.

The abovementioned factors interact with each other, so only by an overall consideration can we obtain a more ideal railway strike.

4.2.2 General Rules in Selection of Strike

The line strike of the designed railway is a series of tangent lines linking important political and economic center points. The crux of strike selection is to select important control points, i.e., “economic agglomeration points.” As from one economic agglomeration point to another, the route needs to stride over natural barriers such as mountains and rivers. Different terrains and river crossover points will also influence the selection of a line strike.

(I) Influence of economic controlling points

Before determining the traffic catchment area of a railway, it is necessary to conduct a preliminary investigation on political economy, resource distribution, and distribution of industrial and mining enterprises in the area served by the designed line. The investigation scope should be wide enough to provide information for organization and planning of economic investigation. Furthermore, it is required to determine roughly the strike of the designed line and distribution of commerce operation stations from a point of view of technological economy, i.e., so-called economic railway location.

From the point of view of technology and economy, transport characteristics will play an important role to the determination of a line strike. Transport characteristics of the designed line refers to the through transport, local transport, and ratio of passenger and freight traffic. For railway lines transporting mainly with through-trains, the line should be designed short and straight as much as possible, and might not pass through some economic strongpoints in order to reduce transport expenses and time. Railways oriented in local transport shall meet local demands. The line shall pass through all bases for passengers and freights, and route location should connect more towns as far as much as possible. For railways with very large passenger traffic volume, the selection of line strike shall focus on meeting the passenger traffic demand and improving running speed. Railways with large freight volume shall take a level, straight and short route with high operation indicators and low transportation cost. Take the design of Guiyang-Guangzhou Railway as an example. Guiyang-Guangzhou Railway directly attracts three provinces, Guizhou, Guangxi, and Guangdong, and indirectly attracts four provinces and cities of Sichuan, Chongqing, Yunnan, and Hainan. In the traffic catchment area, the land area is $158.8 \times 10^4 \text{ km}^2$ and the total population at the end of 2006 was 343 million. GDP per capital in Guangzhou City is the highest, reaching up to RMB 63,100 Yuan, while it is the lowest in Qiandongnan State, being 3747 Yuan, which is only 5.9% of that of Guangzhou City. Uneven economic level and strong complementarity are main economic characteristics along the line. The construction of this line is planned to complete the road network and construct new passage as appropriate according to the condition on growth of traffic volume in long term. It will also complete Liuzhou-Nanning and Guangzhou-Zhuhai interurban railway in the short term. Guiyang-Guangzhou Railway should pass through Guiyang City, Qiannan Prefecture State, and Qiandongnan State of Guizhou

Province, Liuzhou City, Guilin City and Hezhou City of Guangxi Province and Zhaoqing City, Foshan City, and Guangzhou City of Guangdong Province along the line. The line strike is determined by these economic controlling points, as shown by the Fig. 4.2.



Fig. 4.2 Schematic diagram of line strike proposal of Guiyang-Guangzhou Railway.

(II) Selection of major cities and towns passed through by the railway

Selection and determination of line strike is not only an issue of railway itself, but also a part of regional national economic development. It links to national political, economic, national defense, and cultural centers, and also connects to urban and rural areas, and industrial and mining areas and ports. Therefore, in general, a trunk railway should pass through large cities and towns.

For example, within the range of thousands of kilometers long and more than 200 km wide between Chengdu and Kunming, three schemes of line strike were proposed for Chengdu-Kunming Railway after scheme study and field investigations, as shown in Fig. 4.3.

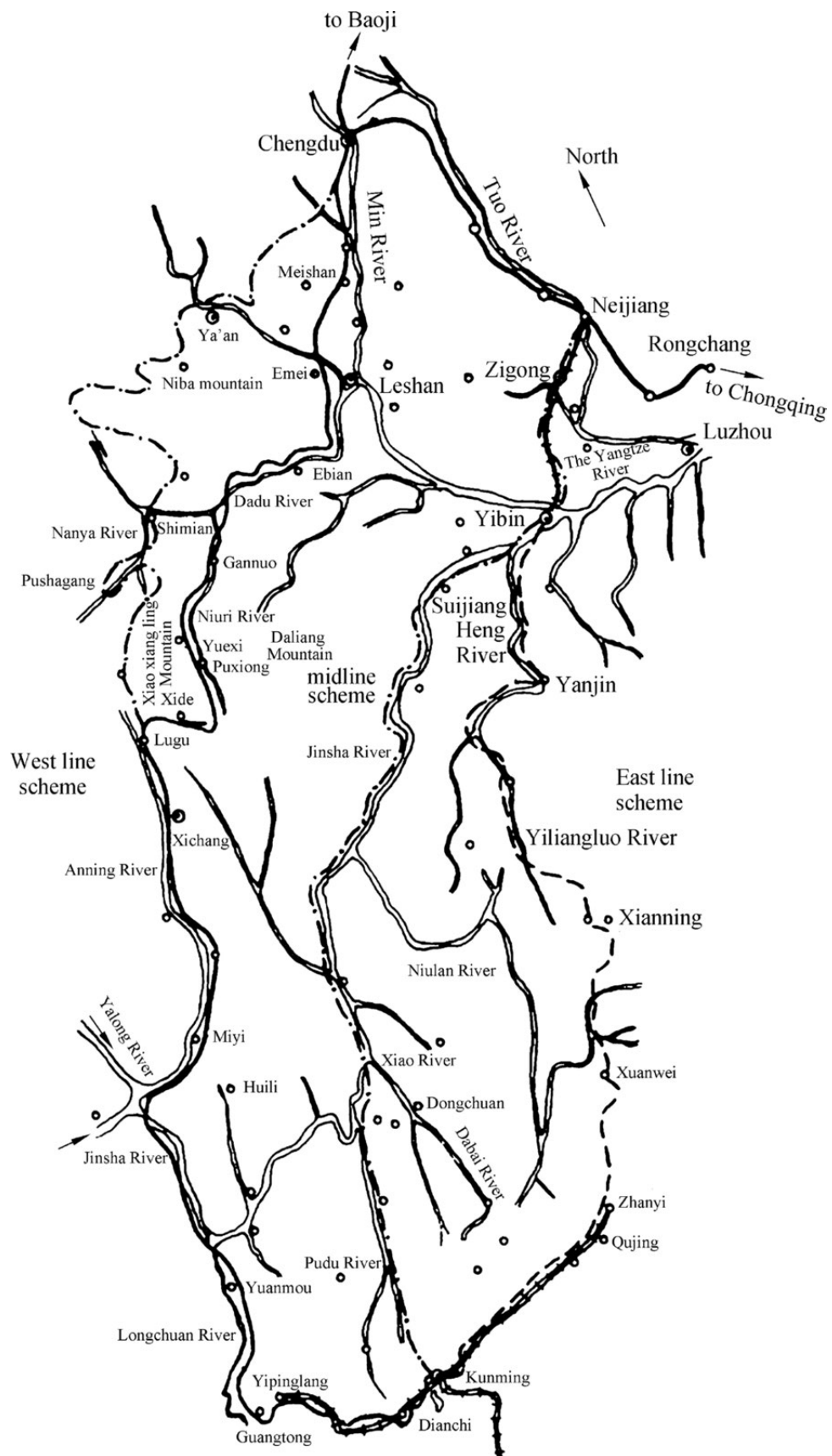


Fig. 4.3 Comprehensive plan of east line, midline and west line schemes of Chengdu-Kunming Railway.

- East line scheme—As junction at Neijiang Station of Chengdu-Chongqing Railway, the line goes through Zigong, Yibin, Yanjin, Yiliang and Weining, crossing Wumeng Mountain and via Xuanwei, Qujing to Kunming, with a total length of 1112 km from Chengdu.
- Midline scheme—As junction at Neijiang Station, the line goes through Kunming via Zigong, Yibin, Suijiang and Qiaojia, along Pudu River to Kunming (upon sketch survey, it passes through Dongchuan and Songming to Kunming, with a total length of 1033 km from Chengdu).
- West line scheme—As junction at Chengdu, the line goes through Meishan, E'mei, E'bian, Puxiong, across Xiaoliangshan, via Xide, Lugu, Xichang, Puba, Miyi, Yuanmou and Guangdong to Kunming, with a total length of 1167 km.

Economic strongholds including Neijiang, Zigong, Yibin, and Dongchuan determined by the east line and midline schemes as two basic line strikes. Main economic and national defense strongholds like Leshan, E'mei, Xichang, and Panzhihua determined west line as another basic strike scheme. In order to meet China's national requirements for construction and development of E'mei, Xichang and Panzhihua, the west line scheme with the most kilometers was selected for the line strike of Chengdu-Kunming Railway.

In addition, in a study of the west line scheme of Chengdu-Kunming Railway, a comparison was conducted between two alternatives of passing through Ya'an and E'mei. Although Ya'an option passes through Ya'an, an important political and economic point in western Sichuan, the passage is far away

from industrial base E'mei and has a longer distance, higher elevation, and greater difficulty in construction. Eventually, this option was abandoned.

Another example is the selection of line strike of Xuzhou-Shanghai section of JingHu high-speed railway. Two line strike proposals for Xuzhou-Nanjing section have been primarily compared: passing through Bengbu proposal (Bengbu proposal) and connecting Xuzhou-Nanjing directly proposal (directly proposal). Comparing with the Bengbu proposal, the direct proposal can shorten the line by 23.8 km, saving investment of about 900 million yuan. However, Bengbu city has more than 8 million incoming and outward passengers per year, and an expected annual traffic volume of 18 million passengers. Its incoming and outward passenger flow on the direction connecting to Shuijiahu reaches more than 5 million per year. Two proposals have been worked out for the direction in Nanjing-Shanghai section: existing Zhengjiang Railway Station proposal (proposal A) and 12 km away from Zhenjiang proposal (proposal B). Although proposal A is 5.9 km longer and over 200 million yuan more than proposal B, Zhenjiang Station expects to realize an annual incoming and outward volume of 20 million passengers per year. On considering the role and function in the road network, Bengbu and Zhenjiang are two important cities. Bengbu is an important gateway for northeastern Anhui, and would departure high- and medium-speed passenger cars to Hefei, provincial capital, and other cities in Anhui. Zhenjiang plays a role in extending passenger flow attraction to Yangzhou and other places. Although these two cities are not in the short and straight line directions, Beijing-Shanghai High-speed Railway still treats them as important cities and has high-speed stations established in these two cities. Therefore, from an economic point of view, the Bengbu proposal and existing Zhengjiang Railway Station proposal

were employed for Xuzhou-Shanghai section as the through proposal.

For the line strike of Tianjin-Ji'nan Section of Beijing-Shanghai High-speed Railway, two different proposals are worked out due to different geographic locations of economic strongholds Linyi and Dezhou (see Fig. 4.4). The Linyi proposal features a shorter and straighter line, better plane conditions, across fewer existing railways and highways, less bridge works and construction difficulties, and an investment reduction of about 1.4 billion yuan. However, as the line does not pass through a major passenger flow collection and distribution center, Dezhou, conditions for attracting passenger flow are poor. Although the line is 20.891 km longer than the straight-line scheme, across more railways and high-class highways, and very difficult in construction, Dezhou proposal passes through Dezhou city and areas near Tianjin-Pukou Railway. It is favorable for passenger flow attraction and economic development of Dezhou and other cities. It is expected that the Dezhou proposal will attract more passenger flow in one way, 480,000 passengers by 2015, and 5.1 million passengers by 2020. The route location conforms to Dezhou urban planning and facilitates passenger transfer and city economic development. Therefore, the Dezhou proposal is recommended.

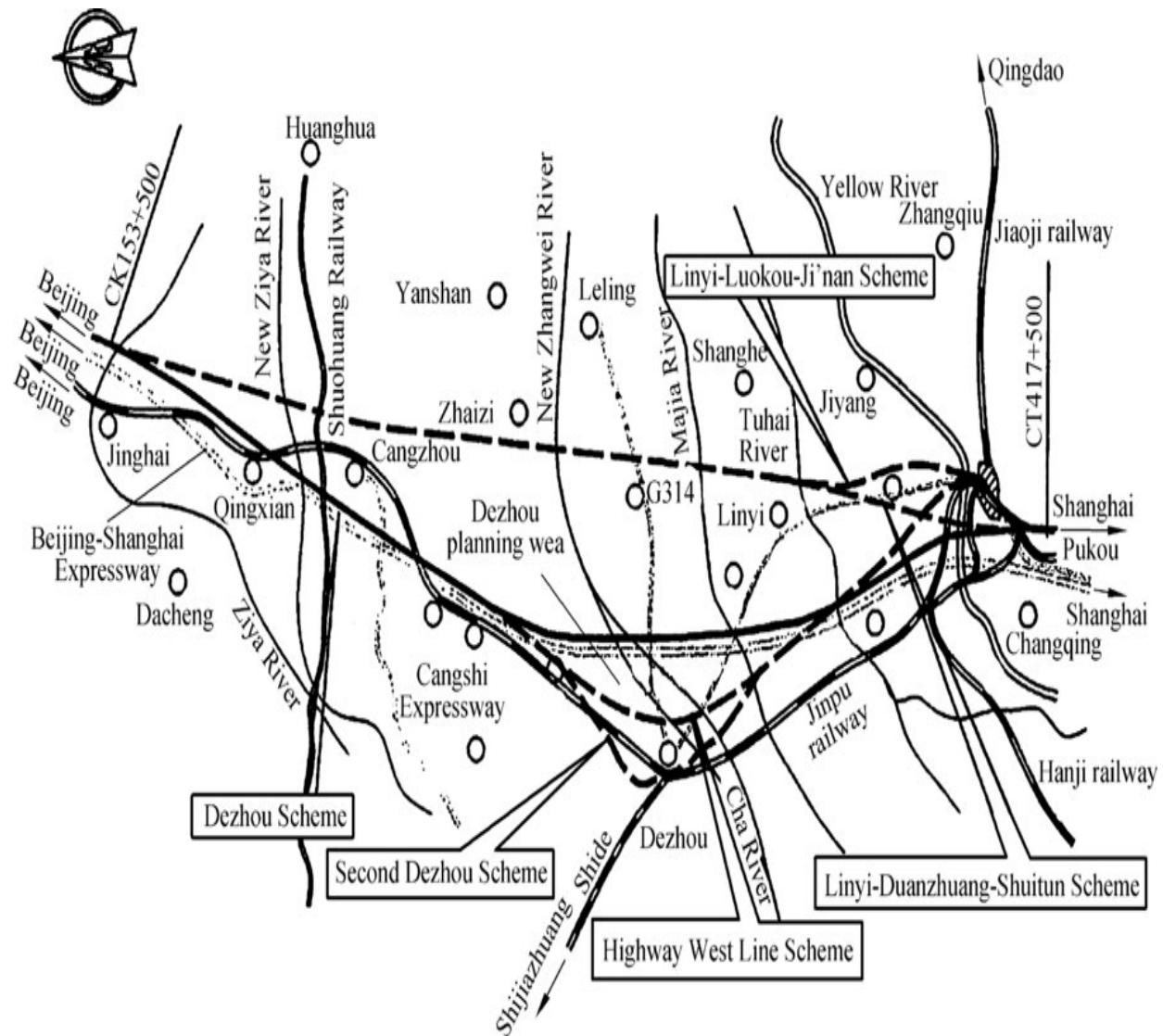


Fig. 4.4 Sketch map of route of Linyi Luokou line of Beijing-Shanghai High-speed Railway.

(III) Locational industrial and mining enterprises

If there are large industrial and mining enterprises in the traffic catchment area of the designed line, how to link various industrial and mining enterprise strongpoints reasonably and make them combine with railway transportation is also an important factor for selecting a line

strike. Take Chengdu-Kunming Railway as an example, where development of copper mines in Dongchuan in the 1950s decided the selection of a midline scheme. It was recognized that the midline scheme was shortest, smallest engineering quantities, and favorable for copper mine development in Dongchuan. It was recommended although the survey found that engineering cost would increase significantly, as both sides of Jinsha River were in unfavorable geological conditions. Later, according to national economic development, the copper mine construction in Dongchuan stopped, and at the same time, Xichang Satellite Launch Center and Panzhihua iron and steel base were proposed. With these economic reasons, the midline scheme could not adapt the development of main resources including coal and industrial distribution planning. Despite longer construction mileage, higher cost, and more difficult works, the west line scheme would pass through areas with rich mineral resources, meet requirements for iron and steel base and industrial distribution and feature more economic strongpoints and wide attraction scope. The line would also pass through ethnic minority areas, have proper geological location and facilitate trunk and feeder railways access to play a key role in road network. Therefore, the west line scheme was employed.

For another example, Suzhou in Xuzhou-Guzhen section of Beijing-Shanghai railway is a coal city. From Xuzhou to Guzhen, The scheme rounding Suzhou is about 12 km longer than the straight-line scheme. Beijing-Shanghai Railway rounds Suzhou County and sets Suzhou Station, which is of great importance in local industrial and resource development. The local government has urged that Beijing-Shanghai High-speed Railway should pass through this county and set a high-speed station. However, Beijing-Shanghai High-speed Railway is a passenger-oriented railway. Considering the small passenger flow and

development space in Suzhou and comparison of advantages and disadvantages in engineering economy, the Xuzhou-Guzhen straight-line scheme is employed for Beijing-Shanghai High-speed Railway, instead of the Suzhou scheme.

(IV) Selection of traffic corridor

In economic developed areas where urban construction has been established, various artificial structures are dense and traffic facilities crisscross. A line strike of railway should comply with urban development planning and should be laid along traffic corridors as much as possible in order to share space with other traffic facilities and reduce house demolition and land requisition. In developed areas, several traffic corridors have been formed or planned between central cities. The selection of traffic corridor shall be coordinated with station distribution, leading in control points and road network linking. For example, in railway location of Shanghai-Hangzhou intercity railway, traffic corridors having been formed and planned between Shanghai and Hangzhou include Shanghai-Suzhou-Zhejiang-Anhui Expressway, Shanghai-Jiaxing-Huzhou-Hangzhou Expressway, Shanghai-Hangzhou Expressway, existing Shanghai-Hangzhou railway, National Road 320, and Hangzhou-Pudong Expressway. See Fig. 4.5 for the sketch map of the Shanghai-Hangzhou traffic corridors. If the newly built station of the intercity railway is laid in Shanghai South Station, the straightest route is along Shanghai-Hangzhou Expressway and existing Shanghai-Hangzhou Railway corridor. On considering Shanghai Integrated Transport Hub is established at Hongqiao and Shanghai Hongqiao Airport becomes an essential point of the intercity railway, the route going along Shanghai-Suzhou-Zhejiang-Anhui Expressway and Shanghai-Jiaxing-Huzhou-Hangzhou Expressway

corridors should be compared in the study with the Shanghai lead in route proposal.

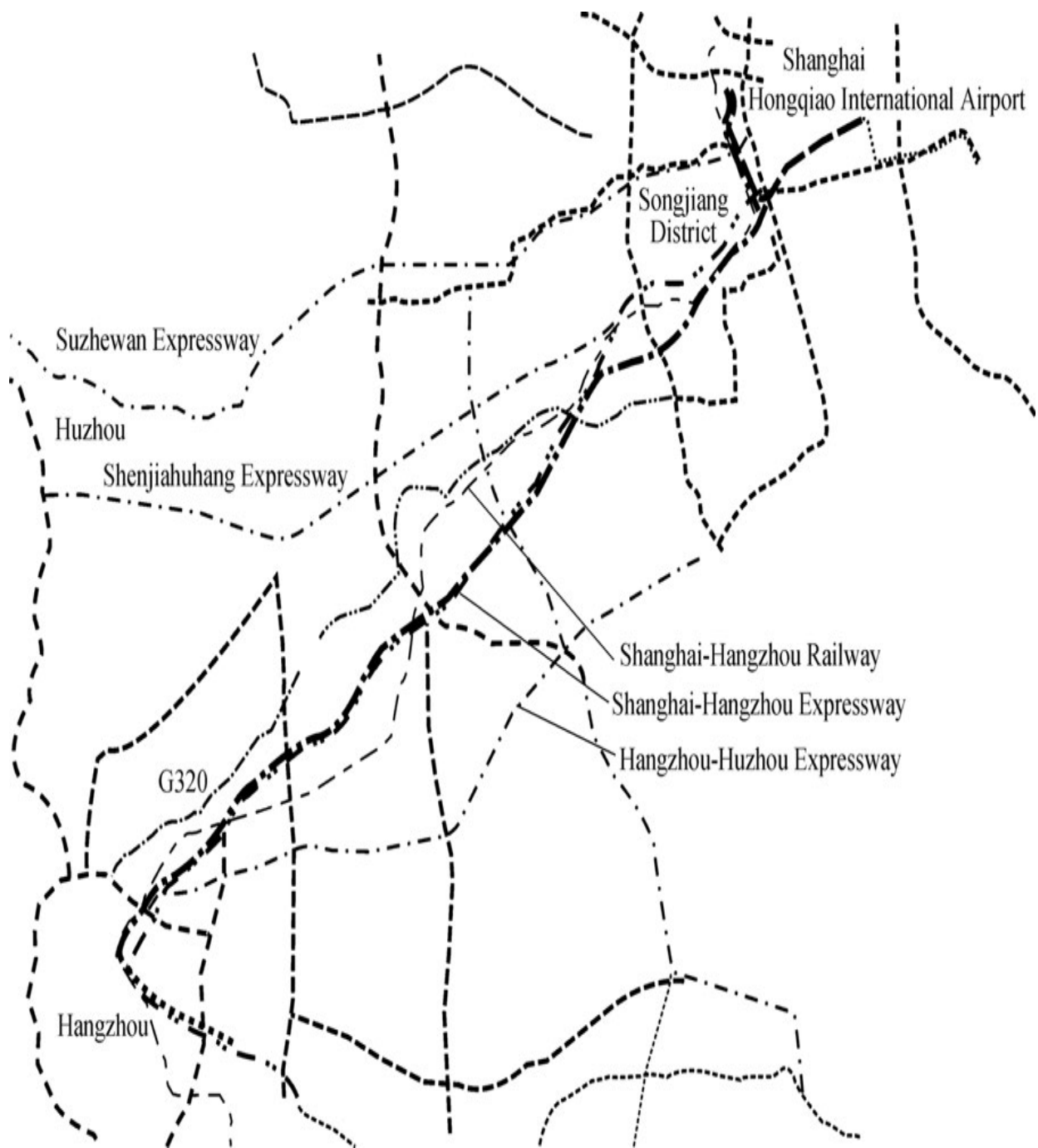


Fig. 4.5 Sketch map of Shanghai-Hangzhou traffic corridor.

(V) Influence of location of intermediate stations

There are many intermediate stations between start and end points and important strongholds of the designed line. The selection of intermediate station sites tends to be an important factor affecting regional proposal of a line strike.

For example, separating from Chengdu-Chongqing Railway in Chengdu Station, Chengdu-Kunming Railway could go through directly Qinglongchang via Chengdong industrial zone, but in order to set Chengdu South Station, the line rounded South Chengdu. Despite some line extensions, the line is favorable for industrial construction and passenger and freight transportation. For another example of Kunming terminal of Chengdu-Kunming Railway, preliminary survey line was from Yangfang'ao, along the hillside via north of the city to Bijiguan. In order avoid preventing relation and development of downtown and industrial zone, the line changed to go through south of the city and pass through downtown via Dian lake in Yunnan Province. The changed proposal solved problems of soft soil subgrade passing through Dian Lake, and met requirements of urban planning and industrial layout.

Site selection of intermediate stations of high-speed railways has obvious impacts on line strike. Intermediate stations of high-speed railways are widely distributed and attract large passenger flow along the line, and are important windows for high-speed railway to serve the local residents, passengers, and local economic construction. They are economic strongholds along the line and also control points for railway location of high-speed railways. In order to facilitate

attracting passenger flow, a high-speed passenger transport line is usually laid along the city. In general, station sites proposals are first determined, and then select specific line strikes between stations.

Specific location of an intermediate station should consider many factors such as passenger flow attraction, engineering conditions, and urban development. It is necessary to work out with comparison of alternative proposals. Station site proposals could affect the line strike and even the selection of line standards. For example, there are seven intermediate stations in Xuzhou-Shanghai Section of Beijing-Shanghai High-speed Railway, namely, Zhenjiang, Changzhou, Wuxi, Suzhou, Kunshan, Suzhou and Chuzhou. As each station has several site alternatives, tangent lines by linking these station site proposals form multiple alternative line strikes. Fig. 4.6 is a sketch map of site proposals of Zhenjiang Station of Beijing-Shanghai High-speed Railway. Zhenjiang City is located in the region along the south bank of Yangtze River. Existing Nanjing-Shanghai Railway has Zhenjiang Station. In order to provide convenience for passengers in Zhenjiang and Yangzhou regions, the high-speed station site shall be as near the downtown area as possible and shall be designed to reduce rounding length of the high-speed railway and decrease investment. Five station site proposals have been made successively and studies on proposals 1-3 have been investigated with similar precision.

As shown in Fig. 4.6, proposal 1 is located 6 km to the south of Zhenjiang; proposal 2 is located 1.6 km to the south of Zhenjiang; and proposal 3 is Zhenjiang Station of the existing railway. Proposal 1 is straight, involves less demolition, and can save over 170 million yuan in engineering investment, but the high-speed railway is far away from downtown and infrastructure should be built to adapt the station, causing an increase in urban construction

investment. Proposal 3 passes through the existing Zhenjiang Station, is convenient in passenger transfer, but it is hard to rebuilt existing facilities. Near the existing Zhenjiang Station, Proposal 2 provides convenience for passenger transfer and sound supporting facilities, and is an ideal station site. However, since the line location has been occupied by urban road construction, the proposal is infeasible. Therefore, Proposal 1 is recommended as the best option.

In short, selection of a line strike maintains a very close relationship with the distribution and site selection of railway stations. The railway location procedure shall integrate selection of line strike with location of intermediate station, reasonable proposals for intermediate station distribution, and station site selection should be determined after multi-factor comparison.

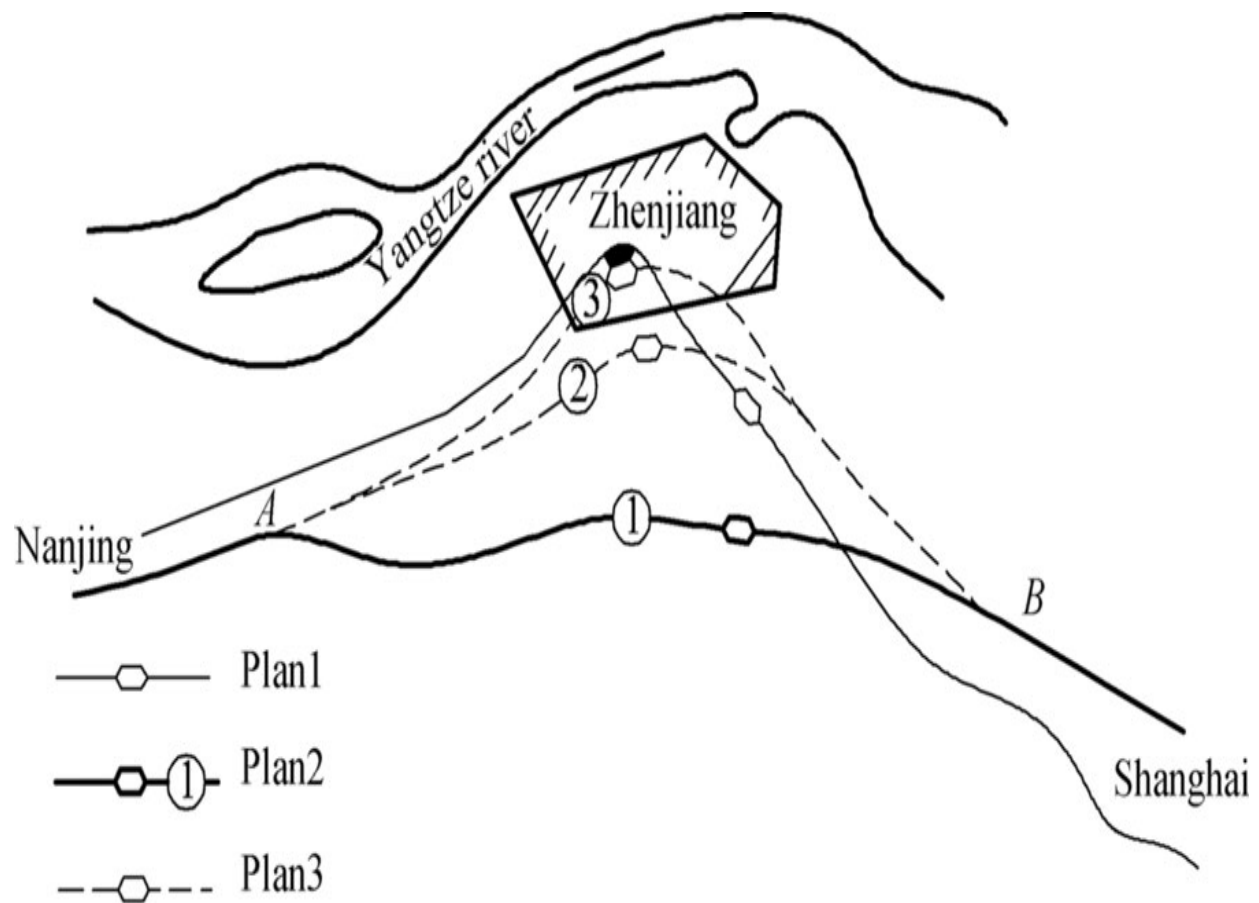


Fig. 4.6 Sketch map of site proposals of Zhenjiang High-speed Station of Beijing-Shanghai High-speed Railway.

(VI) Location of large and complicated bridge sites

Large and complicated bridge sites should, in principle, be located in river reaches with straight channel, stable river bed, less erosion and deposit, fewer shallows, and better geology. The route should cross the river at a perpendicular angle. These bridge sites become often control points of the line. Line alignment should generally meet requirements of these control engineering. For example, the lead-in Jinan terminal proposal of Beijing-Shanghai High-speed Railway is mainly controlled by the Yellow River Bridge location and

high-speed station location. According to comprehensive analysis of governing factors, there are two favorable bridge site proposals. One is a new Yellow River Bridge in Wangjiazhuang between Caojiajuan Yellow River Bridge and Luokou Bridge, together with a new high-speed station. The corresponding route scheme is called the west scheme. The other is a new Yellow River Bridge to be built 80 m in the upstream of Luokou Bridge in the existing Ji'nan railway station. The corresponding route scheme is called the east scheme, as shown in Fig. 4.7. According to comprehensive analysis and comparison of line, engineering, operation, and planning adaptability of two schemes, the east scheme is longer, involves greater engineering investment than west scheme, and its construction gives more serious interference on operation. Despite the convenience in passenger transfer, the advantage is not obvious. Except for unfavorable transfer for passengers, the west scheme is better in other aspects. Moreover, the west scheme is in better harmony with urban planning. Therefore, the west scheme is employed.

For another example, there are two proposals for bridge site across Yangtze River in Nanjing for Beijing-Shanghai High-speed Railway, namely, Shangyuanmen and Dashengguan. Two proposals connect to economic strongholds Zhenjiang and Danyang in the south bank of Yangtze River to form about ten detailed route alternatives, as shown in Fig. 4.8. In railway location, technical and economic comparison should be worked out among proposals in order to select a favorable one.

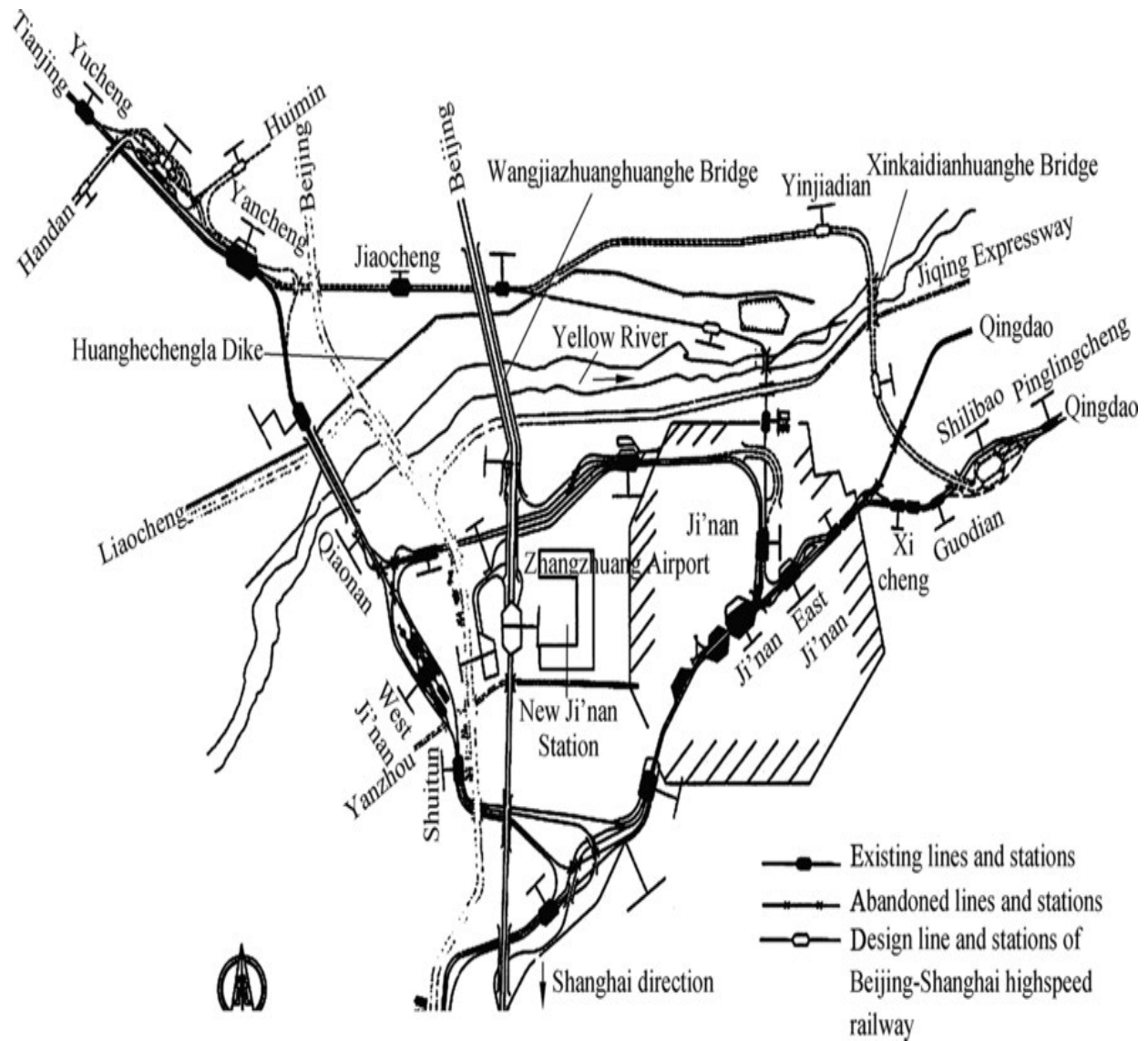


Fig. 4.7 Influence of Yellow River Bridge location in Ji'nan hub on route plan of Beijing-Shanghai High-speed Railway.

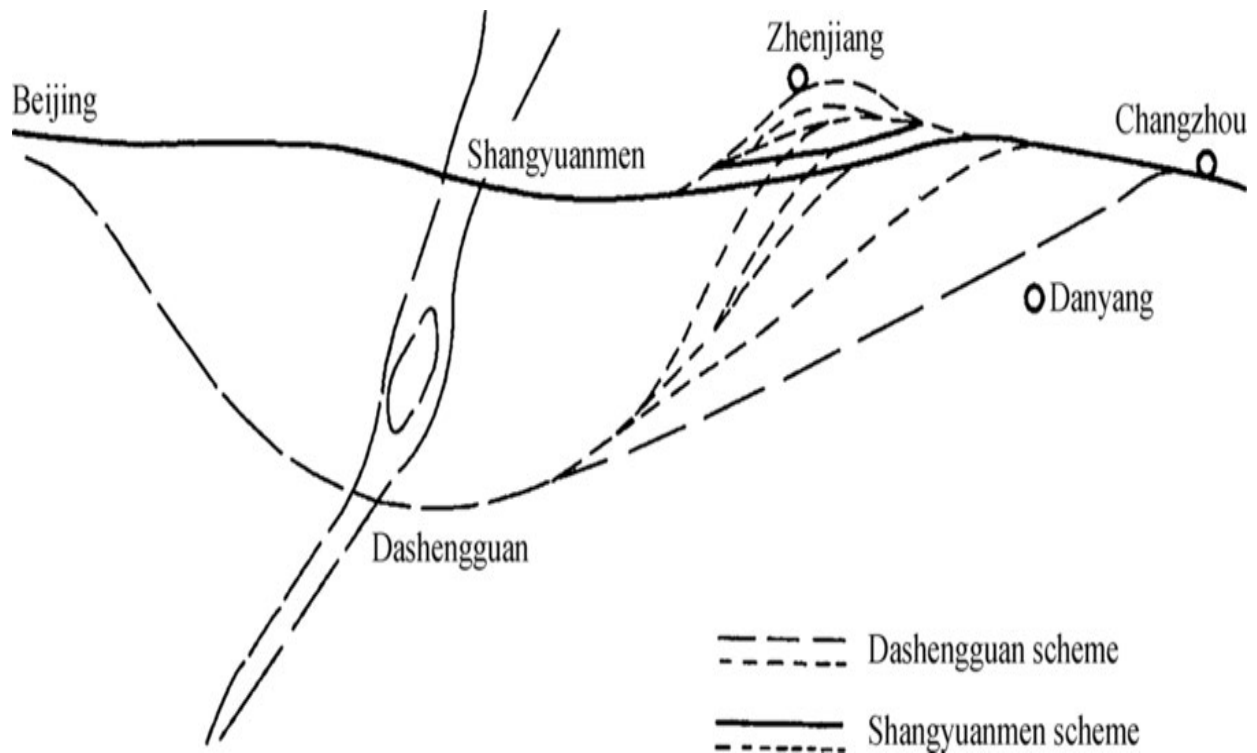


Fig. 4.8 Sketch map of relationship between the bridge site in Nanjing where the Beijing-Shanghai High-speed Railway crossing Yangtze River and the route.

(VII) Railway location along rivers and across mountains

Mountain railway generally crosses over watershed from one river basin to another river basin, therefore selection of crossing pass of mountain and river valley selection are two important parts of mountain railway location. Between major strongholds of basic strike, different crossing pass of mountain always cause difference of specific route. In railway location, regional line strike between major control points shall be determined after the same-precision comparison to all possible puertos and river valleys. Knowledge of railway location over mountain areas is described in Section 4.6 of this chapter.

(VIII) Influence of geological conditions

A line strike closely relates to geological conditions along the line. As China is a vast country, there are different geological conditions in different areas. The line shall detour seriously unfavorable geological areas such as landslide, rocks, collapse, and mudslide. If it is difficult in detouring or passing-through is more reasonable than detouring, measures shall be taken for solving completely unfavorable geological problems without hidden danger. However, the treatment of geological diseases would necessarily greatly increase engineering cost. Railway location methods for complex geological regionals are described in Section 4.7 of this chapter.

4.3 Distribution and Position Selection of Stations

Stations are boundaries with additional tracks besides main line. As demarcation points (train spacing points), stations (or block posts) divided a railway line into several intervals. Single track railways take the central line of a home signal mast at station as the boundary between station and section. Double track railways take the central line of home signal mast or station limit sign at station as the boundary between station and section for each track, respectively. In order to improve the carrying capacity of section, a station section is divided into several block sections and takes the block signal masts as boundaries at the same direction.

Station is a basic production unit in the railway transportation, and various technical equipment relating to transportation is concentrated there. With regard to different operation contents and natures, stations in mixed passenger and freight railway are divided into passing station, overtaking station, intermediate station, district station, and marshalling yard. High-speed railway stations are divided into overtaking station, intermediate station, and starting station. Intermediate station of passenger line can be divided into large, medium, and small station according to the passenger throughput.

Complying with the transportation requirement, distribution, and positions of stations shall be determined after comprehensively comparing with factors including topographical and geological conditions, difficulty degree of engineering; conditions for other tracks connecting, and whether it is convenient for local passenger and freight transportation.

4.3.1 Distribution of Stations

4.3.1.1 Basic Principle of Distribution of Stations

To ensure a railway has enough carrying capacity, can carry out necessary technical work and handle passenger and freight service, stations must be reasonably distributed.

To ensure sufficient carrying capacity, a railway line is divided into several sections. Fig. 4.9 is a diagram of station section in a single-track railway section, with home signals as train spacing point of sections.

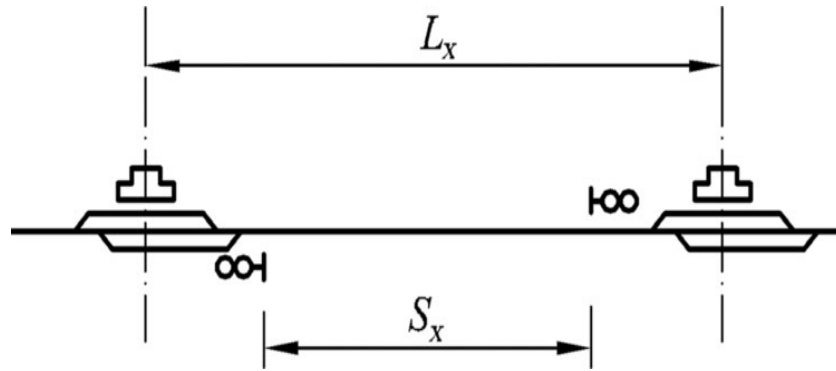


Fig. 4.9 Station-to-station section diagram.

Distribution of stations has close relationship with regional passenger and freight transportation service and national economic development. Stations (especially large station above district station) enjoy large quantity of work and too many personnel, with dense equipment and buildings, which requires large investment and large area of land and is hard to remove after construction.

Distribution of station, one of the key problems of railway location, should be organically combined with railway location. In railway line for mixed passenger and freight traffic: firstly distribute district stations together with the design of locomotive routing; then combining the paper location of line, distribute generally intermediate station, passing station or overtaking station to meet the required carrying capacity. In railway line for passenger traffic: firstly distribute the large station according to the distribution of cities along the line, and then distribute medium and small station together with the route location. In a word, only when the distribution of stations is combined with the selection of route, a better scheme with desirable route location and suitable distribution of stations can be achieved.

4.3.1.2 Distribution of District Station for Mixed Passenger and Freight Railway

A district station is an important technical operation station of mixed passenger and freight railway. Distribution of district station has great influence on the line strike, engineering, and operation conditions, especially the operation efficiency of the locomotive. Therefore, several distribution schemes must be made by integrating the design of routing. The station distribution proposals should be compared and studied, combining with the requirement of the local government, demand to motivate local economic development, smoothness and straightness of the railway line, engineering status, adaptation of environmental sensibility area, as well as geological conditions, etc., based on the review comments of the feasibility study and the review comments of proposal optimization and adjustment. Major factors influencing the distribution of district stations:

(1) District station shall be laid out together with the selection of junction station, employing the basic depot of the existing line as shown in Fig. 4.10A and B or the newly

built basic depot of the design line and turning back at the district station of the existing line as shown in Fig. 4.10C and D. It shall be determined after comparing with per the traffic flow, the load of the locomotive depot of the existing line and the reconstruction conditions.

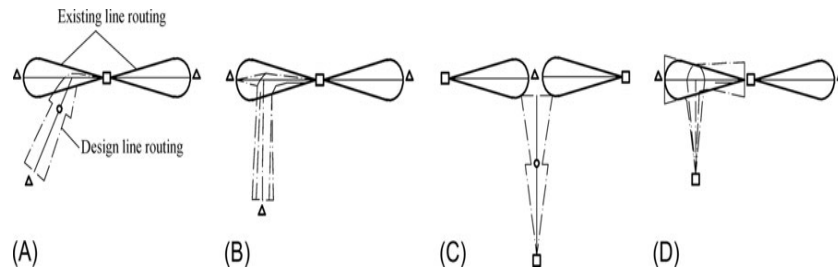


Fig. 4.10 Schematic diagram for routings and district station layout in various track junctions.

(2) District station should be closed to large cities, larger towns and industrial and mining enterprises to meet the requirements for collection and distribution of passenger and freight flow and improve the production and living conditions of the railway personnel. Position of station shall be planned in accordance with the development planning of the city and town.

(3) District station shall be located in the place with plain terrain and good geological condition, with less farmland occupation, convenient for treatment of “waste gas, waste water and waste residue” and with convenient water source and power supply.

(4) To reduce investment in train reorganization equipment and complete assisting vehicle equipment, it is suitable to set up district stations at train transfer places and assisting locatives pick-up places.

4.3.1.3 Distribution of Multiple Unit Train Depots Workshop in Line for Passenger Traffic

A multiple unit train depot workshop in lines for passenger traffic is usually located at a high-speed train departure station. Therefore, distribution of multiple unit train depot workshop is essentially the distribution of high-speed train initial station and terminal station. Distribution of multiple unit train depot (workshop) shall comply with the following principles:

(1) Multiple unit train depot workshop shall be distributed combining with railway network planning and city layout along line, as well as a high-speed train departure station. At the start station and terminal station of a high-speed passenger dedicated line, multiple unit train depot shall be laid out, while at a large railway junction terminal, large intermediate station in municipality and provincial capital city, and distributable motor train maintenance station or operation station, inspection and service point shall be laid out. For

example, Beijing Station and Shanghai Station are the initial stations of Beijing-Shanghai High-speed Railway, and Tianjin Station, Ji'nan Station, and Nanjing Station are intermediate stations with high-speed trains originating and terminating there.

- (2) Distribution of multiple unit train depot workshops shall combine with train operating plan and train traction power analysis calculation, in favor of circulation operation of multiple unit train.
- (3) Distribution of multiple unit train depot workshops shall be made in accordance with the requirement of the transportation organization as well as the parking condition of multiple unit train in the high-speed station at night.

4.3.2 Distribution of Intermediate Station, Passing Station, or Overtaking Station

4.3.2.1 Mixed Passenger and Freight Railway

To distribute the passing station, overtaking station and intermediate station on the mixed passenger-freight railway is to meet the desired carrying capacity of railway and serve the passenger and freight transportation of urban and rural along the line. Such kinds of stations are not large scale but with large quantities. Their arrangements exert great impacts on the railway operation, project investment, and industrial and agricultural output as well as the residents' material and cultural lives along the line. Distribution of those stations should cover the following major points:

- (1) It is necessary to meet the national requirements of the annual traffic capacity and number of train pairs.
- (2) The passing station and overtaking station shall be distributed according to the running-time standards of freight trains required by carrying capacity. Namely, the designed carrying capacity N shall be larger than the demanded one. The station distribution of a newly built double-track railway shall apply different standards according to the various categories of trains, pairs of passenger trains and running speeds. As specified in the Code for Design of Railway Line, the station-to-station running time of freight train in single direction shall not exceed the values listed in Table 4.1.

In case it is hard to satisfy the requirements in the above table, the running time of freight trains between some individual stations can be 1-2 min longer than the specified values.

Table 4.1

Station-to-Station Running Time of Freight Train in Single Direction on Newly Built Double-Track Railway

Designed Running Speed of Passenger Train on One Section of Railway (km/h)	160	140	≤120
Number of passenger train pairs (pair/d)	—	≤30	>30
Type of locomotive	Electrical	20	25
Diesel	25	40	35

(3) The intermediate station for passengers and freight transportation shall be properly distributed as per the average daily volume and in combination with other transport ways in local areas, and in coordination with the urban or regional program. In particular, the intermediate station with technical working shall comply with the technical operation requirements, if any.

The back and forth running time of section adjacent to technical working station in single-track railway shall be shorter than the maximum back and forth running time from station to station. The regulations are specified as follows:

① Running time between the sections adjacent to district stations shall be reduced by 4 min, respectively.

② In other technical stations, if the carrying capacity from station to station is influenced by the technical operation time, and such influence cannot be eliminated easily in the future. The station-to-station running time therefore needs to be reduced as required.

(4) The balance of station-to-station carrying capacity shall be taken into consideration, as is expressed in factor j as follows:

$$j = \sum_{i=1}^n \frac{T_i}{nT_{\max}}$$

where n is the number of stations; T_i is the period in the train diagram of interstation i (min); and $T_{\max}$ is the period in the train diagram between control stations (min).

(5) Topographical, geological, hydrographic, and railway operation conditions shall be taken in to consideration.

(6) For some sections of the newly built single-track railway, if it may cause a large amount of work to lay out the station, the double-track railway can be designed to extend the interstation distance based on the comparison of engineering economy, so as to reduce the amount of work.

(7) Double-track standard is better for the distribution of stations, if the newly built railway is proposed to be double-track in long-term and single-track in the short term. In the case of single-track in the short term not being able to meet the carrying capacity, passing stations shall be added and other provisional measures shall be adopted. If the technical and economic data are available, the stations shall be distributed based on the requirements of single-track volume in the short term. Regardless, the provisional measures shall be taken to accommodate both short and long terms so as to decrease quantities of abandoned construction works.

(8) Minimal interstation distance of newly built railway shall be as follows:

Single-track: no less than ($\geq$) 8 km;

Double-track: no less than ($\geq$) 15 km.

The interstation distance of railway junction terminal shall be no less than ($\geq$) 5 km. The stations in too short a distance will cause additional construction and operation costs, and even worsen the operational indicators.

(9) The stations to be started by stages on a newly built railway shall be specifically confirmed according to the designed annual passenger-freight carrying capacities in different designed years and local transport demands.

(10) During the rebuilding or new building of railway line, the stations with relatively small volumes shall be closed off in the prerequisite of reaching traffic ability.

4.3.3 High-Speed Railway

The distribution of intermediate stations of high-speed railway shall comply with the design capacity, and shall be convenient for operation management and passenger boarding and alighting, and organically coordinated with city overall planning and other modes of transportation while maintaining a certain development condition.

4.3.3.1 Distance Between Stations

Average distances between stations of high-speed railway in different countries are quite different. Average distance between stations in Japanese Tokaido Shinkansen is 34.3 km and its longest section is 68.06 km. The shortest distance between stations in Sanyo Shinkansen is 10.55 km. In France's high-speed railway, the longest and shortest distances between two stations are 100 km and 9.9 km, respectively. The distance between two stations of high-speed railway with passenger transportation business in China is mainly constrained by the city layout and distance between cities. Nanjing-Shanghai Section of Beijing-Shanghai enjoys a higher city density, and average distance between passenger stations is about 40 km while Xuzhou-Nanjing Section enjoys fewer cities, and the average distance between stations is about 66 km. The average distance between passenger stations of Beijing-Shanghai Railway is about 55 km. In addition, as train running speed of high-speed railway is not the same, it is necessary to set up an overtaking station between passenger stations with long-distance for high-speed railway to keep the distance between stations balanced. Generally, the average distance between two stations including an overtaking station is preferably 30–50 km. When the distance between naturally distributed passenger stations is longer than 50 km, if the section is not limited by throughput capacity, there is no need to set an overtaking station in the section, and reserve forward conditions for future station-adding.

4.3.3.2 Distribution of Large Intermediate Stations

Large intermediate stations of high speed railway are usually set in the railway junction terminal, municipality, and provincial capital city, and these serve abundant passenger transportation business, e.g., Tianjin Station, Ji'nan Station, and Nanjing Station of Beijing-Shanghai High-speed Railway. Large intermediate stations mainly deal with service for stopping of most high-speed and medium-speed trains, and passing operation of few high-speed and medium-speed trains as well as starting and ending operation of many high-speed trains. Large intermediate station has a large scale and is equipped with locomotive and vehicle facilities for high-speed train operation and maintenance station. Distribution of large intermediate stations should involve paying attention to the connection to adjacent railway lines in order to make it deal easily with the transit operation of high-speed train and medium-speed train or possible locomotive change of medium-speed train at the station or neighborhood through high-speed and medium-speed contact lines.

4.3.3.3 Distribution of General Intermediate Stations

To attract passengers from large and small cities along the railway, general intermediate station of high speed railway is distributed as per the location of municipality, county town and county-controlled city along the railway. Theoretically, the distribution of high-speed railway shall be good for attracting passengers from large and small cities along the railway. However, if there are too dense stations, it is hard to increase the speed of stopping trains. Trains operating in dense station bottle-neck areas will influence the riding comfort of passenger and add unsafe factors, as well as increasing difficulty of maintenance. It costs too much money to construct a high-speed station, especially to construct overhead station or demolish many buildings due to objective factors, and it costs up to 100 million Yuan to construct an intermediate station. Too many stations may require a large increase of investment. Therefore, it is necessary to set stations reasonably while maintaining enough passenger flow for high-speed railway. According to the actual conditions of the country, the high-speed passenger station shall be set in the place with large passenger flow and prefecture cities (province-controlled cities), including county cities with developed economy. According to the passenger stations of Beijing-Shanghai High-speed Railway, stations should be set in the cities with expected traffic volume of about 2 million passengers per year.

4.3.3.4 Other Factors to Consider in Distribution of Stations

When the high-speed railway is close to the track-connection passenger station of the existing railway (connecting the existing stations of main line in many directions), with more passengers transiting high-speed line and local reception and departure, a high-speed station should preferably be set near the existing station.

As per the distribution of maintenance bases of high-speed railway in foreign countries as well as national conditions, set a comprehensive maintenance area at an interval about 50 km. The station shall be distributed in accordance with the comprehensive maintenance

area to connect the branch line with the main line at the high-speed station. While selecting the position of station, consider the straight-way for comprehensive work area.

If possible, coordinate the distribution of crossovers in section with that at station, and integrate the crossovers in sections with that at station bottleneck to reduce the section crossovers.

The number of passenger stations at the terminals shall be determined according to the comprehensive factors, such as the passenger traffic volume at the terminals, the number of lead-in tracks, passenger train operation scheme, the existing equipment configuration, the passenger traffic layout of the terminal, as well as the overall urban planning, etc.

The position selection of the passenger stations shall be determined by taking into consideration of the following factors, i.e., the alignment strike of lead-in lines, the location and conditions of the existing passenger stations, the overall urban planning, and the topographical and geological conditions, etc. The priority selection shall be the existing passenger stations or the locations in urban areas. Given the circumstance of two or more selected passenger stations, there should be convenient links among the passenger stations.

If there are two or more passenger stations in the terminal, the work division of passenger station shall follow the principles of smooth routing for passenger trains, well-coordinated transport capacity between stations and line, and convenient boarding and boarding of passengers, and be carried out according to the direction of lead-in tracks, the types of passenger trains, the passenger train operation scheme, etc.

Distribution of stations shall meet the needs of distribution of passenger flow, travel convenience for urban dwellers, train operation optimization, design capacity, and maintenance. distribution of station should also be convenient for travelling at traffic hubs and tourist resorts.

4.3.4 Rules for Selecting Positions of Intermediate Stations

4.3.4.1 Combining the Urban and Rural Layout and Meeting the Requirement of Local Passenger and Freight Transportation

As stations can directly handle passenger and freight transportation business, the station position should widely attract passenger and freight flow to a great extent. Under the conditions of complying with the transportation capacity stipulated by the state, the running time between two stations shall be adjusted properly and stations shall be set near the cities and towns, as well as large industrial and mining enterprises, so as to meet the requirements of local transportation.

Generally, intermediate passenger station of high-speed railway is relatively small, in which the buildings are designed in coordination with urban facilities. Therefore, a high-speed

railway station can be set in the downtown to provide much more convenience for the urban residents and attract more passengers.

When it is hard to make route and stations close to cities or industrial and mining enterprises, it is required to formulate schemes of branch (close to) or highway combined transport (not close to) as appropriate and make a comparison.

For example, Tokyo Station connecting Tokaido Shinkansen and Tohoku Shinkansen in Japan is located in the downtown area, and Narita Airport is over 80 km away from the downtown area; it takes about 1.5 h from airport to downtown by expressway, but it takes only 1.5 h from Tokyo Station to Nagoya by high-speed train. Therefore, most airport passengers between cities with the distance ranging about 500 km to high-speed train like Osaka and Tokyo choose to take the high-speed train. Other countries have the similar conditions. In Paris, for example, there are eight railway stations, including six stations within 4 km of downtown.

For example, according to the comparison between straightening scheme of Xuzhou-Nanjing Section of Beijing-Shanghai High-speed Railway and the roundabout scheme through Bengbu, the former line is 23.8 km shorter, and the investment of approximately RMB 900 million Yuan can be saved. However, Bengbu now receives and dispatches over 8 million passengers per year and is expected to reach 18 million passengers per year. The route between Bengbu and Shuijiahu enjoys over 5 million passengers per year. The existing railway station of Nanjing-Zhenjiang-Shanghai is 5.9 km longer than the scheme route 12 km to Zhenjiang, increasing investment over RMB 200 million Yuan. But Zhenjiang is expected to receive and dispatch 20 million passengers per year. Bengbu Station and Zhenjiang Station are both very important and enjoy more advantages than disadvantages. Bengbu is an important gateway in northeast Anhui Province. It can initiate high-speed and medium-speed passenger trains to Hefei City, provincial capital of Anhui, and other cities. Zhenjiang can expand passenger flow to Yangzhou, etc. Therefore, both cities set high-speed railway stations at the place complying with urban planning and convenient for attracting passengers.

An intermediate station of high-speed railway shall preferably be located in the downtown. When it is quite difficult to realize or it costs too much, one should try to set the station near the downtown or close to the city region.

4.3.4.2 Engineering Conditions Including Landform, Geology, House Removal, and Reconstruction

Stations cover a wide area and have many buildings and equipment. Therefore, stations shall be located in plain terrain with sound geological condition. Try to keep the route parallel with the contour line. Avoid setting the station in high-filling and deep-excavated place, high bridge and tunnel to reduce the work quantity of engineering and facilitate operation management and maintenance. Water source and power supply shall be taken into consideration while selecting the location of the station.

To meet the requirement of transportation capacity, mixed passenger and freight railway need to set passing station or an overtaking station at both sides of summit bealock. The position of the station shall be proposed in accordance with the overall condition of mountain and the transportation requirement. From the perspective of engineering,

generally speaking, station close to bealock shall be located in the terrain with slow longitudinal slope and sound leading line. When the route is across deep ditch or large river and route develops toward downstream of a river, if the landforms and geological conditions in both sides are not quite different, the station should be set after crossing the ditch to lower the height of the bridge.

When a high-speed railway is located in the downtown to set a passenger station, it is necessary to solve the contradiction between station construction and buildings removal. The station close to downtown usually requires a large quantity of house removal for constructing the leading line and has poor engineering conditions. It costs too much to construct houses for compensation as well as involving difficulties in house removal of enterprises and public institutions, factories, and residents. Secondly, the selection of station position shall solve the contradiction between station and its leading line and the city road and highway. To set the station in the downtown, it requires adding a large amount of investment for overhead line erection due to highway and road crossings. Therefore, while selecting the position of station, one should comprehensively consider the distance to the downtown and the engineering condition and select the position reasonably through the negotiation with local government.

4.3.4.3 Taking Full Advantage of the Existing Railway Facilities

The existing railway facilities can be considered as one of the factors for comparison of station location of high speed railway. A high-speed railway station close to the existing station creates a condition for making full use of the existing railway facilities, which utilizes the existing passenger transportation facilities such as station building, waiting room, square, etc., channels including underpass and overhead channel, and living service transportation facilities in the station area and lowers investment in railway and city.

4.3.4.4 Combination of Station Position and Urban Planning

As the window for external contact of a city, railway station and leading line are an important part of city foundations, its land use and position scheme are among the urban planning. The existing railway station shall be coordinated with the current city functions and suitable for the development planning of city decades later.

4.3.4.5 Reasonable Combination Between Station Position Selection and Section Main Line

To reduce the project investment, route selection should be as straight as possible in consideration of various factors. However, it is a common phenomenon that “the station position is good but the route isn’t smooth or the route is smooth but the station position is bad.” For that reason, one should treat it differently as per different places. Compare the cost to the achievement. Abandon the scheme with no advantages or more disadvantages than advantages. Meanwhile, take the status and importance as well as special meanings in aspects like military and politics of the city into consideration, and follow the country’s benefits. In fact, in the railway construction, enterprise benefit and national benefit are almost consistent.

4.3.4.6 Other Rules

The design of railway terminals and large passenger stations of big cities shall comply with the following principles:

- (1) According to the overall plan of urban and railway terminal, it shall be realized gradually that of “separated tracks for passenger and freight traffic, passenger traffic inside city while freight traffic outside city.”
- (2) Determine the number of passenger station based on comprehensive study.
- (3) Select the location based on approach directions and urban master plan to develop urban traffic hubs.
- (4) Make the allocation of the EMU depot and workshop based on approach directions and upsized with space for further development.
- (5) The connecting line for running cross-line trains shall be set up according to the traffic demand and the principle of connecting for primary lines and passenger transfer for secondary lines.

4.4 Basic Methods of Railway Location

Topographic conditions, especially the average natural ground slopes, exert a tremendous influence on alignment positions and methods for railway location. Railway location involves two circumstances, which shall be handled differently:

(1) If the maximum designed gradient is larger than the average natural ground slope ($i_{\max} > i_{gs}$), the line is not limited by elevation barriers, wherein the major problem of location lies in the plane design. By laying out route in short and straight direction and avoiding plane barriers, a reasonable line location can be obtained. This kind of section is called a section of easy grade.

(2) If the maximum gradient is less than or equal to the average natural ground slope ($i_{\max} \leq i_{gs}$), the alignment would not only be limited by plane barriers but also controlled by elevation barriers. This kind of section is called a section of sufficient grade, wherein the major problem of location lies in the profile design. It is required, according to the topography changing, to select ground in which average natural ground slope basically consistent with the maximum gradient to lay out line using route development consciously and reach a predetermined elevation.

Since the section of sufficient grade and section of easy grade are in different conditions, methods for railway location in such sections are also different.

4.4.1 Location for the Section of Sufficient Grade

(I) Key points of railway location for the section of sufficient grade

A maximum gradient is generally used for the section of sufficient grade for railway location in order to reach appropriate elevation and not to additionally develop the route. When a location is confronted with huge elevation barriers (such as crossing a watershed), it is unable to reach predetermined height or a long over mountain tunnel exists if route is laid out in a short and straight direction. In order to reach a predetermined elevation, it is required to develop the route by using maximum gradient and according to terrain conditions. This is called route development.

In section of route development, railway location shall focus on natural conditions such as terrain and geology, and gradient design shall leave room for alternative profile design.

Without special reasons, no counter-slope is used for the route development section in order to avoid increase of any unnecessary line extension arising from ascent of elevation and increase of operation expenditure. For railway location of a section of sufficient grade, the route is generally laid from difficult terrain to flat and easy terrain. Because the terrain near bealock is difficult and route development is hard, therefore, it is proper to lead in the line from the predetermined mountain tunnel portal downward. In individual cases, if it is controlled by the control points on the

foot of the hill (e.g., high bridge), railway location from the foot of the hill to bealock is also allowed.

(II) Route development mode

If roundabout route development is required to overcome huge elevation difference, combined with the terrain and geological conditions, the route shall be developed as required mode by combining tangents and curves, such as overlapping curve, bulb-shaped curve, spiral curve, etc. For overlapping curve, in the case of locating a route along the river valley, if the natural slope of the main river valley is bigger than the maximum gradient and side valley is wider, an overlapping curve is often used to develop route in side valley (Fig. 4.11). A simple overlapping curve is composed of three curves, with each curve having a deflection angle not more than 180° .

Bulb-shaped curve: To develop route using overlapping curve in the side valley with a narrow valley mouth, it is required to build tunnels or deep cutting in the valley mouth that cause large engineering. In order to adapt the narrow terrain better in the valley mouth, a bulb-shaped curve route development can be used. It is composed of three or more curves (in the case of three curves, the middle curve shall have a deflection angle of more than 180° but less than 360°). According to the plane and profile shown in Fig. 4.12, a bulb-shaped curve proposal (solid line plan) can save two tunnels and some earth-rock work, compared with an overlapping curve proposal (dotted line plan).

Spiral curve: In sections of very difficult terrain, the line can appear as a 360° roundabout ring, which is called a spiral curve. In the crossing of upper and

lower curves, a crossover bridge or tunnel can be used (see Fig. 4.13).

There is no standard mode for route development. Various route development modes shall be combined subject to actual terrain conditions and shall be consistent with each other.

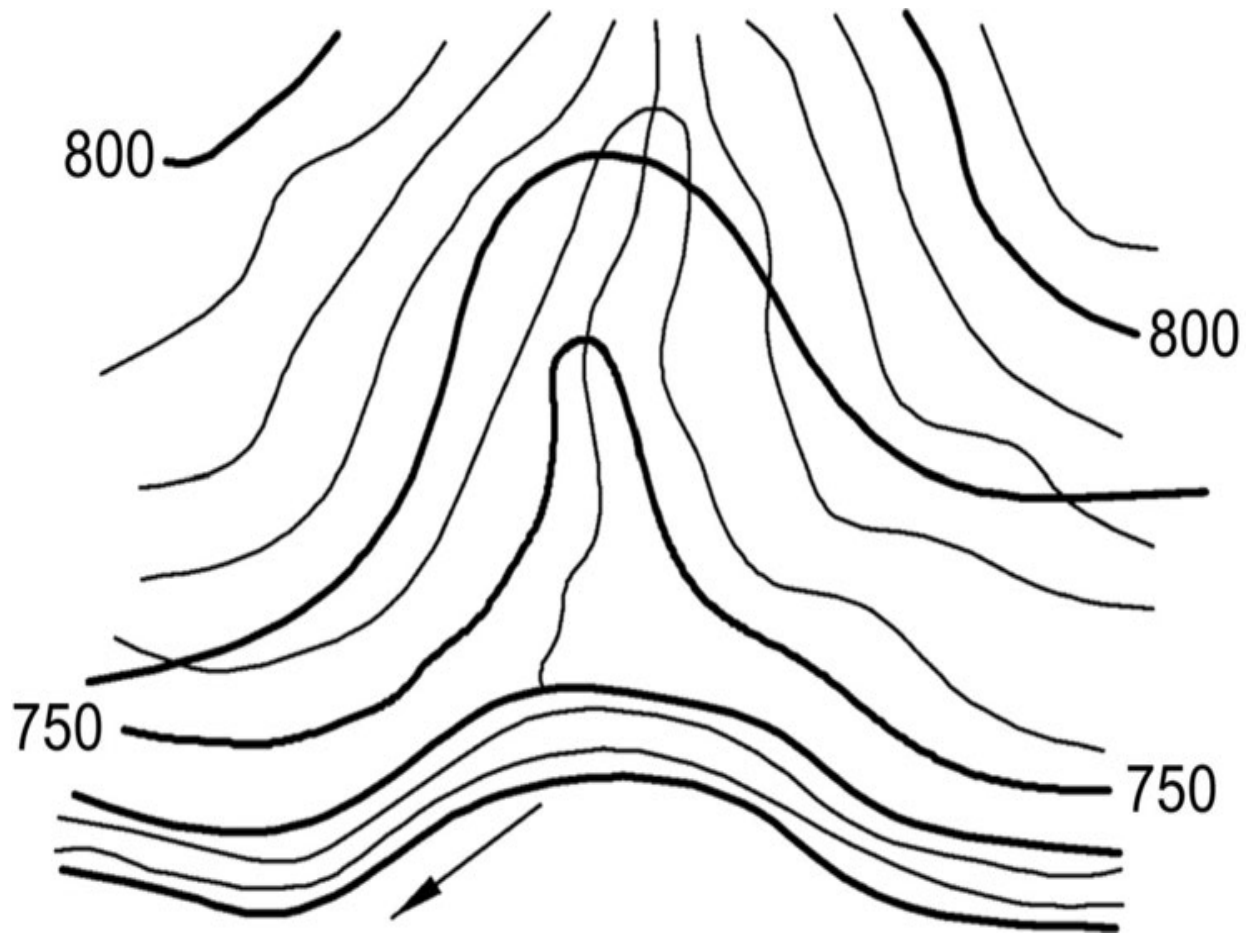


Fig. 4.11 Overlapping curve.

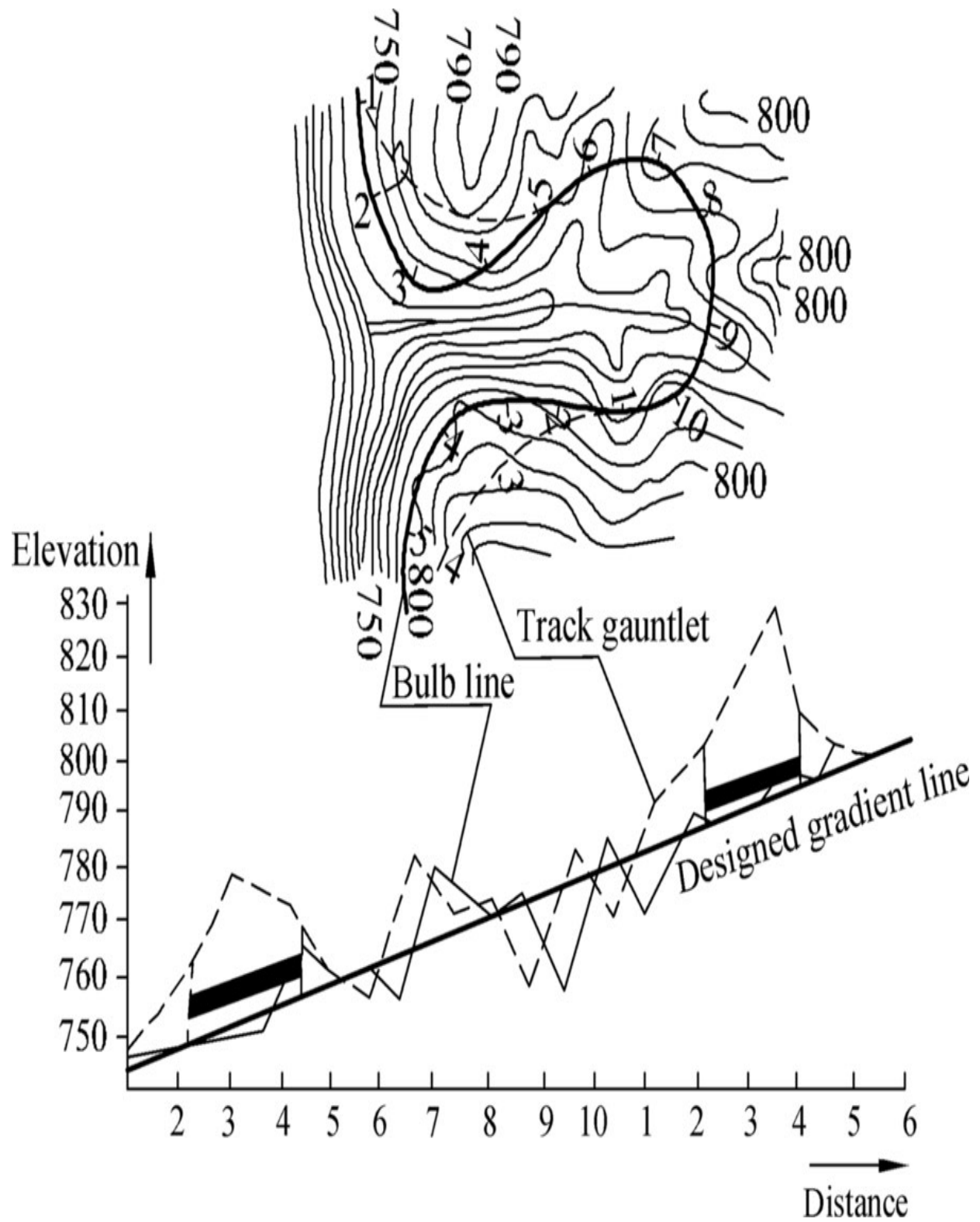


Fig. 4.12 Bulb-shaped curve.

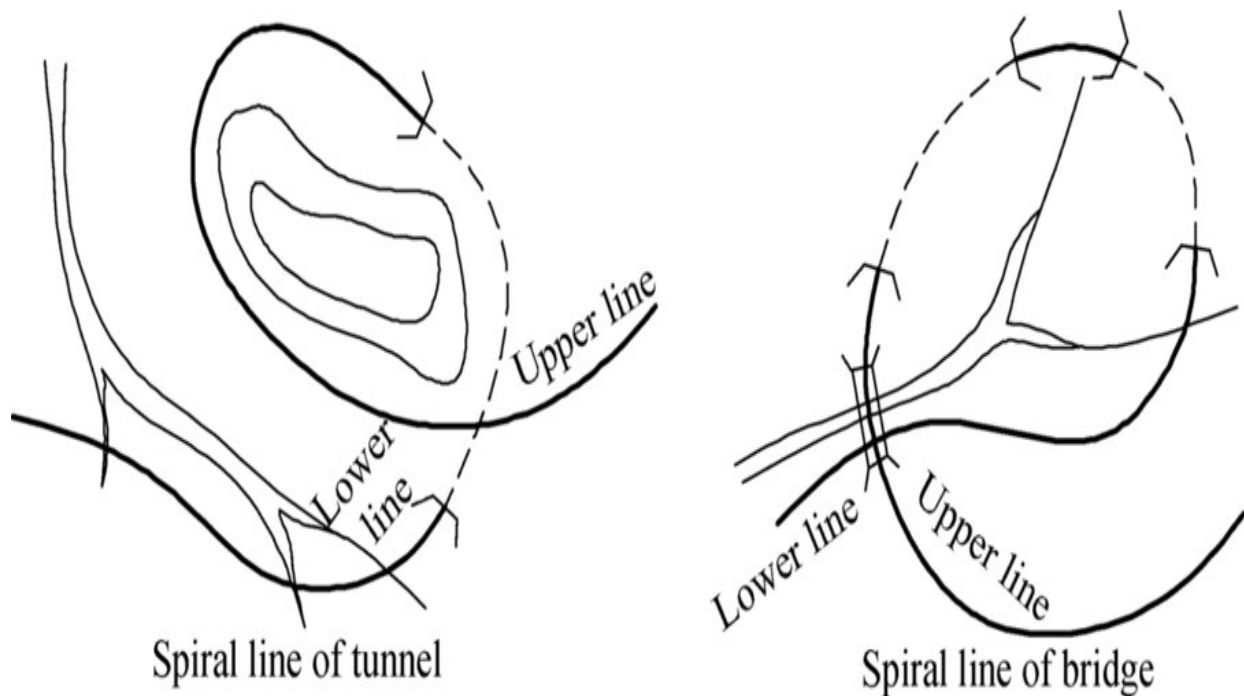


Fig. 4.13 Spiral curve.

(III) Railway location method by leading line

In the section of sufficient grade, preliminary position and partial strike of route may be laid out by using leading lines. A leading line is a broken line having maximum gradient and zero cut and fill at the crossing with the contour line. Therefore, it is a preliminary plan of route with maximum gradient, minimum cut and fill and being suitable for terrain conditions.

A leading line is worked out by using compasses on a small scale topographic contour map. The railway location steps are as follows:

(1) Based on the contour interval Δh (m) on the topographic contour map, calculate the distance of lead needed to raise the route a height of Δh (m)—railway location step Δl (km), namely,

$$(4.1)$$

where, i_d is design gradient, Δi is the average grade compensation of curve and tunnel, taking according to difficulties of terrain and geology.

(2) By reference to the planned profile, select a proper station position on the topographic map. From the station center in the section of sufficient grade, draw half a length of station site ($L_z/2$) forwards as the start point of the leading line (or from other predetermined control point).

(3) According to the scale of the topographic map, take compasses opening as Δl , fix one foot in the contour line at the start point or nearby ground with elevation similar to designed shoulder elevation, and use the other foot to capture adjacent contour line and draw a point. Similarly, take many points in the contour line and connect these points to a broken line, namely, the leading line (see points a, b, c, d, e ... in Fig. 4.14). Between the same start and end points, several leading lines may be drawn. For example, the dotted line in the figure is another leading line, which may be abandoned since it deviates from the short and straight direction farther than the fine solid line and increases the line length.

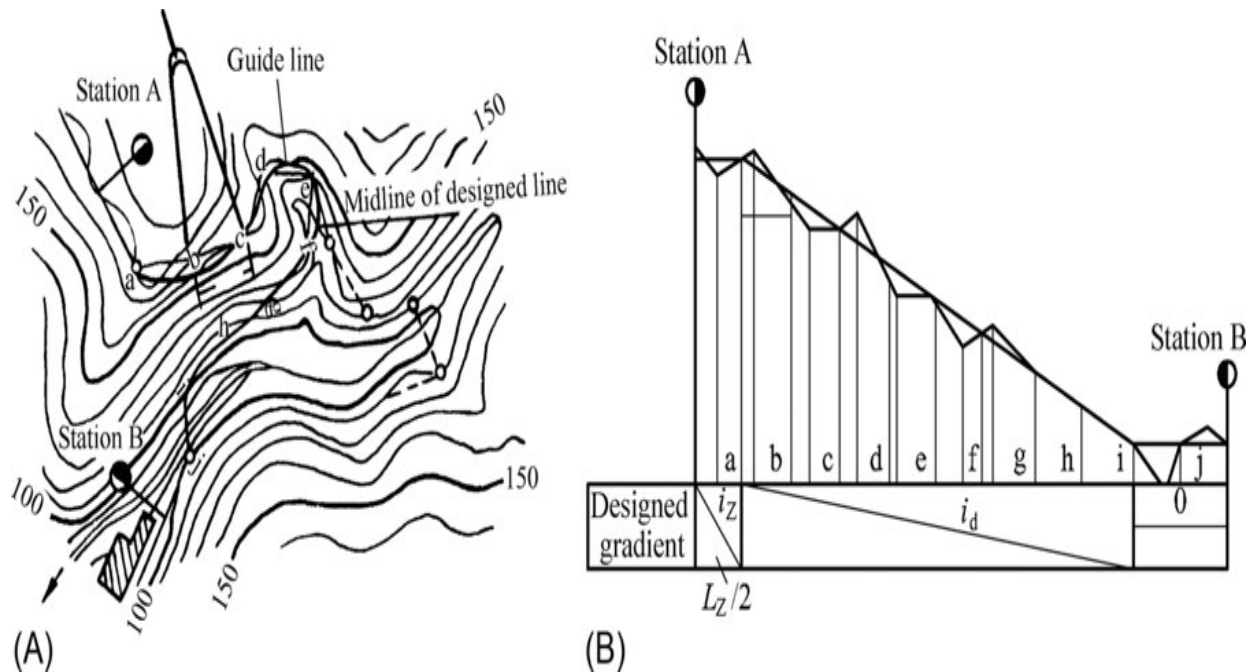


Fig. 4.14 Railway location by leading line.

Attention shall be paid to the following aspects while drawing leading lines:

- (1) The leading line shall detour unfavorable geological area and tend to forward control points (or station).
- (2) If compasses opening (railway location step) Δl is less than the contour horizontal distance, it represents that the railway location gradient is larger than natural slope of partial ground, the line is not controlled by elevation, and the route can be laid out according to short and straight direction of the line. Go on with this method until the section of contour horizontal distance is less than Δl , then continue to lay out the leading line of next section.
- (3) Bridges and culverts should be set when the line crosses a valley, thus it is unnecessary to descend the leading line to the bottom of valley; it can be directly lead to the opposite

side (e.g., points i to j in Fig. 4.14). Cutting or tunnel is required when the line passes through the spur, thus the leading line need not rise to the ridge and can directly skip the spur. When crossing a valley or spur, the ratio of rail approach distance to Δl , that is, how many Δh the line will decrease or rise, shall be used to decide the contour line on the opposite side of valley or spur from which to laid out a guide line.

(4) A leading line is a broken line, which may only represent preliminary route of line. In order to locate a line plane, the leading line plan (see Fig. 4.15) must be smoothly and straightly drawn based on the leading line with a railway French curve and a triangle in accordance with applicable railway specifications.

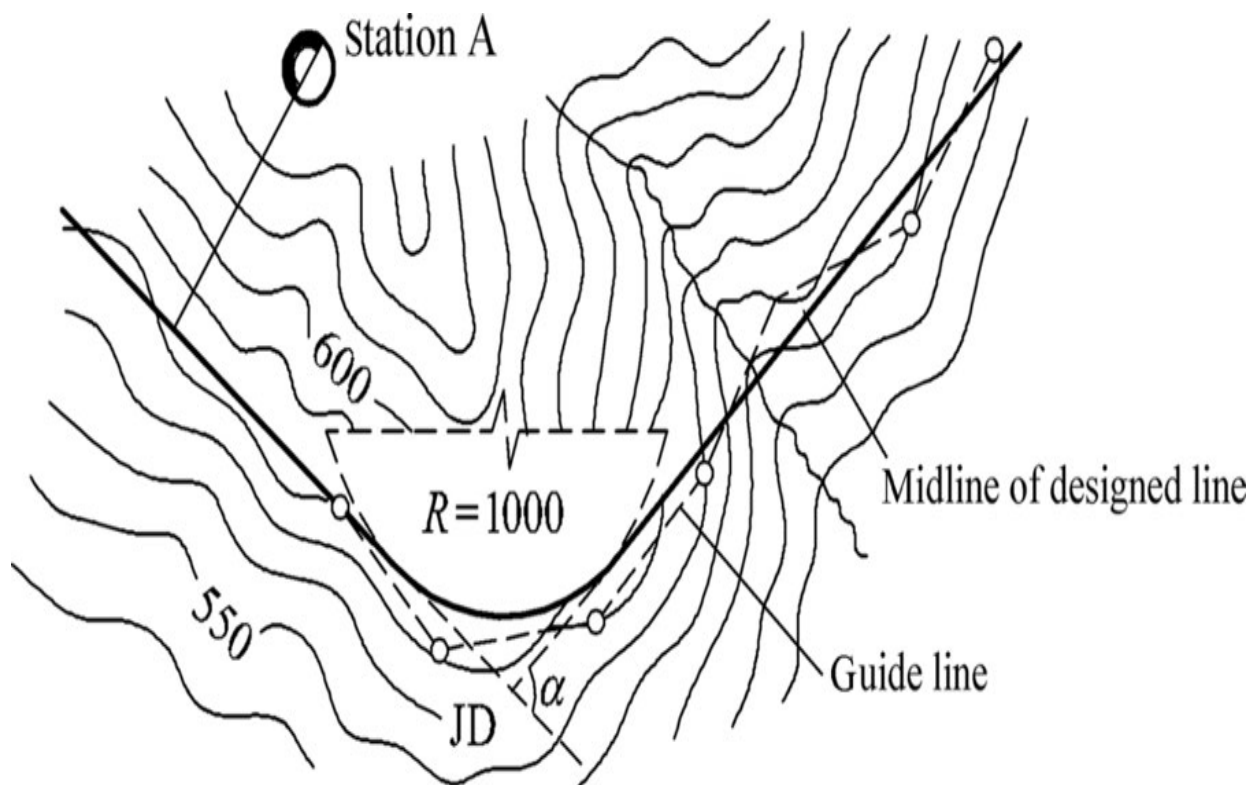


Fig. 4.15 Railway location along leading line and radius selection.

4.4.2 Location for Section of Easy Grade

As in the section of easy grade, the terrain is flat and easy, railway location may take the aviation line as main direction, manage to make route smooth and straight and save engineering investment, the following points shall be paid attention to:

(1) If it is necessary to deviate the line from short and straight direction in order to avoid barriers, the forward barriers must be detoured around as early as possible to reduce the deflection angle. Fig. 4.16 shows two methods for detouring around a lake. The dotted line plan seldom deviates from short and straight direction within the total length, but it increases number of curves, total deflection angle, and line length, compared with the solid line plan. Thus, in avoiding barriers, the route shall go from one barrier to another as early as possible.

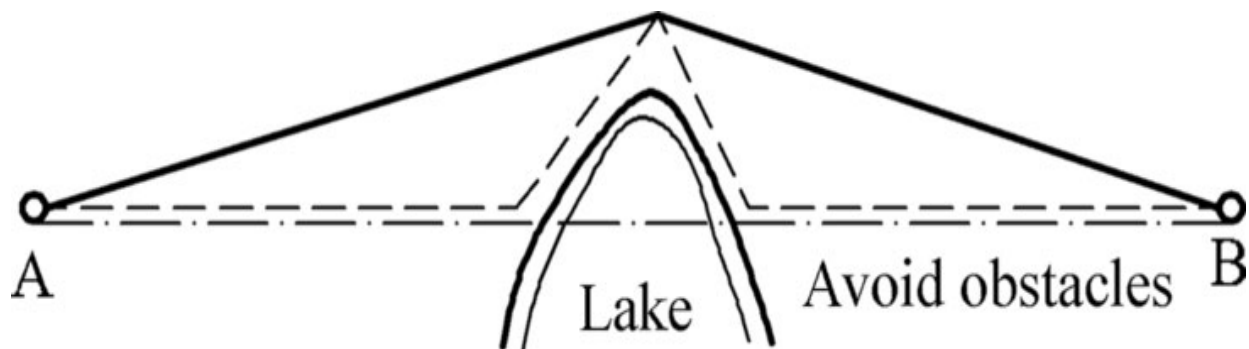


Fig. 4.16 Detouring around barriers.

(2) When the route avoids spur or crosses valley or other barriers, the point of intersection of curves must align with main barriers to set the barrier in the inner side of the curve and minimize its deflection angle. It can be seen from Fig. 4.17 that the solid line plan in which the curve aligns with the obstacle uses less earth and rock than the dotted line plan in which the curve does not align with the obstacle.

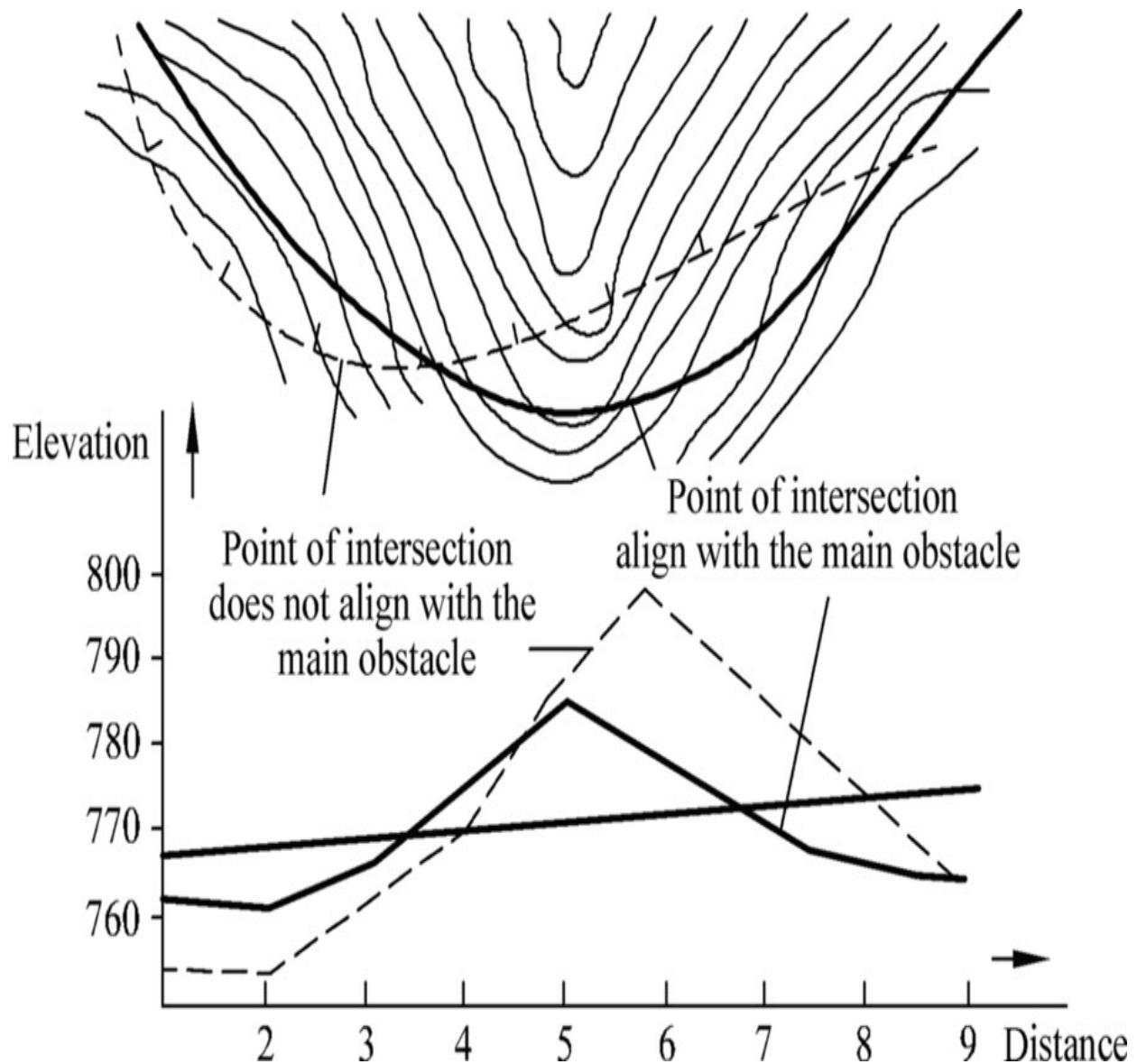


Fig. 4.17 Reasonable location of plane curve.

(3) A curve can only be set where there are barriers. The curve radius should be as large as possible in light of the terrain. In the section of easy grade, the degree of line extension depends on line significance, traffic volume, terrain, geological conditions, railway network trunk and other factors, the route development should be smooth and straight. Railways for regional traffic should be close to cities

and towns with less cost. General route development coefficient is about 1.1 for plains and 1.2–1.3 for hilly areas.

(4) The length of grade section would be better if it were not less than the train length. Down grade without the necessity of braking, namely harmless grade, should be used.

(5) Efforts shall be made to reduce total elevation, but serious comparison and selection shall be conducted when the route is developed for detouring elevating barriers.

(6) Stations shall not deviate from the short and straight direction of the line. Efforts shall be made to set the station in a convex section. The terrain shall be flat and wide to reduce the amount of work.

As shown in Fig. 4.18, designed elevation of Station A is 600 m, Station B is to be set about 9.3 km forward and reasonable design elevation of station B is about 608 m, and there is a section of easy grade between the two stations. The line profile between the two stations can be designed into three forms.

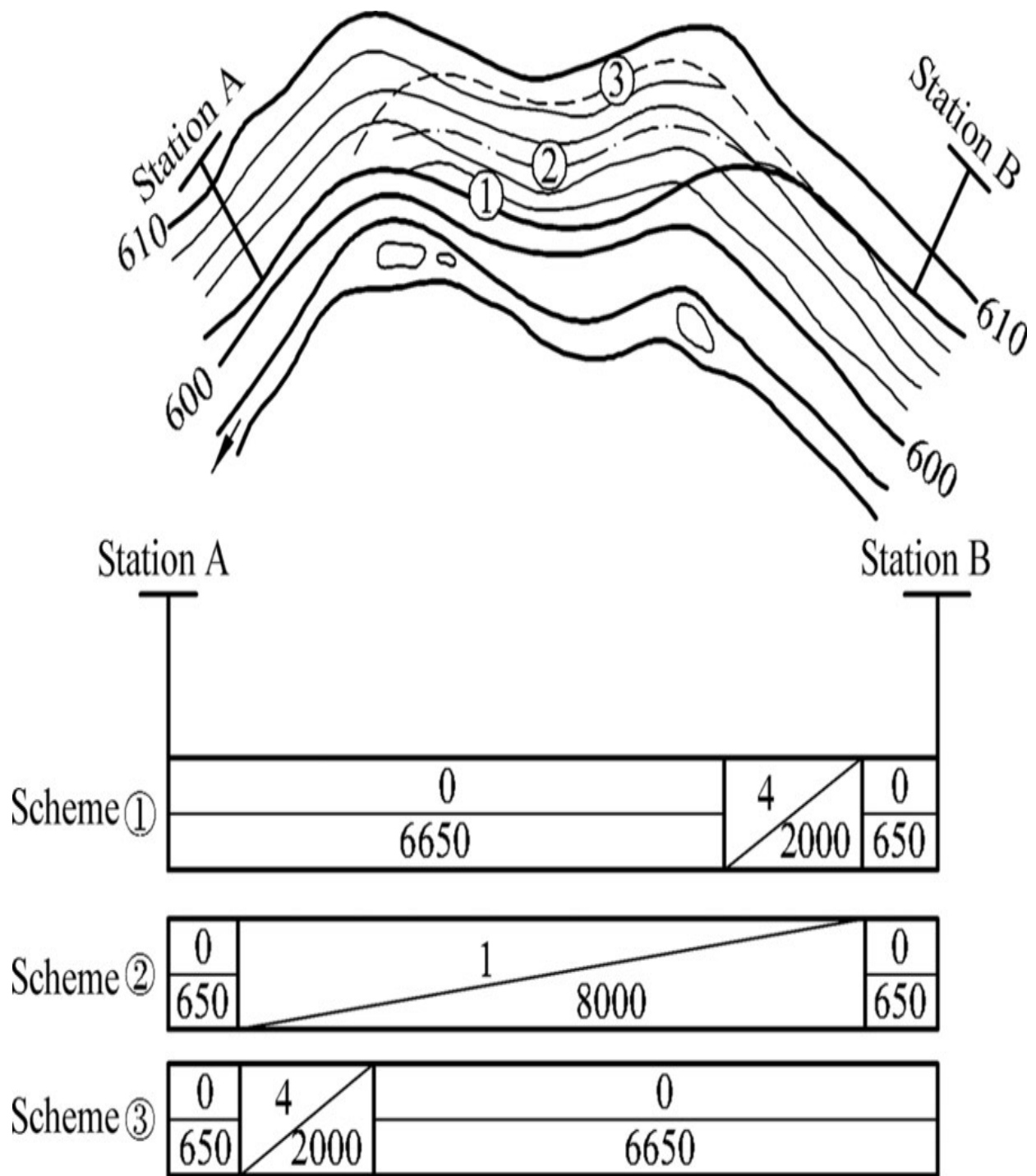


Fig. 4.18 Inter-station profile design of section of easy grade.

The line length and work quantities of these three plans are very close, but with respect to conditions for exit acceleration and entry deceleration of trains, Plan 1 is the most favorable for both Station A and Station B. The profile in Plan 1 shall be used for plane location of the line, and this may improve the running conditions of trains.

4.4.3 Railway Location Considering Cross-Section

In the section of steeper cross slope and unfavorable geological section, cut and fill height is not high from longitudinal profile and the plane is reasonable, but from a cross-section, large works may occur or the line is in very unfavorable geological conditions. Therefore, railway location should make the line reasonable in plane and longitudinal profile and also the cross-section. This requires route to be located on considering with cross-section condition after preliminary profile location. Working procedures are as follows:

(1) First find out the cross section which restricts route position. Investigate and map the cross-section for the section with steeper cross slope, unfavorable geological, river bank with serious scour, and representative hectometer positions.

(2) According to the predesigned shoulder elevation for each control section, a reasonable scope of the cross-section in which the line center can move left or right shall be determined. For example, in Fig. 4.19B, it can be seen that the embankment slope toe of the predetermined line has

extended into the river, which is obviously unreasonable. The midline should be modified towards the mountain, wherein two subgrade cross sections can be designed: one is that location point P of the midline in the river side can be obtained by extending embankment slope toe to the bank without scour; the other is that location point Q of the midline in the mountain side can be obtained by moving towards the mountain to make cut slope height equal to the maximum allowable value. The scope between P and Q is the reasonable scope for the line center may move in the figure.

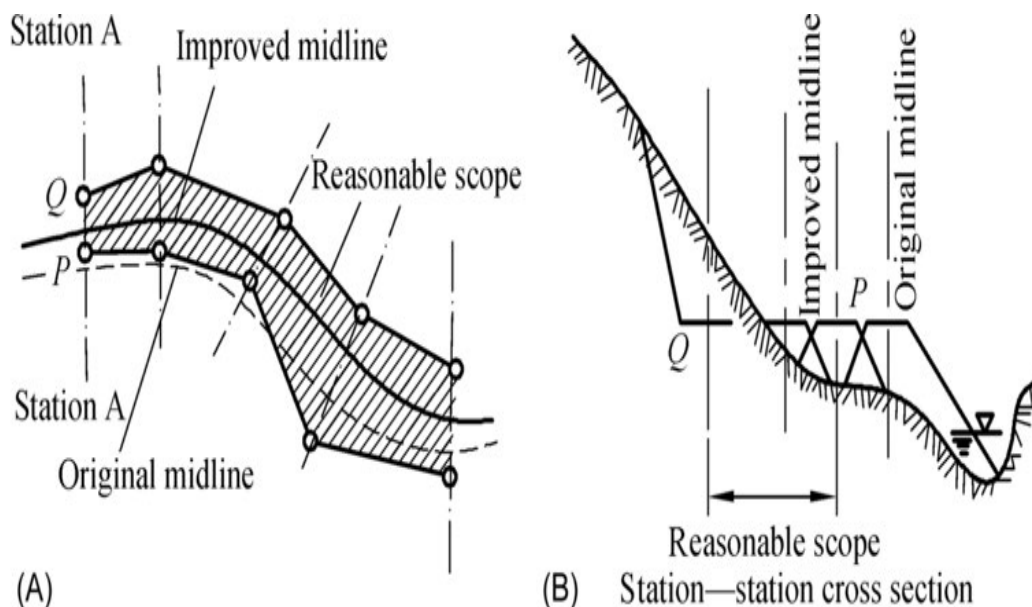


Fig. 4.19 Sketch map of railway location considering cross-section.

(3) Replot the limiting points (e.g., P and Q) to which the line can move left and right on each cross-section drawing onto the plane graph with relevant distance and scale, and connect limiting points to obtain a reasonable scope in which

the line can move in the plane graph. See the shaded area in Fig. 4.19A.

(4) Within the scope within which the line can move in the plane graph, redesign the plane and properly connect two ends with the predetermined line to obtain a new midline location more reasonable in the plane, profile, and cross section.

4.4.4 Improvement of Plane and Profile

Study and analyze the preliminary plane and profile, find out problems and solutions, and conduct local modifications. Minor changes are determined by experience, and major changes should be determined by technical and economic comparison. In design, the factors of plane, profile, and cross-section may interact and restrict each other, thus any modification to one view shall be subject to reasonableness of other two views in order to obtain design consistence.

Occasions requiring plane and profile improvement include:

- ① comparison and selection of partial plans;
- ② reduction of cut and fill, bridge and tunnel works;
- ③ avoiding unfavorable geological section;
- ④ adjustment of station, bridge and culvert distribution;
- ⑤ improvement of construction conditions of some construction sites;

- ⑥ improvement of operation conditions of local sections;
- ⑦ improvement of design of local section applying minimum standard allowed by specifications; and
- ⑧ reduction of farmland occupation and building demolition.

Taking several common examples of changing plane and profile to reduce cut and fill quantities, as explained below:

(1) If predesigned gradient is improper and partial sections have large quantity of cut and fill, grade section or designed elevation can be changed to reduce cut and fill quantities, as shown in Fig. 4.20.

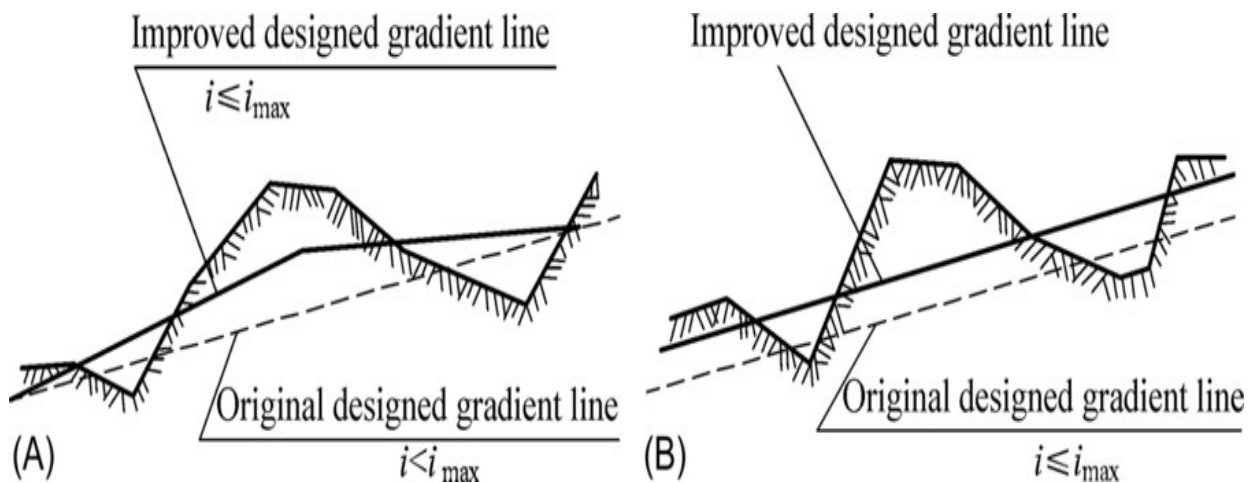


Fig. 4.20 Changing the designed gradient to reduce work quantity.

(2) If it is not suitable to change the predesigned gradient (eg the maximum gradient has been used) but cut and fill height in the profile gradually increase from one end to another to an unreasonable extent, the plane location of line

can be changed according to specific circumstances, for example, twisting the line by an angle (see Fig. 4.21).

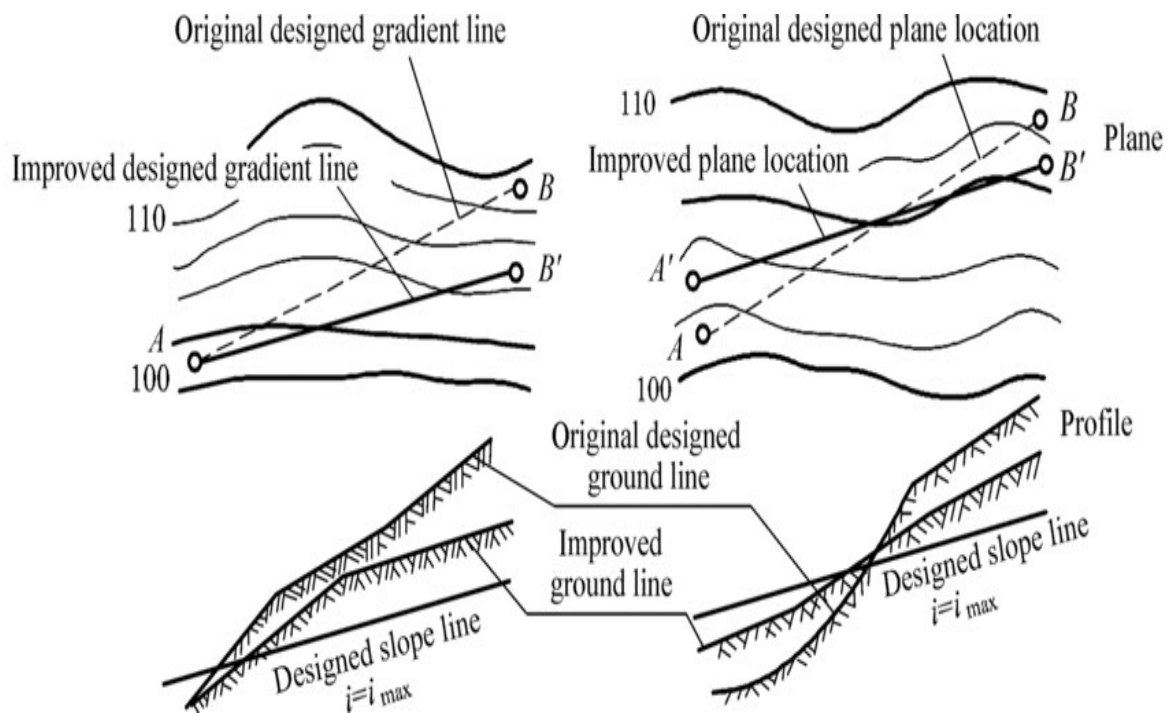


Fig. 4.21 Turning the tangent line to reduce work quantity.

(3) If predesigned gradient is reasonable and cut and fill height in the profile gradually increase from two ends to middle to an unreasonable extent, it is available to add new curves or change curve radius to reduce the cut and fill the height in the middle (see Fig. 4.22).

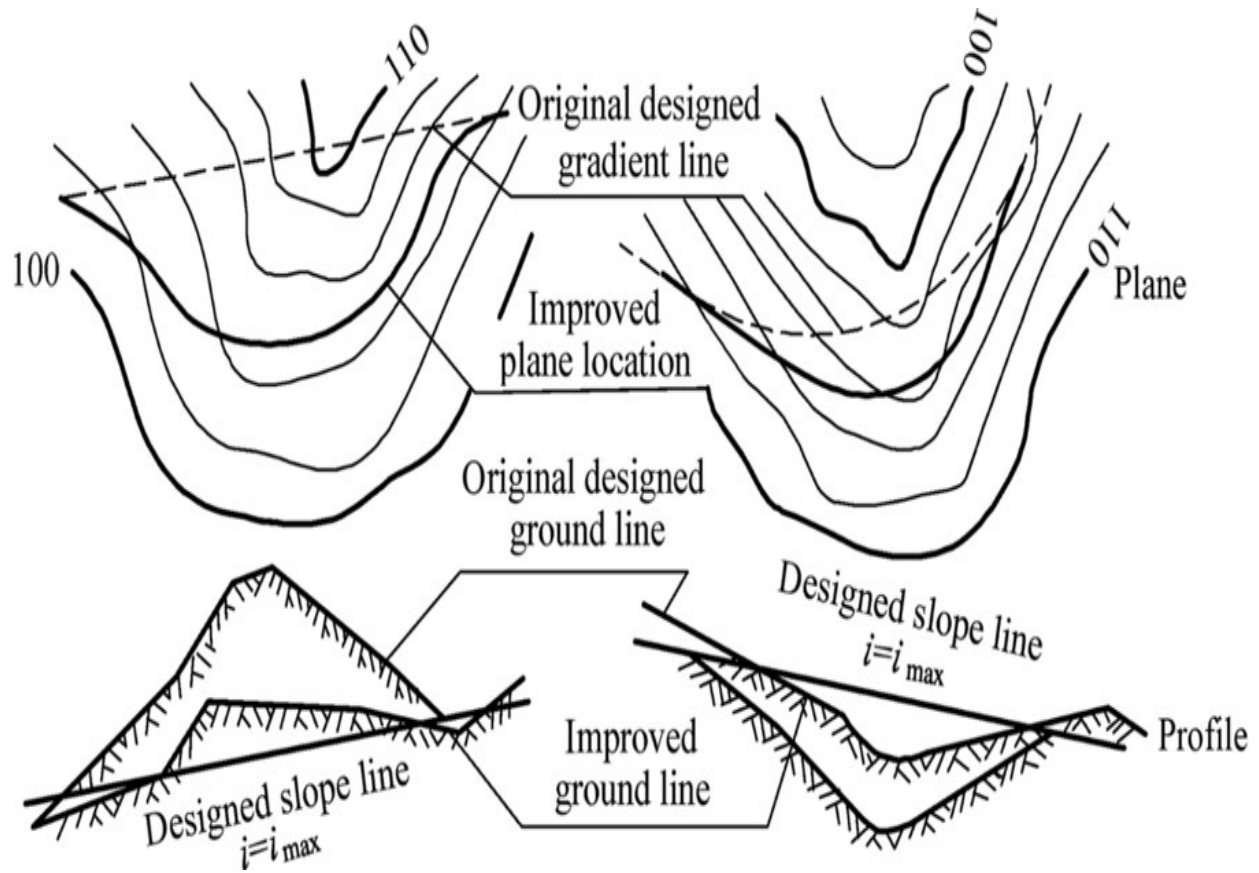


Fig. 4.22 Changing curve to reduce work quantity.

(4) If work quantity increases as a result of improper coordination of plane curve and tangent line, it is required to readjust the deflection angle and configure curves to reduce work quantity. As shown in Fig. 4.23, in the original line profile, there are more excavation between two culverts and fill quantity in the right side. According to study on the plane graph, it is found that horizontal movement of the line downwards at the excavation and horizontal movement of fill section upwards can reduce excavation and fill. Thus, the curve radius and the direction of the tangent line in the right side are changed.

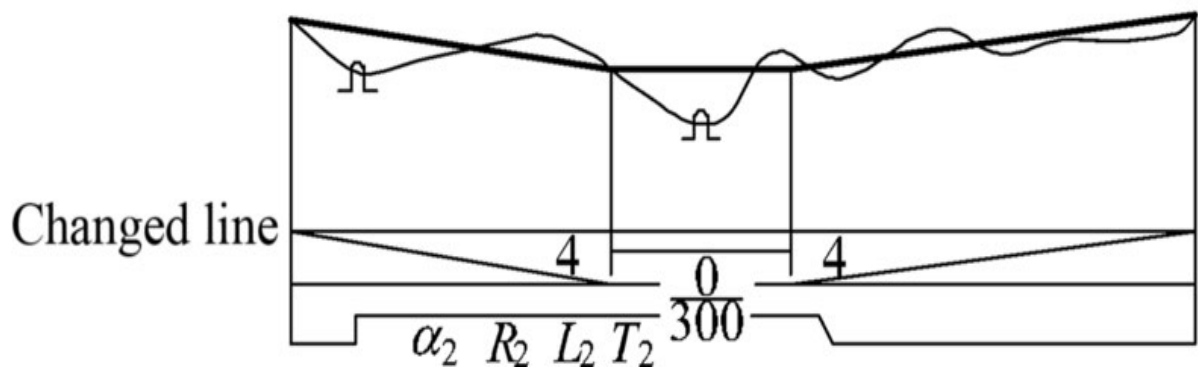
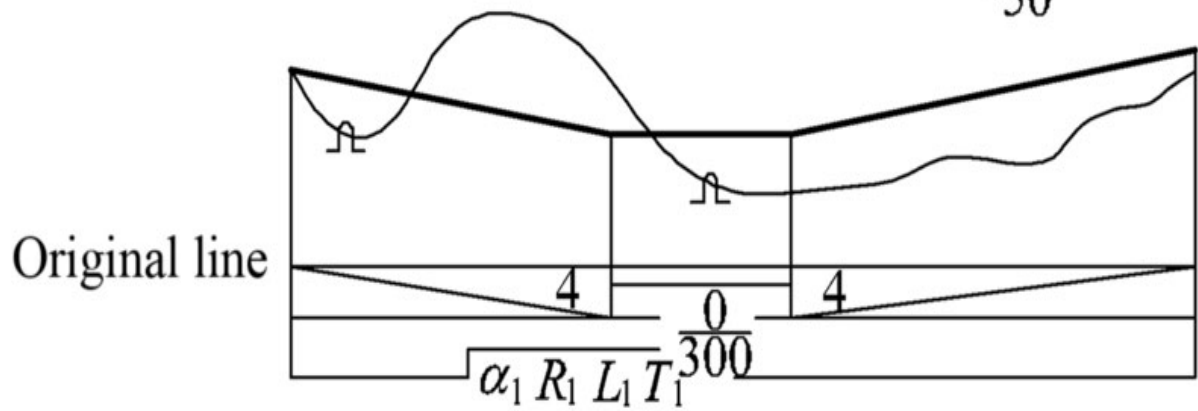
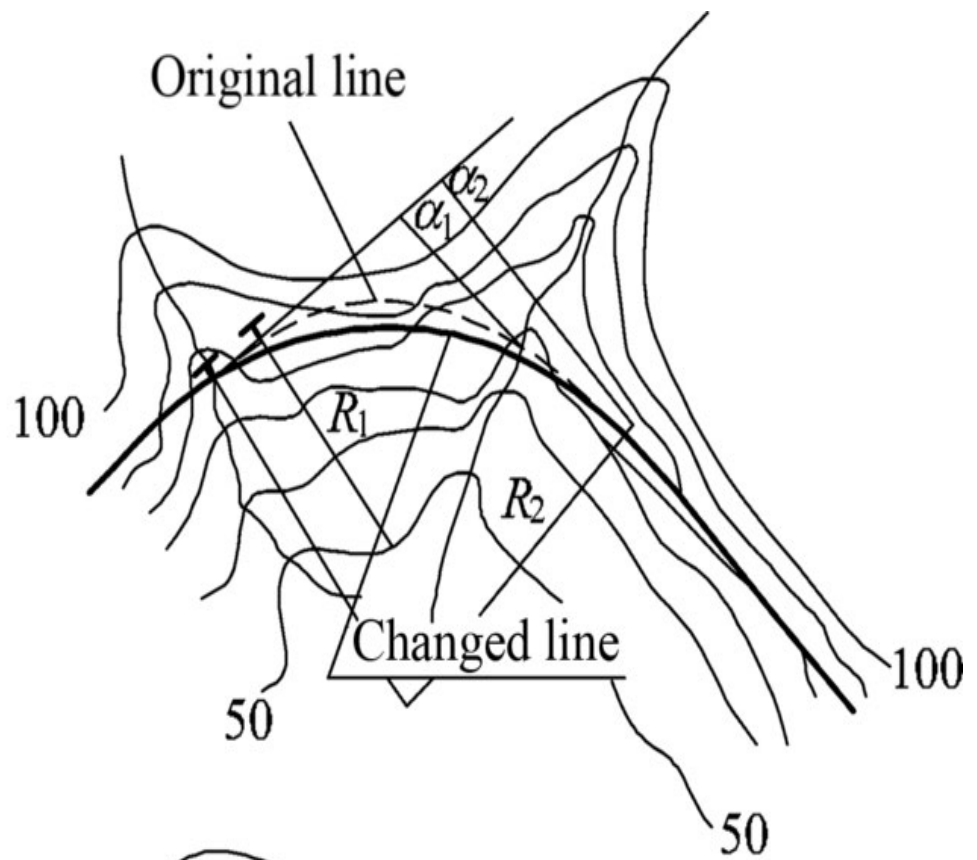


Fig. 4.23 Changing tangent line and curve radius to reduce work quantity.

4.5 Location in Complicated Geological Conditions

Engineering geological conditions is important basis to decide a line strike and location which determine the stability and economic rationality of the railway buildings. Hence, it is necessary to give sufficient attention on engineering geological conditions during railway location process.

With its vast territory, China has very complicated geological conditions. Common unfavorable geologic phenomena include landslide, collapse, talus, lava, debris flow, gully, soft soil, marsh, desert, salinized soil, permafrost, earthquake and reservoir regions, etc.

In large-area route selection and route principle schemes comparison, engineers should understand regional geological conditions and carefully study possible route schemes based on geologic structural features. For route selection passing through unfavorable geological zones, it is necessary to carry out in-depth investigation, determine whether to detour or to employ some regulation measures after thorough analyzing and comparing each unfavorable geology with its scale, cause of formation, development condition, harmfulness on railway and complexity of improvement, etc.

In zones with particularly complicated geological conditions, comprehensive geological prospecting is needed, including special geological prospecting for key engineering sites with complicated conditions; then the prospecting results will be

the guidance for selection of specific route. Integrated exploration techniques are adopted for comprehensive geological prospecting, including satellite remote sensing, large-area geological annotation, hydrogeological research, geophysical prospecting, drilling and other relevant tests (e.g., comprehensive well logging, ground stress test, gas test as well as earth, rock and water sample test, hydrological test) and observation (flow of spring and underground river), to investigate further the significant engineering geological problems and hydrogeological problems of the route scheme, such as landslide, underground river, etc.

The key points of location in complicated geological conditions are illustrated as follows.

4.5.1 Location in Landslide Zones

A landslide is a phenomenon where soil mass on mountain slope slides down along mountain slope due to action of gravity. In most cases, the occurrence of a landslide is related to the action of surface water and groundwater.

In terms of location in landslide zone, engineer shall fully master the engineering geological and hydrogeological conditions, find out the position and shape of sliding layer and ascertain stability of landslide. If the route passes through a landslide zone, it is better to detour around it. If it is difficult to detour around, the following route proposals should be selected after a comparison:

(1) Wherever possible, the route should pass through from the upper part of landslide zone in the way of zero-filling and zero-cutting roadbed or shallow road cutting.

(2) Route passes through from lower part of landslide zone with low embankment.

(3) Route passes through under sliding surface of landslide with tunnel.

(4) Large-span viaduct may be adopted in landslide zone where sliding layer is not very thick.

(5) If the landslide zone is neither large in area nor deep in thickness, engineering measures may be taken to clear all sliding soil mass and set subgrade on stable soil mass.

When the route passes through a landslide zone, the zone should be treated by using some engineering measures such as placing anchor plate at upper part, constructing retaining wall at lower part, setting gutter at upper part, improving surface water, etc.

In the location of Yichang-Wanzhou Railway, by strengthening the geological mapping and exploration for zones of Langping to Gaoping, Enshi to Lichuan and Qiyue Mountain area before the preliminary survey, basically investigate the basic features of geological conditions, such as geological construction, stratum lithology and Karst development of, analysis on major engineering geological and hydrogeological conditions, such as underground river system, significant unfavorable geology, etc. which may affect route scheme, various engineering technology treatment measures and several possible route proposals were studied based on comprehensive analysis and comparison with engineering geological conditions, hydrogeological conditions, engineering economic and

technology conditions; Moreover, the route selection scheme is constantly improved and optimized according to the results of special geological work. Thus, a safe, reliable, and economical route proposal is selected. The selected proposal detours around many unfavorable geological bodies, such as landslide, bedding, talus and underground rivers, etc. See Fig. 4.24 for a route scheme sketch map of Langping to Gaoping section. See Fig. 4.25 for a route scheme sketch map of Enshi to Lichuan section.

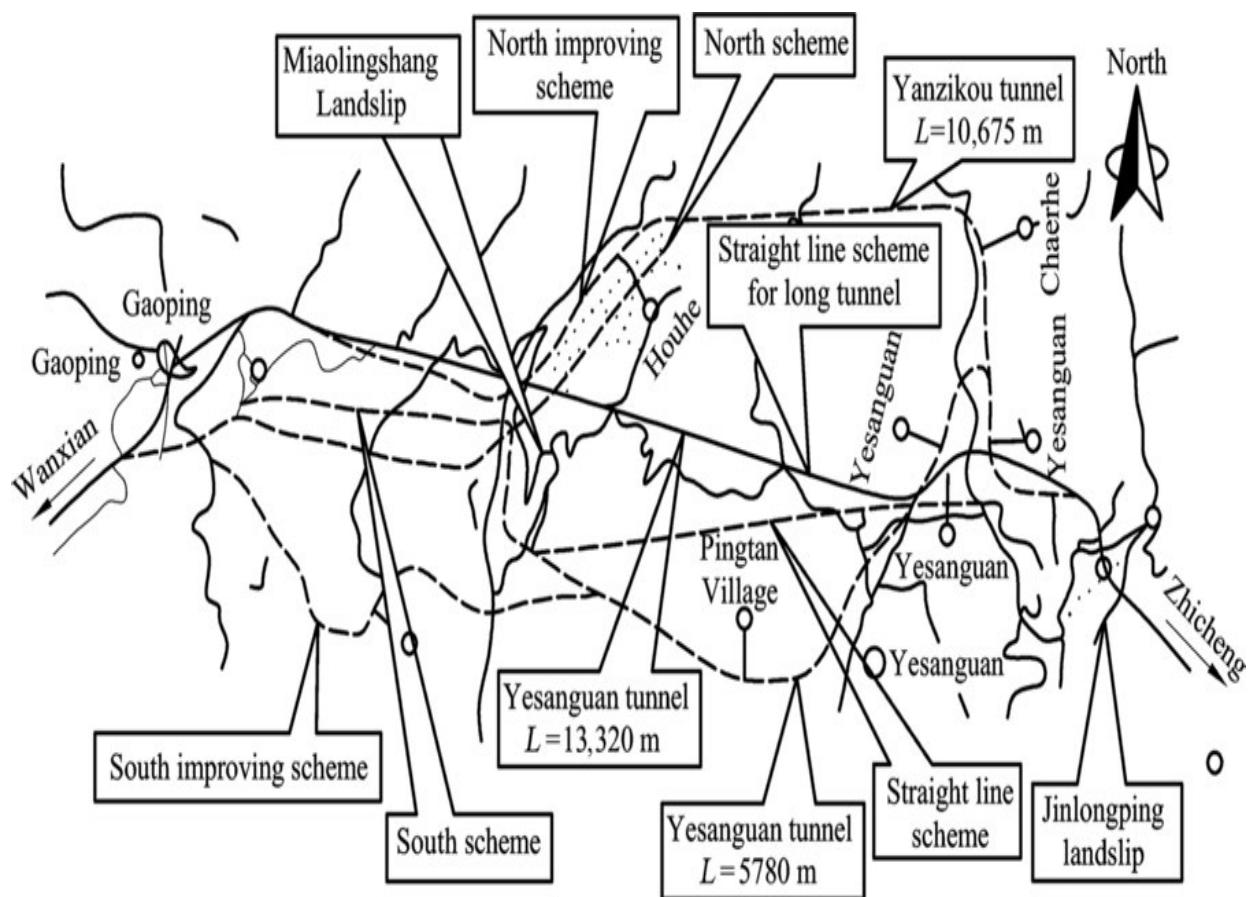


Fig. 4.24 Sketch map of route scheme from Langping to Gaoping section.

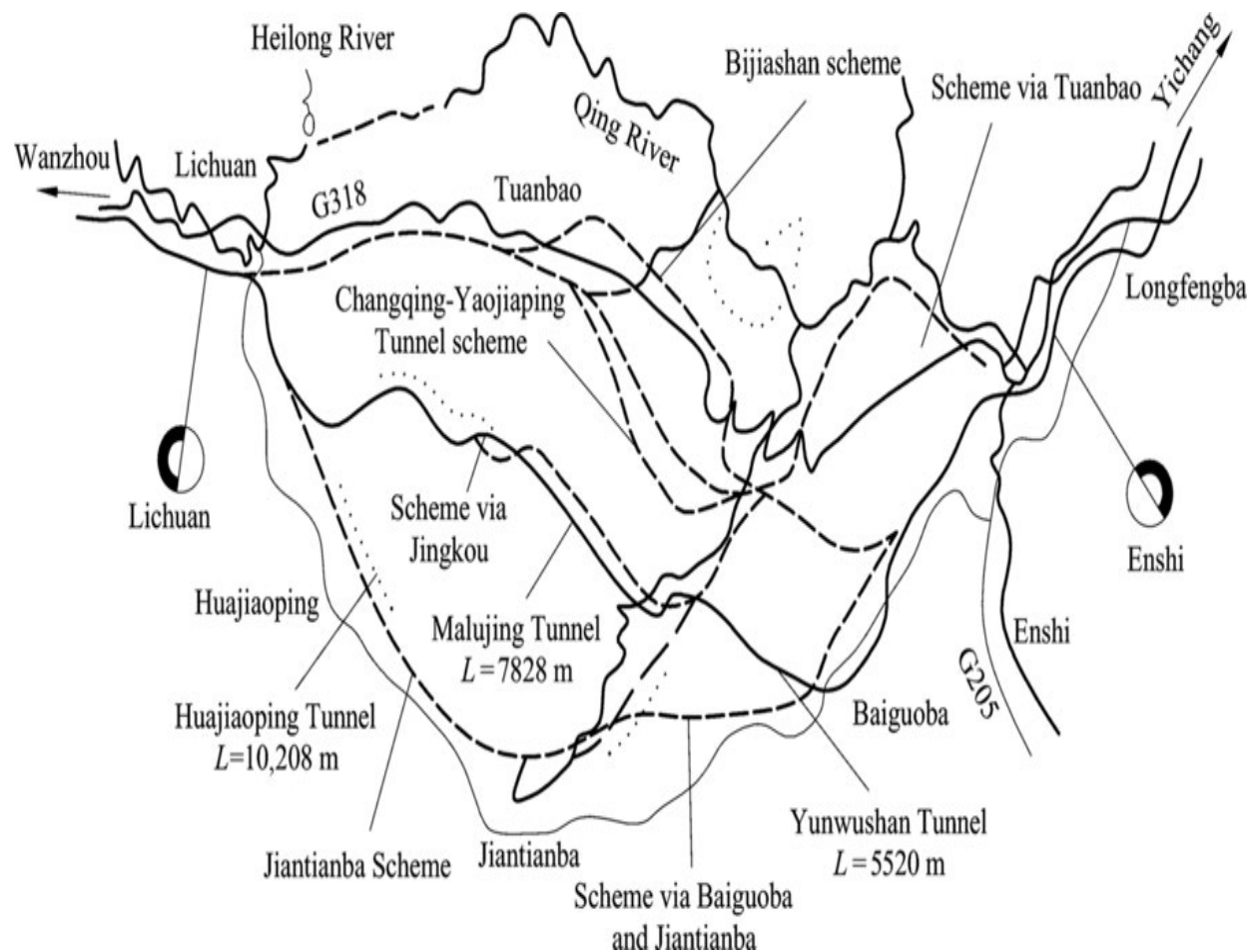


Fig. 4.25 Sketch map of route scheme from Enshi to Lichuan section.

4.5.2 Location in Talus Zones

Rock stratum suffering from severe weathering on high and precipitous slope may roll down due to action of gravity after

being broken by weathering. The tapered accumulation formed by this phenomenon at the foot of mountain is called talus. When the route passes through a talus zone, an investigation of the active level of the talus is needed. In selecting and determining route, route proposal should try to avoid active or unstable talus and be laid out at stable hillside. Route should detour talus with stable outlook. If detouring is unavailable, the route should pass through the talus in low embankment, and moreover, enhance retaining structures of subgrade.

Let us consider the example of Yichang-Wanzhou Railway. After leaving from the railway station at Hejiaping, line set Baozheng Tunnel at Baozheng mountain. Baozheng Tunnel is located at the junction zone between the limestone stratum layer and clastic rock stratum layer. The limestone area is in the south part and dominated by marlstone; in the north part, it is a clastic rock area dominated by carbonaceous shale. On the basis of geological mapping and surveying, and relevant prospecting work, and to avoid the impact of karst problem in limestone area on tunnel, finally, it is decided to locate Baozheng Tunnel in a clastic rock area. During the tunnel's construction, high ground stress resulted in large deformation of soft rock due to deep burying of tunnel, which is a major problem. Specific to this problem, the corresponding grading high ground stress tunnel supporting and lining structure are adopted on the basis of scientific research achievements. During construction, integrated monitoring and test method is adopted to find out the rule of large deformation of soft rock resulted by high ground stress. Tunnel supporting and lining structure are adjusted timely according to result of comprehensive test, which, however, influences the construction period. To satisfy the requirement of overall project construction period, an auxiliary pilot tunnel with length of nearly 2 km is constructed in marlstone area in the south of the tunnel. Due

to sound geological conditions of an auxiliary pilot tunnel, construction is quickened without any impact resulted from unfavorable geology—karst. Therefore, from a perspective of construction result, if the route of Baozheng Tunnel is close to the south part and located at marlstone zone, the results of investment and construction period may be better than those of the currently implemented scheme. See Fig. 4.26 for a sketch map of Baozheng Tunnel route scheme.

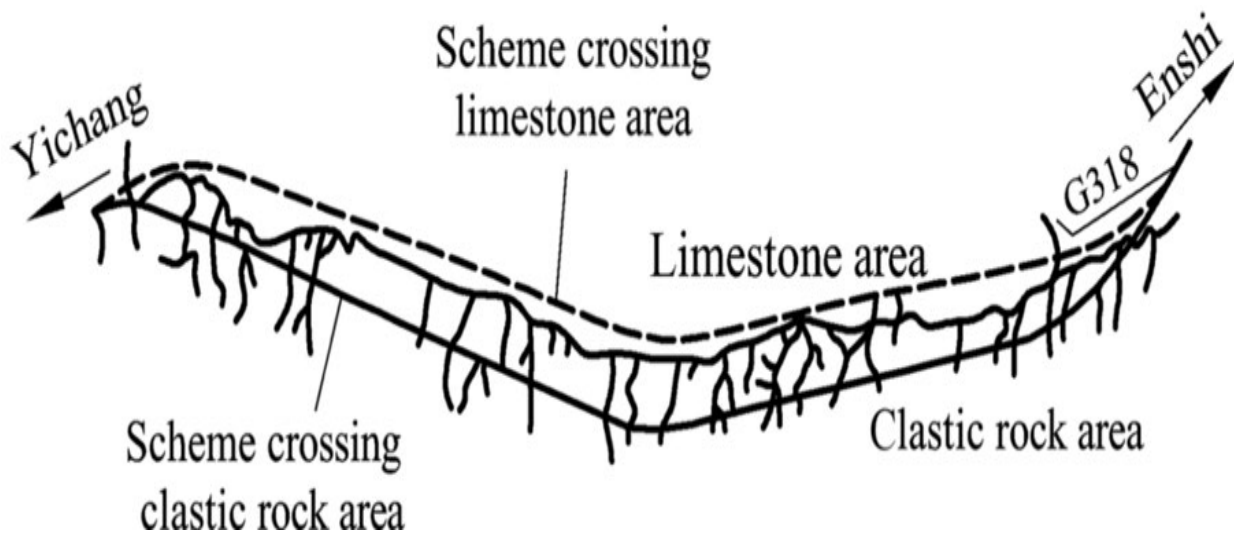


Fig. 4.26 Sketch map of Baozheng Tunnel scheme.

Another example is passing through mountain section of Hengshan Mountain of Shuohuang Heavy Haul Railway. According to the specific conditions of dangerous rocks, the zone along the route was by using working measures, such as eliminating dangerous stones on surface, filling joint fissure with cement mortar, suspended mesh uniting, filling with mortar rubble and setting intercepted stones. To ensure safe operation of the route, the route detoured around dangerous rocks while being very close to the margin of coal

mining goafs, and its position was improved by lengthening tunnel. In this way, the route just pass through part of VII collapse zone and VII collapse zone, the length of route in collapse zones was only 280 m. Through measures such as elimination and strengthening, the total amount of dangerous rock is reduced to 16.6% of the original amount, so that the danger is basically eliminated with no future trouble. Many years of operating practice has proved that safety guaranteed. Sketch map of route scheme in zones with abrupt slope, collapse, and rockfall is indicated in Fig. 4.27.

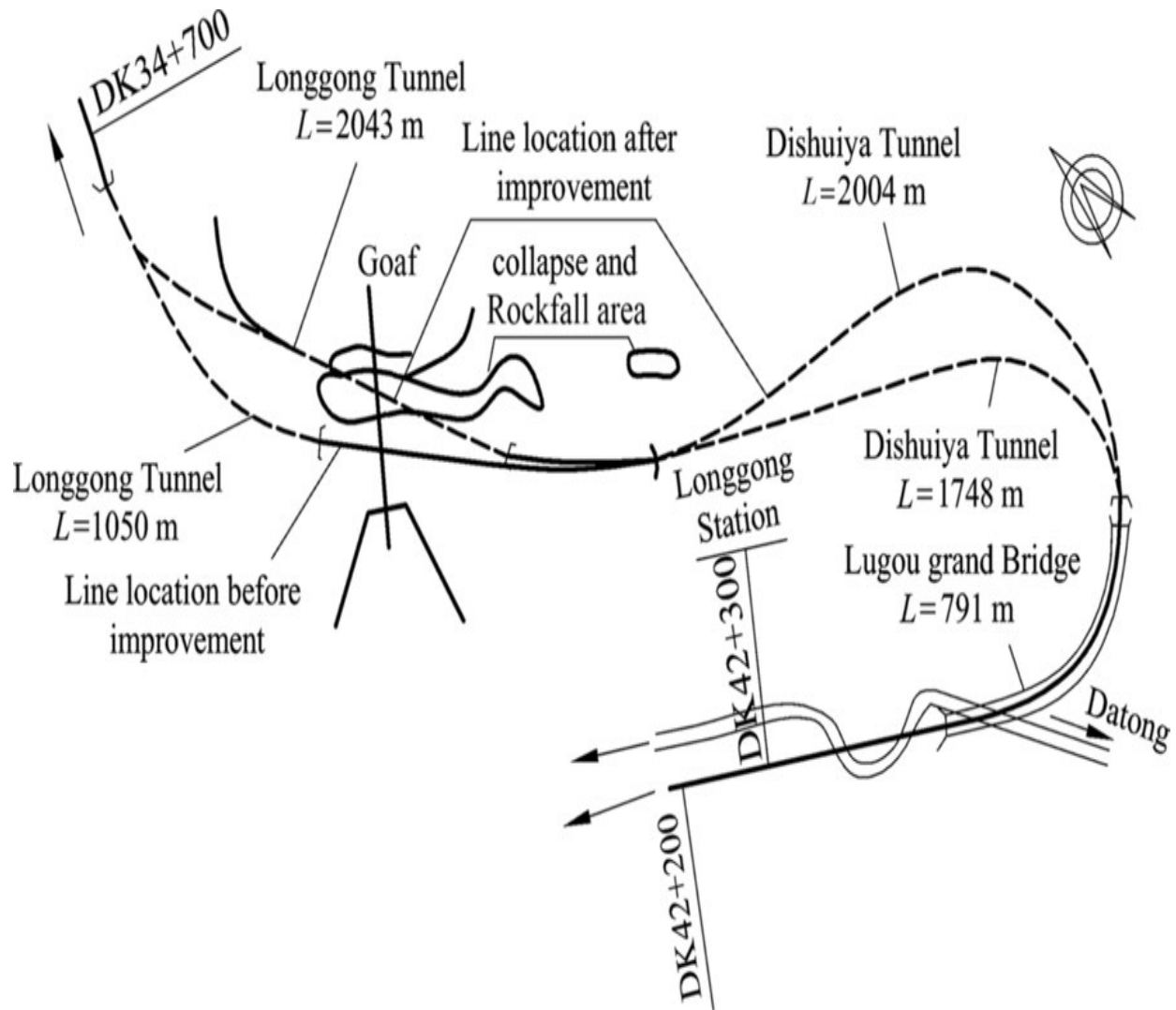


Fig. 4.27 Sketch map of route scheme in zones with abrupt slope, collapse, and rockfall.

4.5.3 Location in Mudslide-Stricken Regions

The longitudinal slope of mountain river valley is a relatively steep. A large quantity of mudstone carried by the flash flood surges out of mountain pass and becomes solid flow; this phenomenon is called debris flow. It can bury roads, destroy bridges, and interrupt driving.

In terms of location in mudslide-stricken region, route shall go from upper part of debris flow deposition area in the form of large-span bridge, and a throttling dam shall be constructed in upstream of the route to throttle debris flow. In the long run, it is vital to take fundamental measures such as closing the land for reforestation and conservation of soil and water.

4.5.4 Location in Gully Regions

Because of the loess soil structure characteristics, the loess area is cut into deep and large-scale gullies after suffering from current scour. The depth of a gully can reach tens of meters.

When the route passes through hillsides of watershed, attention shall be paid to find out that whether there is unstable section of active gully region. The location should make the route avoid gully sections. If the gully region is widespread and cannot be bypassed completely, the route shall go from a relatively narrow area upstream in bridges, and strengthen the environment by constructing dikes in gullies and reinforcing through impermeable layers. Through these methods, further expansion of gully can be prevented, to ensure the stability of the subgrade.

For route selection, features such as stratum structure and formation lithology of loess gully region shall be surveyed. Mechanical properties of loess and condition of groundwater shall be ascertained through field investigation and exploratory point.

In terms of loess landslide development area, the principle of “safety first” shall be implemented to ensure the railway is located in the safest zone. It is not allowed to locate the route at an unfavorable section.

As an example, in the Xinzhuang area where Yinchuan-Xinjiang Railway passes through, loess landslide mainly develops in the middle reaches of gullies. In the upper reaches and lower reaches, loess landslide does not develop. See Fig. 4.28 for specific distribution.

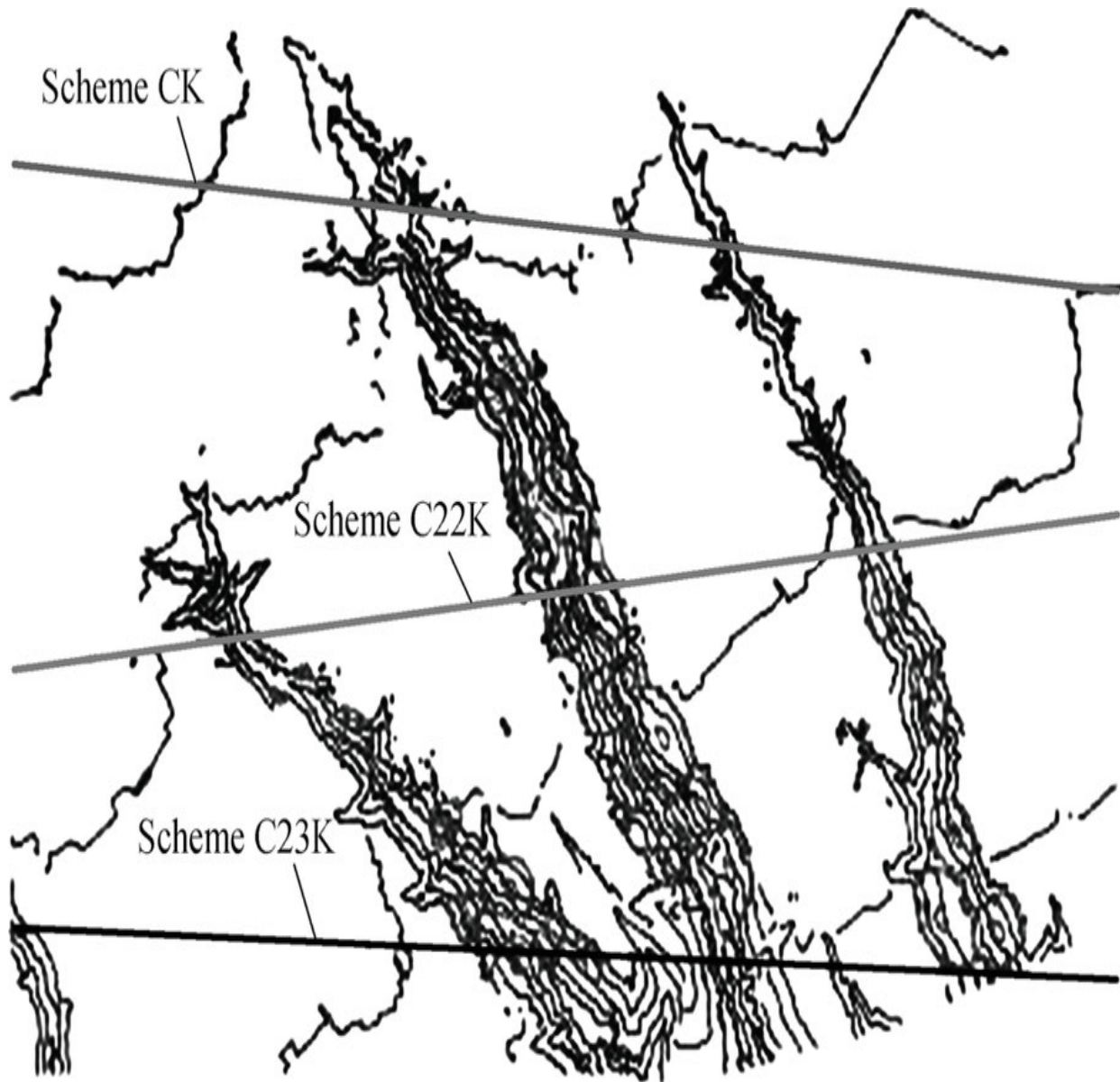


Fig. 4.28 Loess landslide distribution condition in the Xinzhuang area.

Preliminary survey period of this route focuses on research of long tunnel CK scheme on plateau, short tunnel C22K scheme on edge of plateau and C23K scheme in which route extends along Jinghe River. In terms of C23K scheme, expense spent in handling loess landslide at tunnel portal is

relatively high and it cannot be ensured that after handling, tunnel portal will not be impacted by rainfall or secondary loess landslide resulted by it will not occur. In addition, the slope instability of tunnel portal cannot be avoided. Therefore, it is hard to ensure the railway's safety. Although the C22K scheme bypasses loess landslide, most parts of the tunnel elevation are exactly located at interface area of Quaternary system loess and Cretaceous system bedrock. Generally, such an interface is rich in water, which has a relatively big impact on tunnel. And during construction, hidden dangers may be generated easily and thus impact construction safety. Through comprehensively weighing advantages and disadvantages, schemes C22K and C23K were abandoned, while scheme CK was finally selected.

4.5.5 Location in Karst Zones

A limestone zone usually has severe funnel holes, namely the so-called "karst."

As the sinkhole phenomenon is formed under the dissolving effect of deep subsurface flow, it is very dangerous to build a railway in the zone with such a phenomenon. Route selection scheme passing zones with dissolve sinkhole depends on the nature and distribution area of sinkhole phenomenon. If the dissolving area is large, the whole area threatened by the dissolving sinkhole shall be bypassed wherever possible. If bypassing is unavailable, or engineering investment will increase considerably due to bypassing, the route shall pass through the area with a relatively low risk of dissolving sinkhole. In addition, necessary treatment measures shall be taken.

Taking Yichang-Wanzhou Railway as an example, at that time, as being restricted by locomotive tractive effort and to meet the need of railway transport capacity, to improve operation condition and reduce operating cost, route was designed with relatively gentle gradient, i.e., ruling gradient of 9‰ and dual-locomotive pusher grade of 18‰. However, in bridge construction technology of Yichang-Wanzhou, many railway bridges whose type, span, and height enjoy leading position in China, Asia, and even the world by technical innovation and tackling key problems in science and technology are employed. This enhances the railway's capacity in adapting to topographic conditions, further elevates route elevation and reduces the impact caused by unfavorable geological conditions, such as landslide, talus, collapse, rockfall, and deep karst developing horizontally, etc. To prevent risk and disaster, advanced forecast and predication of tunnel construction geology in complex karst zones are designed in detail and brought into construction procedure during construction. Innovative disaster alarm system design and meteorological and hydrologic observation design are carried out for tunnel construction in complex karst zones. Meanwhile, inspection is carried out after construction for karst tunnel basement, periphery and hidden karst of karst cutting basement. In addition, treatment measures are put forward on the basis of inspection, analysis, and research.

As another example, Chongqing-Lichuan Railway (hereinafter referred to as Yuli Railway) is located at transitional zone from northeastern foot of Yunnan-Guizhou Plateau to eastern edge of Sichuan Basin, with route connecting to Yichang-Wanzhou Railway in the east. Yuli Railway passes through anticline of Qiyao Mountain by Yujia Tunnel. This anticline features with close fold and steeply plunging stratum. Besides, petrofabric of each aquifer has a banding distribution. Lower Triassic Series Daye Fm (aquiclude,

including shale) and Permian Series impure carbonate rocks outcrop often exist in axial part of anticline. The two wings are Jialing river group of pure carbonate rocks, earth surface ponor, corrosion depression, and funnel which develops along bedding surface or longitudinal fracture in beaded shape. Plentiful rainfall supplies plenty of water to groundwater through these vertical karst channels and solution cracks. If the route passes through the bottom layer of soluble rock, it will result in risk of water inrush, mud inrush, environmental damage, etc. during construction.

Groundwater in anticline of Qiyao Mountain is mainly karst pipe water with drainage type of stripped anticline and transverse valley, as shown in Fig. 4.29.

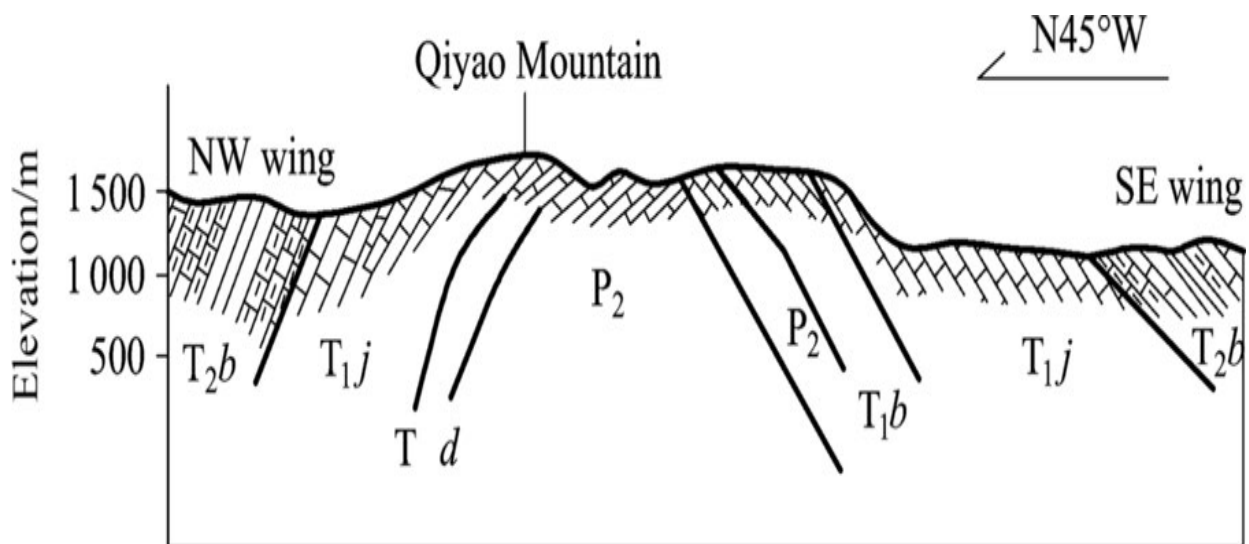


Fig. 4.29 Sketch map of anticline groundwater flow direction in Qiyao Mountain.

Through analyzing geological structure, groundwater features and underground river system in detail and

integrating geographical and geological location factors, such as terrain, surface feature, karst engineering geological condition, Longdong cavern super major bridge site, Xindou Mountain National Reserve, etc. northern line and southern line proposals are studied and compared emphatically for route passing through Qiyao Mountain section. Here, 75 m bridge and 95 m bridge southern line proposals are mainly studied, as shown in Fig. 4.30.

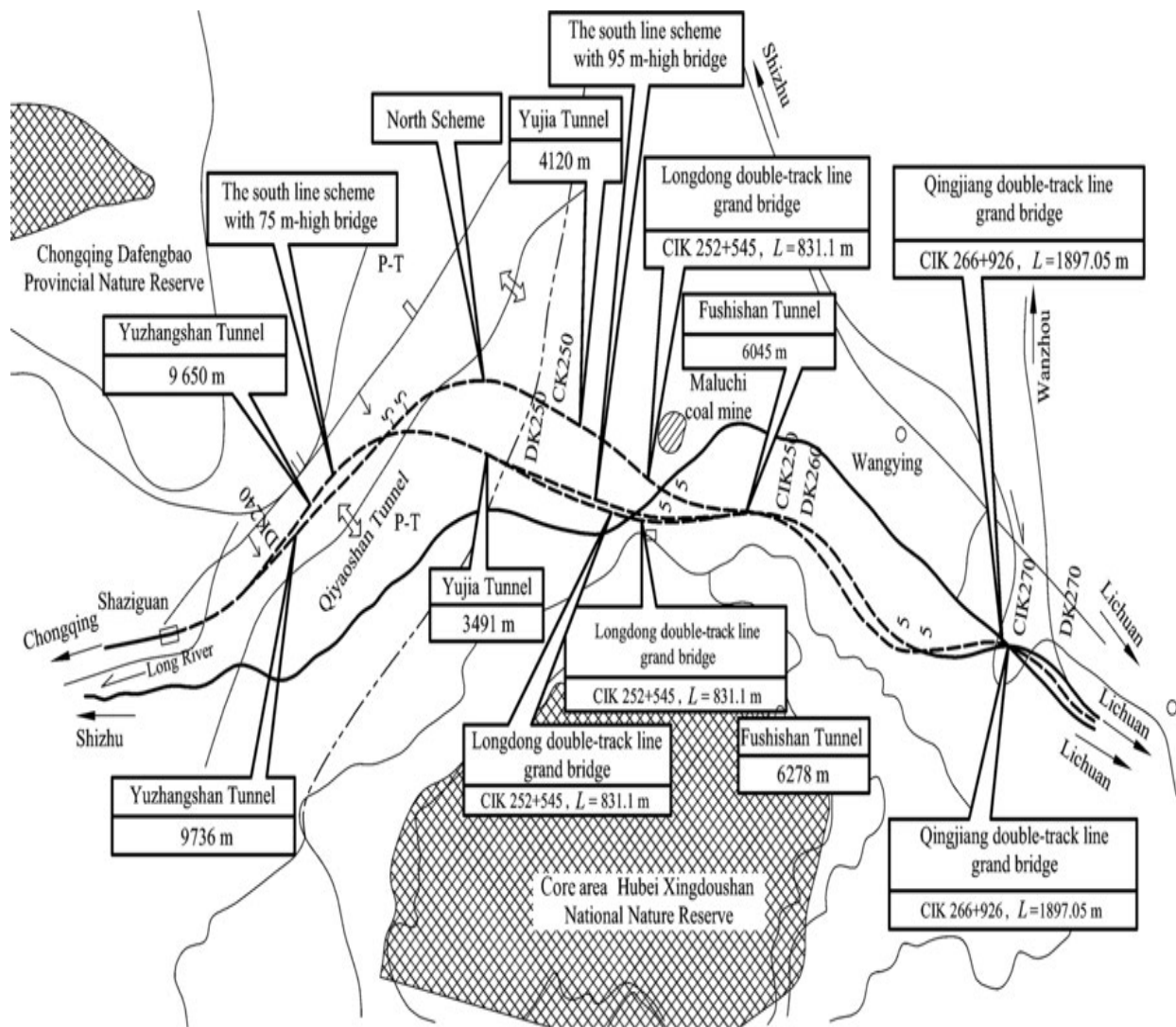


**Fig. 4.30 Route scheme sketch map of Yuli Railway
Qiyao Mountain area.**

The southern line proposal studies 75 m bridge and 95 m bridge southern line schemes.

Advantages of the 75 m bridge southern line scheme are that the height of Longdong cavern double-line super major bridge pier is only about 67 m and that the route totally bypasses Xingdou Mountain National Reserve. The proposed Yujia Tunnel can use construction experience of Shanghai-Chengdu Expressway Qiyaoshan Tunnel for reference to reduce construction risk, which contributes to construction safety and investment reduction. The disadvantage of this scheme is that Fubaoshan Tunnel passes through a relatively long swelling-rock section.

The advantages of 95 m bridge southern line scheme are that the height of Longdong cavern super major bridge pier is lower than that of the northern line scheme and that the route totally bypasses Xingdou Mountain National Reserve. The proposed Yujia Tunnel can use the construction experience of Shanghai-Chengdu Expressway Qiyaoshan Tunnel for reference to reduce construction risk, which contributes to construction safety. The disadvantage of this scheme is that the geological conditions of Dutingshan Tunnel entrance and exit are relatively poor. At the entrance, dangerous rock and rockfall develop. In addition, the entrance is located at edge of landslide mass and treatment is necessary. The height of Longdong cavern double-line super major bridge pier is about 8 m greater than that of the 75 m bridge scheme. Therefore, the bridge span is large; construction is relatively difficult; and investment is relatively increased.

The advantages of the northern line scheme are that the route totally bypasses Xingdou Mountain National Reserve and that the Fubaoshan Tunnel passing through relatively short swelling rock section. The disadvantage of this scheme is that the height of Longdong cavern double-line super major bridge pier is 127 m, increasing construction difficulty and investment. The elevation of Yujia Tunnel is lower than that of Shanghai-Sichuan Expressway Qiyaoshan Tunnel which is under construction, and Yujia Tunnel is far away from the Expressway Qiyaoshan Tunnel, which increases construction risk and investment, relatively speaking.

Landform, formation lithology, and geologic structure of these three schemes are basically the same. All of the schemes pass through the anticline of Qiyao Mountain with a wide angle. The groundwater is karst pipe water. The southern line scheme is close to Shanghai-Chengdu Expressway Qiyaoshan Tunnel; its elevation is higher than that of the expressway tunnel, and its route is located in a downstream direction from the groundwater. Construction of the expressway tunnel indicates the engineering geological and hydrogeological condition of this region to some extent, intercepts and drains off groundwater flowing to the route and improves the construction condition of the proposed Qiyaoshan Tunnel. Taking into account environmental protection and construction risk, the southern line scheme is better than the northern line scheme.

Combining with the engineering geological conditions, the route selection sticks to principles that the route is elevated as much as possible and passes through the corrosion groove of Qiyao Mountain in the manner of subgrade, so that the groundwater recession, surface water loss, or spring loss of Qiyao Mountain corrosion groove will not result, and that the construction risks of Qiyaoshan Tunnel will be reduced; meanwhile, the height of Longdong cavern bridge pier is

reduced and Xingdou Mountain national level nature reserve in Hubei Province is bypassed wherever possible. Due to the 75 m bridge southern line scheme, the height of Longdong cavern double-line super major bridge pier is only about 67 m, and the route totally bypasses Xingdou Mountain National Reserve. The proposed Qiyaoshan Tunnel can use the construction experience of Shanghai-Chengdu Expressway Qiyaoshan Tunnel for reference to reduce construction risk, which contributes to construction safety and reduces project investment. Therefore, the 75 m bridge southern line scheme is recommended.

The following basic guidance principles of route selection can be concluded through studying the route selection of karst tunnel in Yuli Railway Qiyao Mountain area and analyzing and summarizing feedback information obtained during construction:

- (1) Regional geological structure, karst groundwater environment, and underground river system shall be analyzed and studied systematically, to ascertain the regional geological structural conditions and find out the activity rhythm of groundwater and interrelation between underground rivers and surface water environment.
- (2) Route height of crossing mountain zone shall be elevated as much as possible to facilitate route passing through peak and corrosion groove areas, reducing length of tunnel and making the route be located at a relatively safe zone where seasonal variation of karstic water exists.
- (3) The route shall not be extended along the contact zone of soluble and non-soluble rock, and may pass through with a large angle if necessary.
- (4) The route shall as close as to the existing underground structure to take full advantage of the defective area formed

by the existing underground structure. In addition, data related to the underground structure under construction and the existing data shall be fully collected and utilized to provide scientific reference or a basis for route design.

4.5.6 Location in Marsh Zones

A marsh is a kind of zone where supersaturated water exists on the ground for most of the year. It can be divided into lowland marsh and upland marsh according to its location. Upland marsh usually exists in watersheds and is generally formed due to atmospheric precipitation on impervious ground. Such marsh is not deep, so it will not seriously affect the railway construction.

Lowland marsh is composed of lake-marshes where plants grow and of old river beds; its water source is groundwater. Such marsh is usually deep and sometimes has subsurface flow. Usually, lowland marsh cannot be used as a railway subgrade basement.

In terms of route selection in marsh zone, a route shall pass through the zone with the narrowest and shallowest marsh. In addition, the selected marsh zone shall not have cross fall or its grade shall not exceed 1:20.

If the sludge is not thick, the passing scheme is usually adopted, as it is more economical than the bypassing scheme; however, if it is thick, the passing scheme and the bypassing scheme shall be compared.

4.5.7 Location in Permafrost Regions

It is possible for the temperature to be subzero for a fairly long-term period in underground layers at certain depths. This phenomenon is called “permafrost.” Route selection in the permafrost region shall comprehensively analyze the soil type of permafrost, humidity of active layer, and degree and depth of water content of permafrost, etc.

(1) During route selection, the zone with high-humidity soil layer shall be bypassed wherever possible and the route shall pass through the gentle hillside of relatively high or low platforms.

(2) The higher the water content of permafrost is, the more disadvantage for railway construction this is, and especially, the impact on the railway station construction will be greater. Therefore, permafrost zones containing much water should be bypassed wherever possible. If such a zone is difficult to bypass, the relatively thick turf insulating layer should be used to make the ice layer remain frozen.

(3) The depth of the permafrost has the biggest impact on route selection. The railway location scheme shall maintain a permafrost zone in a natural state so as to use it as a basement of the route. The route should not pass through permafrost in road cuttings. If this is unavoidable, it is better to adopt designed expanded-form road cutting. In addition, the turf and vegetation shall be reserved to be used as an insulating layer.

In terms of location in valley or hillside in permafrost, a southward or westward slope with much sunlight and relatively little active layer temperature change is better.

4.5.8 Location in Desert Regions

The main climatic features of desert and semi-desert region are gales and great temperature changes throughout the year. In desert and semi-desert regions, reducing the risk of sand burial should be considered in railway location as much as possible. Attention should be paid to the following issues during location:

- ① The route shall go forward along following predominant wind direction and the section with relatively mild sandstorms shall be given priority.
- ② As long as the original covering layer is not damaged, the route can pass through fixed dunes.
- ③ When the route passes through semi-fixed dunes, temporary protective measures can be taken to fix the dune. A sandbreak forest can be planted after railway is opened to traffic.
- ④ A route passing through sand dune zones shall adopt road cuttings wherever possible, and embankments shall not be adopted.
- ⑤ The route shall bypass active dunes wherever possible. If it is necessary to pass through these, a protection method shall be studied carefully; the route shall be parallel or at a relatively small angle to the predominant wind direction; the route shall use the curve as little as possible to avoid accumulating sand.

4.5.9 Location in High-Intensity Earthquake Regions

Earthquakes are a phenomenon of crustal movement. Most of earthquakes happen in bending mountain system regions, i.e., the Pacific Ocean and Alps-Caucasus-Himalaya.

Earthquake can be divided into megaseisms and microseisms. Megaseisms can be felt by human beings and are also called felt earthquakes. Microseisms cannot be felt unless instruments are used. At present, earthquakes are divided into twelve grades according to their intensity. The intensity of the first grade earthquake is the weakest, while the twelfth-level earthquake is very destructive. Besides, the destructive power is very big.

In China, the occurrence of intense earthquakes is relatively frequent in Gansu and the western part of Yunnan. Following these two regions, Xinjiang, Anhui, Sichuan, Heilongjiang, Hebei, Taiwan, etc. sometimes also have earthquakes.

The impact of earthquakes must be taken into account when building railways in earthquake regions.

Damage degree of the same grade earthquake varies with different geological conditions, saturation conditions of groundwater and properties of building, etc. In terms of traffic facilities, bridge, culvert, high filling and deep cutting subgrade, tunnel and other artificial structures are the first ones to be damaged. The earthquake damage on tunnel is relatively light than that on high and large-span bridges and high filling and deep cutting subgrades. The higher the subgrade is, or the deeper the road cutting is, the more severe damage on subgrade is. Soil property on the bottom surface of subgrade has a significant impact on damage

degree. If the subgrade is constructed on rock stratum soil or dense rock, the damage will be relatively light, while, if it is constructed on soft soil, the damage will be relatively severe.

The stability of railway engineering structures cannot be ensured if the route in the earthquake zone passes through bold shore, gully, gorge, landslide, collapse, talus and quick-sand zones, etc., or is located at a fault zone or near a zone whose terrain suffers from intense cutting.

If railway location is carried out in a high-intensity earthquake zone, attention shall be paid to earthquake amplification effect of special field, such as active fault, unfavorable geology, etc. and the near-field effect of near field. The route shall bypass zones with large-scale unfavorable geology development, severe earthquake damage, or severe secondary earthquake damage; if it is necessary to pass through such zone, engineering form whose shock capacity is high and which is easy to be repaired shall be adopted. Besides, the following principles shall be abided by:

(1) The route shall bypass active fault wherever possible. In terms of wide active fault zones, if bypassing is unavailable, a relatively stable part shall be selected on the basis of making a thorough investigation of regional active fault structure and difference of stability. For example, a “safety island” with relatively weak activity shall be selected. Otherwise, the route can pass through a zone with a relatively narrow fault width with a wide angle.

(2) Route development shall not be carried out in the active plate of an active fault. Major engineering shall be laid on the passive plate of a structure wherever possible. At the end and corner of an active fault, large buildings which are hard to repair, such as high bridges, tunnels, high filling and deep cutting subgrades, etc. shall not be constructed.

(3) When the route passes through an active fault, reasonable position with angle facilitating rescue shall be selected by combining with a tunnel structure. The short tunnel group shall be avoided for the route and double track railway should be constructed, respectively. The tunnel portal shall bypass areas with unfavorable geology development, such as collapse, landslide and dislocation, etc., and sections with disadvantages such as vulnerable ridges, isolated mountain tops, etc. Sections with straight slope and complete rock mass are better to use as portals. The principle of “earlier entrance and later exit” shall be implemented in portal location selection.

(4) The route shall bypass fault bundles wherever possible. If this is unavoidable, high bridges, tunnels and high filling and deep cutting subgrades should not be located in such areas.

(5) When subgrade engineering is employed for a route, the route shall pass through zones with a relatively narrow range of non-liquidation soil layer. When soft soil is used to construct subgrade, if it is located at the ninth-grade earthquake area, the height of subgrade shall not exceed 12 cm; if it is located at the eighth-grade earthquake zone, the height shall not exceed 15 cm.

(6) The subgrade shall not be constructed on abrupt slopes. It is also inadvisable to construct subgrades on steep half hillsides. On stone half hillsides, a part tunnel is proper, while a part cut-part fill subgrade is inadvisable.

(7) Reasonable plane position and elevation shall be selected when a route passes through debris flow development zones. A route shall pass through from favorable sections and with reasonable engineering types to avoid the damage on railway caused by debris flow disaster induced by earthquakes.

(8) The route shall bypass zones where there is any possibility of shallow earthquakes inducing secondary geological disasters. It shall also bypass latent unstable slope, soft hillside accumulation formation, unstable cliffs and deep gullies and towering isolated hills where large-scale landslide and collapse and earthquake secondary geological disasters may occur.

4.5.10 Location in Reservoir Region

In terms of location in reservoir region, the elevation of a route must be at least 0.5 m higher than the maximum water level of reservoir (plus wave invasion height); in addition, reservoir bank collapse, sedimentation, and groundwater rise shall be studied. Moreover, the relationship between railway construction and reservoir planning shall be handled well.

4.5.10.1 Treatment of Reservoir Bank Collapse

Once the newly constructed reservoir begins storing water, reservoir bank collapse may result from wind wave impacting, water erosion and water level fluctuation, etc. Before location, it is necessary to ascertain the potential risk of bank collapse and the scope of influence. The route shall

be located beyond the scope of bank collapse, as shown in Fig. 4.31.

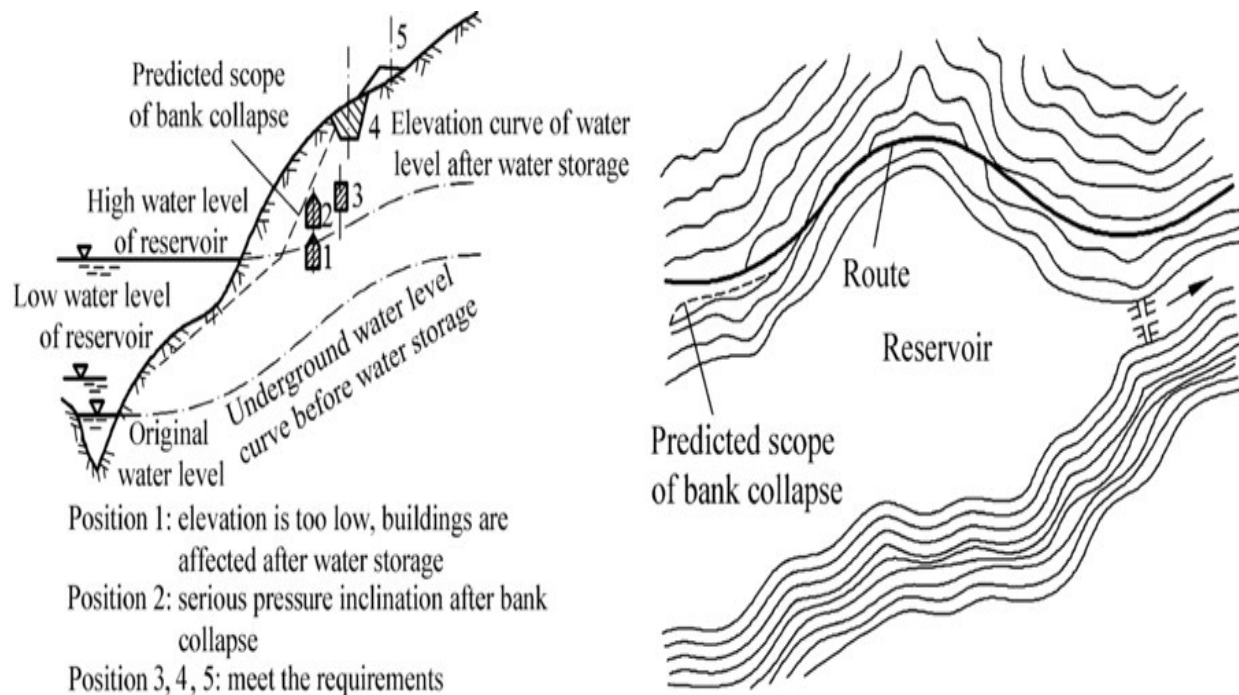


Fig. 4.31 Impact of reservoir bank collapse on route.

When bypassing is unavailable, protective and reinforcement measures shall be taken for a bank slope with potential risk of bank collapse to ensure railway safety. When the route crosses over a feeder drain of reservoir bank, the possibility of bank collapse or possible unfavorable geologic phenomena should be figured out according to property of ground and size of cross slope to correctly select and decide route position and subgrade protective and reinforcement measures by combining with arrangement of bridge and culvert.

4.5.10.2 Treatment of Reservoir Sedimentation

Within the scope of backwater of reservoir, plenty of sediment is accumulated due to slow flow rate caused by blocked current. In particular, in terms of river with high sediment concentration, the sedimentation speed may be fast, which increases the water level in backwater zones. Therefore, in respect of a route crossing over backwater zones of reservoir, its design elevation shall be increased correspondingly to ensure that necessary road shoulder height and clearance under bridge.

However, sedimentation formed due to water flow becoming slow from torrential in bank side of reservoir can protect the reservoir bank. It contributes to railway safety if the route passes through such bank side.

4.5.10.3 Treatment of Groundwater Rise

After a reservoir begins to store water, groundwater rise may result in collapsibility, mud pumping, swampiness or induce unfavorable geology, such as landslide, collapse, etc. It may also reduce the basement bearing capacity of building so that buildings are deformed by damage. Therefore, during route selection in a reservoir region, the impact caused by groundwater rise should be taken into account (see Fig. 4.31).

4.5.10.4 Relationship Between Railway Construction and Reservoir Construction Shall be Handled Correctly

Due to the construction of long-term planned reservoir not having begun, to save railway investment, route selection may be implemented as if no impact of reservoir exists after comparison. However, the agreement of relevant parties concerned shall be obtained. In cases where a reservoir construction plan has been implemented, route selection shall coordinate with the requirements of reservoir construction.

In case route passes through lower reaches of reservoir dam and that flood frequency standard adopted by dam is lower than railway standard, to avoid endangering railway safety, route shall be as far as away from dam site. Otherwise, related departments can be contracted to carry out negotiations to reinforce dikes and dams. In cases where flood frequency standard adopted by dam is equal to or higher than railway standard, the impact of a dam break can be ignored. However, if the route is located at lower reaches of dam, a certain distance from dam shall be kept to avoid endangering railway safety due to channel deformation caused by intensive scour.

4.6 Location in Sections of Bridge, Culvert, and Road Intersection

Many bridges, culverts and tunnel structures are distributed along railway line. Route and bridge and tunnel structures are interdependent and their relationship is the same as the relationship between the whole and the part. Therefore, their relationship must be considered comprehensively on the basis of overall design. Generally, super major bridges and long tunnels often have influence on partial strike-off alignment of route, while general bridges, culverts, and tunnels which enjoy a large quantity will be laid out according to route. However, to ensure the safety, economy, and reasonability of these structures, sometimes route will be changed partially according to terrain, geological, and hydrological conditions.

4.6.1 Bridge and Culvert Section

Along the railway, due to river crossing, subgrade drainage and farm irrigation, etc., structures crossing rivers and roads and hydraulic structure shall be built.

Hydraulic structures include bridge, culvert, open channel, elevated reservoir, etc. Besides, to reduce occupying farmland, dry bridge is adopted to replace high-fill embankment; to the benefit of traffic safety, flyovers are adopted to replace level crossings. Route selection must closely coordinate with bridge and culvert distribution and bridge site selection.

4.6.1.1 Bridge and Culvert Distribution

In terms of major bridges and extra-long bridges, bridge site selection is carried out according to position of rivers. Route location shall be subject to bridge site leading line.

During outline location stage, distribution of medium and minor bridges and culverts is carried out by utilizing plan and profile diagram, and will be checked on site during field process. In terms of detailed location stage, it shall be determined according to field investigation data and plan and profile diagram.

In principle, each natural river shall be equipped with one bridge or culvert. Two rivers can be merged only with sufficient reason; this means that two near water channels are combined into one before reaching the passing through the route. In the case of a combination of two bridges or culverts, the hazard arising from scour and sedimentation after realignment of natural rivers shall be estimated fully. Only when the two bridges/culverts are very close, their water collection volumes are not big, realignment work amount is small, and risk of scouring subgrade does not exist can this be considered.

In flat regions, if there is no obvious water channel in a long distance, bridge/culvert shall be constructed at intervals to drain surface water. In overflow zone, the scheme of “constructing many bridges for one river” may be adopted sometimes. The corresponding diversion and protection structure shall be coordinated with for the sake of safety.

Bridge and culvert distribution shall combine with plan location profile design and make surface water in upper reaches of railway route smoothly pass through railway, so that to ensure safety of the railway and lives and properties of people along the railway.

During culvert distribution, the existing irrigation system shall not be changed or less changed wherever possible to avoid impacting agricultural irrigation. Water outlet elevation of irrigation culvert shall be determined through negotiating with local irrigation and water conservancy department. In terms of flood drainage culvert, water accumulation before culvert shall not flood the upstream villages and farmlands. The traffic culverts shall meet the local traffic requirements as much as possible.

4.6.1.2 Bridge Site Selection

Bridge span scopes of the large and medium bridges are relatively large, including bridge beam, abutment, diversion and protection structure and bridge approach. Bridge site selection not only brings impacts on the bridge span but also often brings impact on location of route adjacent to bridge site. Bridge site selection of extra-long bridge may also bring influence on the strike-off alignment.

Major factors which shall be taken into account for bridge site selection can be reduced to several aspects, such as deviation degree from direction of the shortest route, favorable hydrological, landform and engineering geological conditions and bridge approach conditions, etc.

4.6.1.3 Deviation Degree from Direction of the Shortest Route

Generally, bridge site with relatively small deviation degree from direction of the shortest route possesses obvious advantages. Therefore, if conditions permit, bridge site shall be located at the place whose deviation degree from direction of the shortest route is relatively small as much as possible. In particularly, in terms of railway route with large expected traffic volume, to make a route short and straight, it is reasonable to locate a bridge site at a relatively unfavorable place after comprehensively analyzing engineering and operation.

4.6.1.4 Favorable Hydrological and Landform Conditions

(1) The bridge site shall be located at channel segment with stable riverbed, straight watercourse and smooth current wherever possible. Channel segment featuring with complex erosion and deposition effects, such as disorderly current, changeable flow direction, rapid change of riverbed width, etc. shall be bypassed.

(2) To shorten the length of the bridge, bridge site shall be located at channel segment with relatively narrow riverbed. Shoal, ancient stream channel, and river branch shall be bypassed.

(3) The bridge site shall not be located at confluence of relatively large branches to avoid the dramatic change of changeable erosion and deposition resulted by flood fluctuation of two rivers. Otherwise, it will endanger the safety of abutment foundation and approach embankment or lead to poor floodwater drainage. Bridge sites also shall not be located at places easily blocked by drift ice, out-of-control floating raft, and timbers. Change of erosion and deposition is particularly dramatic in outlet of river and ravine in mountain foot. Therefore, several schemes shall be made for bridge site selection and engineering measures shall be implemented to support it.

(4) The bridge shall be perpendicular to the channel and river valley wherever possible. If skew is necessary, skew angle (the angle between normal of bridge center and water flow direction) shall be reduced as much as possible to contribute to draining off floodwater and shortening length of bridge.

4.6.2 Relatively Favorable Engineering Geological Conditions

The geological conditions of place where a bridge site is located not only impacts foundation type, bridge type, bridge span, but also bridge cost, construction complexity, and operation safety. Special attention shall be paid to geological conditions during bridge site selection and determination.

A bridge site shall be located at an area with shallow bed rock burying, rigid lithology, good integrity, and small gradient. If the base cannot be located at bed rock, channel segment featuring with uniform soil property, high allowable bearing capacity and strong wash-resistance shall be selected. Unfavorable geologies, such as fault, karst and landslide, etc. shall be bypassed wherever possible.

4.6.2.1 High and Long-Span Bridge Shall be Selected Reasonably to Improve Route

The progress of long-span and high-pier bridges contributes to select relatively ideal bridge sites in zones with complex terrain and geology. For example, when a route passes through a gorge zone which has high mountains and deep valleys, a bridge is usually located at the concave section of the vertical section. If the bridge is high, then route will be straight; if the bridge is low, the route needs extending. Adoption of long-span bridges can not only

avoid high pier and unfavorable geology but also reduce the total length of line extension. Application of new technology, process, and structure in bridge engineering offers favorable conditions to high and long-span bridge scheme selection. During railway location in mountain areas, it shall be selected according to specific conditions.

4.6.2.2 Design Requirements of Bridge Approach

Design elevation of subgrade near bridge is as shown in Fig. 4.32 and shall satisfy

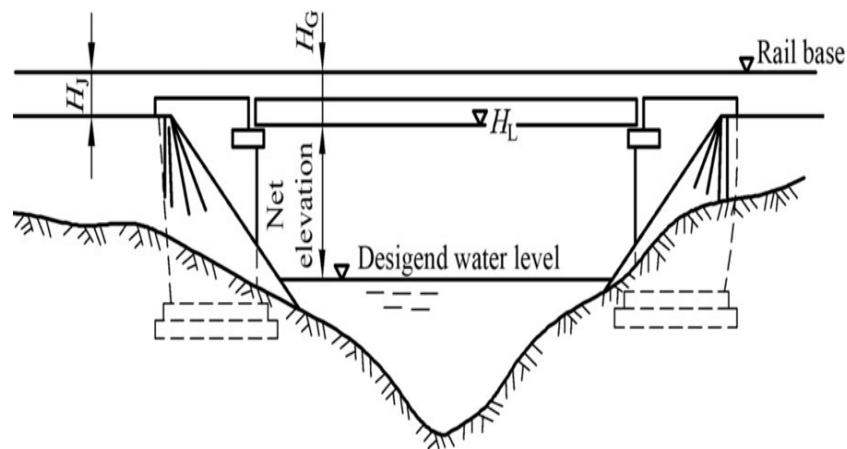


Fig. 4.32 relationship of bridge, bridgehead subgrade and water level.

(4.2)

where H_{min} is the design elevation of road shoulder (m); H_L is the design elevation of beam bottom (m); its value is determined according to design level of specified flood frequency (it is 1/100 for high speed railway and Class I and II mixed passenger and freight railways; 1/50 for Class III railway) and required clearance height which can be obtained by consulting standards issued by relevant department; H_G is the height from beam bottom to rail base (m); and H_J is the height from rail base to road shoulder (m).

In terms of zones where bridge is adjacent to tunnel, the plane and profile design of route shall be comprehensively considered in bridge type scheme. For example, when girder-erecting machine is adopted for building bridge, safety and convenience of construction implemented during girder-erecting machine erecting girder shall be taken into account in determining the plane and profile design and location of tunnel portal. When design elevation is determined, requirements of clearance under bridge shall be satisfied. In addition, attention shall also be paid to impact of muck of tunnel construction.

4.6.2.3 Subgrade Condition at Culvert

Design elevation of road shoulder near culvert shall be at least 0.5 m higher than design level of specified flood frequency (it is 1% for high speed railway and Class I and II mixed passenger and freight railways; 2% for Class III railway) plus back-water height, i.e., it requires that filling height of subgrade (h_{min}) shall be at least 0.5 m higher than height of water accumulation before the culvert (h_p).

(4.3)

To improve the force condition of culvert body, the filling of a certain thickness shall be placed on the roof of culvert to ensure that the minimum embankment height (h_j) required by culvert structure condition. The height of fill of embankment (h_h) at culvert (it is calculated from bottom of ditch) shall satisfy

(4.4)

The minimum embankment height required by height of water accumulation before culvert of the corresponding flow of various apertures and structure condition can be obtained through consulting relevant handbook related to bridge and culvert hydrological computation.

When the height of fill of embankment of profile design fails to satisfy the two requirements mentioned above at the same time, the following measures can be taken:

- ① Culvert types requiring relatively low height of fill shall be used under the condition that requirement of design flow is met.
- ② Aperture shall be enlarged and height of water accumulation shall be reduced. Dual-aperture or multi-aperture can be used to replace the single aperture. However, tri-aperture cannot be adopted.
- ③ Ditches can be properly deep excavated. This applies to gully beds with relatively deep outlets or steep longitudinal slopes.
- ④ Profile gradient can be changed and design elevation of road shoulder can be increased. Otherwise, route plane can be changed and ground elevation of culvert can be reduced.

4.6.3 Tunnel Section

During railway location, adoption of tunnel is a kind of important measure to overcome elevation barriers, reducing over mountain line elevation and bypass unfavorable geology. Reasonable tunnel layout is very important to improve quality of route selection and design. During railway location, a tunnel is often adopted when the following conditions appear:

If the route passes through watershed, tunnel is constructed at bealock, i.e., over mountain line tunnel; in terms of location along river and close to mountain, tunnel is constructed through curve cut-off or bypassing unfavorable geology, i.e., tunnel on valley line, as shown in Fig. 4.33.

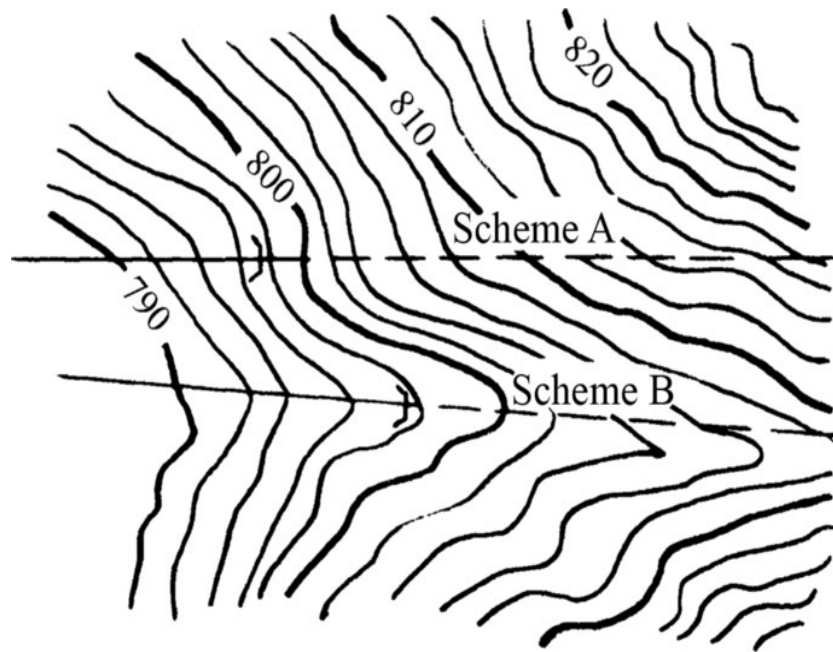


Fig. 4.33 Valley portal location comparison.

4.6.3.1 Tunnel Position Selection

Due to that position and elevation selection of cross mountain line tunnel has been introduced in the above section, it is unnecessary to go into details here. Location selection of tunnel on valley line will be described below:

Attention shall be paid to the following issues during position selection of tunnel on valley line:

- ① If burying is relatively shallow, it is better to move the route inward to avoid overpressure of tunnel.

- ② Unfavorable geologies, such as talus, landslide, etc. and the scope of river bank scouring and reservoir bank collapse shall be bypassed.
- ③ Long tunnel schemes implementing curve cut-off and scheme adopting route along river and bypassing shall be compared according to local terrain and geological condition and work amount, as shown in Fig. 4.33.
- ④ When terrain is twisty and geological condition is complex, a tunnel group usually appears in valley line. When the plane position and elevation of route is determined, sufficient attention shall be paid to mutual interference among muck, water drainage, and shortcut transportation during tunnel construction period and the impact on the existing facilities, such as water conservancy and road, etc. shall be reduced.

4.6.3.2 Selection of Tunnel Portal Position

A portal is the weakness of tunnel and improper management of portal engineering may generate disease and thus endanger traffic safety. The following factors shall be taken into account during location in tunnel section and portal position shall be selected carefully through techno-economic comparison.

(1) The principle of “earlier entrance and later exit” shall be implemented during selection of tunnel portal position; practices obsessed with shortening tunnel length and ignoring slope stability of portal shall be avoided.

It is improper to reduce tunnel length by adopting deep route cutting; otherwise, portal slope and front slope excavation will be too high. As a general rule, excavation height of slope and front slope shall not exceed 15–20 m; and when the surrounding rock is relatively poor, it shall not exceed 10–15 m; when the surrounding rock is relatively fine, it shall not exceed 20–25 m.

Portals cannot be located at the center of ditches; otherwise, engineering geological conditions will be poor and it is relatively difficult to implement water drainage and dispose muck during construction. Therefore, generally, portal is located at one side of valley, as shown in Fig. 4.33, scheme A.

(2) Portals shall be located at place with stable mountain body and good geological conditions wherever possible to ensure portal safety; otherwise, retaining and protective structures shall be constructed or portal shall be extended and open cut tunnel shall be constructed.

(3) Portals should to be located at right-angle grade crossing or near right-angle grade crossing of route and contour line; if skew is adopted, skew portal or open cut tunnel shall be constructed.

4.6.4 Intersection of Railway and Road

When the railway and road intersect with each other, to ensure traffic and personal safety, level crossing or grade separation shall be set. Intersection type shall be determined according to design speed of railway, property, grade, traffic volume, terrain condition, safety requirement, economic and social benefit, etc. of railway and road. Generally, grade separation shall be given priority to reduce level crossing.

4.6.4.1 Setting Conditions of Grade Separation

- (1) If s high-speed railway and road intersect with each other, grade separation is a must. In terms of dense road, grade separation shall be set after considering suitable combination and shift.
- (2) In the case of mixed passenger and freight railway intersects with expressway, the first-class highway, and express way of urban road, grade separation must be set.
- (3) If the mixed passenger and freight railway intersects with other road, grade separation shall be set when one of the following conditions is met:
- ① Class I railway intersects with other roads;
 - ② Railway intersects with secondary road;
 - ③ Railway section with design running speed of passenger train greater than or equal to 120 km/h;
 - ④ Railway intersects with road and the converted traffic volume at crossing in the fifth year since being put into use is greater than or equal to the specified value in Table 4.2;

Table 4.2

Converted Traffic Volume at Crossing With Grade Separation (10,000/Annual Average Day and Night)	
Observational Conditions	Speed of the Section (km/h)

100

80

Good	12.0	16.0
Poor	6.0	8.0

Note: The observational conditions satisfying Table 4.2 are good; otherwise, they are poor.

- ⑤ Grade separation is able to be set on considering terrain condition or bridge and culvert condition;
- ⑥ Due to special needs, grade separation shall be set.

4.6.4.2 Structure Gauge of Grade Separation Between Railway and Road

- (1) When a road crosses over mixed passenger and freight railway, structure gauge of railway shall conform to regulations of national standard “Structure gauge for standard gauge railways” (GB146.2). Railway with double-stacked container transportation demand shall satisfy the requirement of double-stacked container transportation limit.
- (2) In terms of flyover crossing passenger dedicated line, the net height under bridge shall not be less than 7.25 m. When passenger dedicated line crosses beneath the existing flyover, the relatively low net height can be adopted after technology and economy comparison and selection.
- (3) When a road crosses beneath railway, structure gauge of highway, factory-out road and urban road shall conform to regulations of the existing relevant department standards and specifications.
- (4) When a railway intersects with the planned highway (road), crossing condition of planed highway (road) shall be taken into account.
- (5) When the rural road crosses beneath railway, clearance of rural road shall be determined according to the channel type and crossing condition and through negotiating with relevant units. However, it shall not be less than the specified value listed in Table 4.3.

Table 4.3

Clearance of Rural Road Under Flyover

Channel Type	Automobile and Large Agricultural Machinery	Machine-Cultivated Vehicle and Anima
Clear width (m)	5.0①	4.0
Clear height (m)	4.5②	3.0

Notes: ① It can be reduced to 4.5 m under extremely difficult conditions. ② It can be reduced to 3.5 m under extremely difficult conditions.

4.6.5 Setting Condition of Crossing

(1) Crossing shall be located at place where range of visibility is not less than specified value of Table 4.4. For crossing of double track railway with distance between two tracks no more than 0.5 m, 50 m shall be added to lateral minimum range of visibility of automobile driver. Crossing of multi-track railway shall be determined though calculation.

Table 4.4

Minimum Range of Visibility

Speed of Railway Section (km/h)	Minimum Range of Visibility of Train Driver (m)	Lateral Minimum Ra
100	850	340
80	850	270

Notes: Lateral minimum range of visibility of automobile driver is the range within which, the driver can see trains on railways at its both sides at when the motor vehicle is at the road stopping sight distance (no less than 50 m) of crossing equivalent to its grade.

(2) Crossings cannot be located inside the station. It also cannot be located at railway curve section and be placed near turnout, bridgehead and tunnel portal.

(3) The distance between crossings shall not be less than 2 km.

(4) Level crossings of railway and road are better to be right-angled; when they are skew, the crossing angle shall be greater than 45° .

4.7 Railway Environment Location

Railway environment location, also called “green location,” means various environmentally sensitive problems are avoided and solved at the early stage of railway survey and design, i.e., environmental protection concept is integrated into railway location. During route scheme selection, natural conditions, such as terrain, geology and hydrology, etc. are considered comprehensively from the perspective of environmental protection and sustainable development. In particular, the limitation of scenic spot, natural reserve and ecological environment factors on route scheme shall be considered and comprehensive assessment on environmental impact shall be implemented for several schemes, so that to select the scheme which has minimum influence on environment.

4.7.1 Environmental Problem Related to Railway Location

The railway construction will bring some impacts on natural, human, landscape and ecological environments, etc. along the line in varying degrees. Relevant environmental problems include the following aspects:

- (1) Land and cultivated land occupation

Land, especially cultivated land, is extremely valuable as a natural resource. Because railway construction will occupy various land resources, these lands will lose their original function. Meanwhile, land occupation for railway construction will speed up reducing of cultivated land which is not much yet and intensify the pressure on remaining cultivated land.

(2) Geological disaster triggering

Railway construction, subgrade excavation or filling will change partial landform, which is easy to give rise to geological disasters, such as collapse, landslide, debris flow, etc. in zones with vulnerable geologic structure.

(3) Impact on ecologically sensitivity zone

A long railway transportation line will pass through various ecological systems, such as various natural reserve zones, wildlife protection zones and habitats, soil and water loss major prevention zones, forest parks, patches of forest and grassland, water resource zones, wet lands, etc. In the case of passing through such zones, the impacts on ecological balance and damage natural environment will arise.

(4) Gallery effect

A railway is a channel for communications between cities and is also a gallery for inter-relationships of human. For biology, especially land animal, railway is a barrier and plays a role of separation and obstruction. This effect of the railway separates the activity place of animal and sometimes even cuts off their route to water, thus impact their living environment.

(5) Soil and water loss

Railway construction may damage the ground vegetation and make surface soil bare, which will significantly reduce the corrosion resistance of soil. In addition, railway engineering construction will also produce plenty of soil borrowing work or spoil, muck, etc. These unconsolidated rocks and soils have big holes and loose structure. If they do not get proper treatment, new soil and water loss will be generated.

(6) Noise, vibration and electromagnetic radiation

Noise generated during train operation interfere people's normal life and rest and impacts physical and psychological health, which also leads to lower working quality. Vibration generated during train operation also has an impact on human body, building, precision equipment and cultural relics, etc.

Given environmental protection, electric traction is better for train traction. Electric traction has high thermal efficiency, reasonable energy utilization and is able to realize zero release and no pollution. Therefore, if conditions permit, electric traction shall be given priority. However, when electric traction is adopted, the separation and combination of strong current in high-power transmission wire, pantograph and overhead line may generate relatively strong electromagnetic interference to the ambient environment, may affect normal operation of railway communication and signal equipment and result in adverse impact on normal use of sophisticated electronics and digitizing automatic control equipment along the line. Interference level generated by electric traction is related to many factors such as running speed of locomotive, route condition, etc. When speed of electric railway train increases to over 140 km/h, radio interference will increase substantially and its scope of influence will surely expand

with it. Especially, when railway passes through dense residential zones located at two sides of the railway, impact of electromagnetic radiation generated by electric railway cannot be ignored. Therefore, if electric traction is adopted, measures for preventing electromagnetic radiation shall be taken.

(7) Atmospheric pollution

In terms of atmospheric pollution generated by railways, it mainly results from dust during construction and gaseous pollutants discharged by locomotive after operation. The internal combustion traction needs expensive fluid fuels; steam traction has poor thermal efficiency and is energy-wasting. Both of the two traction methods discharge harmful gas. In particular, smoke, slag, grease dirt, waste water, etc. of steam locomotives are a primary pollution source. Therefore, if the internal combustion traction or steam traction is adopted, the corresponding environmental protection measures shall be taken.

(8) Travel obstruction

Railways contribute to social and economic development of their region. But meanwhile, considering the factors, such as environmental protection, safety, etc. the closed channel will be constructed in the zone passed through by train. Certain separation may be caused by social and economic activity on both sides of the railway due to obstruction of railway. It will impact information transfer, exchange of raw material and finished product and travel of resident at both sides of railway.

(9) Protection of landscape resource

Landscape resources, such as peculiar landform, precious and ancient tree, rare living beings, historical relics, gorge,

brook, etc. are important national landscape resources. At the railway location stage, landscape resource shall be detoured wherever possible; otherwise, engineering technology measures shall be taken to protect it.

(10) Impact on other infrastructures

The railway construction sometimes will disturb other infrastructures along the railway, e.g., communication facilities, water conservancy irrigation and drainage facilities, impoundment and flood-control project, and electric power facilities, etc. Disturbance on such infrastructure shall be avoided during the railway location.

4.7.2 General Principles of Railway Environment Location

(1) Coordination between the new railway and urban construction plan

Route selection shall be combined with urban and rural construction plan to coordinate with urban and rural development. Integrity of planning land use shall be maintained. Routes shall avoid passing through dense residential areas, commerce and trade centers, and important culture and science parks.

(2) New railway construction should avoid to damage on the natural landscape, human landscape, cultural relics and historic sites and national cultural heritage

Railway location and site selection should bypass environmentally sensitive areas, such as natural reserve zone, landscape and famous scenery, drinking water protection zone, national important cultural relic protection unit, etc. If the environmentally sensitive zone cannot be bypassed, provisions of relevant laws and regulations shall be abided by. In addition, proper noise and vibration reduction measurements which can mitigate adverse effect shall be taken.

(3) Attention paid to resources protection

The mineral resources and ecological resources shall not be covered during route location.

(4) Attention paid to ecological environmental protection

Attention shall be paid to protect living environment and soil and water environment of flora and fauna along railway. Therefore, railway location shall comply with the following principles:

(1) Land-saving principles

Railway construction occupies plenty of land. During location design, it is necessary to pay attention to arrange and lay out route reasonably, select and use railway construction standard and technical indicator properly, reduce subgrade height and two-side slope, filling, excavation and soil borrow land occupation. Land used temporarily for the railway shall be repaired, recovered, and utilized in a timely fashion.

When a railway passes through ecologically and environmentally sensitive zone located in hill terrain, it is better to use overhead line to reduce ecological damage caused by earth surface excavation during construction.

After completion of construction, green belt can be constructed at two sides of railway to recover green ecology and protect ecological environment.

High filling and deep cutting engineering shall be used as little as possible with respect to location in mountain ridge and hilly area. Effects on soil and water environment and ecological environment caused by railway construction shall be reduced as much as possible. Therefore, the following location schemes can be adopted:

(i) The maximum gradient and minimum curve radius standard shall adapt to the terrain to decrease length of line extension, high filling and deep cutting, and thus to reduce railway land use, fertile farmland occupation, vegetation damage, part of soil and water loss and impact on slope stability and to safeguard ecological environment.

(ii) Linear requirements of a railway can be properly lowered. When route passes through ecologically and environmentally sensitive zone, if adoption of gentle gradient and recommended value of curve radius will result in high filling and deep cutting, linear requirement can be properly lowered and technology condition under difficult conditions can be adopted to reduce high filling and deep cutting and to avoid damaging environment and ecology.

(iii) During railway location, if deep cutting section appears, tunnel engineering can be increased properly according to geological conditions.

(iv) Subgrade section should have balance filling and cutting to make subgrade cut-fill adjustment can realize filling using cutting material, so that to reduce borrowing and discarding earth and stone and reduce cultivated land occupation. Tree and grass should be planted within scope of land acquisition

at both sides of subgrade so that to carry out green work and maintain ecological environment. Subgrade of high speed railway should adopt protective measures combining green plant protection with engineering protection. Besides, requirements of beauty, environmental protection, soil and water conservation, land saving, etc. should also be considered.

(2) The continuity principle of original ecological system

Although an ecological system has certain self-healing functions, damage and change of any element or procedure will affect the stability and existence of the system.

Therefore, the continuity of an original ecological system shall be ensured by any possibility during the railway construction. Especially, the corresponding measures shall be taken for some natural reserve areas, wetlands ecosystems, wildlife protection areas, and water resource conservation zones.

(3) Natural vegetation protection principle

Natural vegetation in an ecological system is an environmental element which can adjust the system.

Therefore, natural vegetation along railway shall be protected to ensure stable development of an ecological system.

(4) Ecological environment recovering principle

After completion of railway construction, the original natural ecological system has been damaged and it is difficult to recover this completely. In this case, new ecological balance system shall be established. Therefore, directional design, especially greening design, and environmental protection design are required for location.

(5) Assessment of effect on natural environment along river exerted by route location scheme of river valley zone shall be reinforced

When railway location is carried out in a river valley zone, interaction of route location engineering and river shall be considered in detail. Not only the influence on route exerted by natural environment along river shall be studied, but also the influence on natural environment along river exerted by railway project after completion of railway construction shall be studied. Route location principle of “bypassing first, combining bypassing with treatment” shall be implemented for environmentally sensitive site. In addition, various influence factors shall be analyzed comprehensively to select a route location scheme coordinating with environment and ecology. The major factors affecting railway environment location in a river valley zone include:

- (i) Selection of route scheme in which project coordinates with hydrological environment, i.e., plane design and profile design of alignment.
- (ii) Influence exerted by project on flood discharge capacity of river cross section, i.e., the change in discharge capacity made by relative plan position, altitude difference, bridge pier and abutment and flood-control project and facility of route and river.
- (iii) Influence on route exerted by natural environment along river; how a railway project deals with the threat or impact of flood.
- (iv) Influence on natural environment exerted by railway project; influence on gallery along river shall be calculated and analyzed and measures shall be taken to protect it.

(v) Change in hydrologic factors of river; future fluctuation of flood shall be forecasted; the change rule of flow and water level shall be known.

(vi) Route location and elevation of narrow gorge (canyon) zone, which mainly means location and elevation selection of special subgrade and bridge and tunnel along river.

(vii) Influence on flood discharge capacity of river exerted by bridge and subgrade along river, i.e., issue that railway project occupies part of flood discharge channel.

(viii) Influence on cross section flow of bridge exerted by river-crossing bridge, i.e., river-crossing bridge reducing flood discharge cross section when changing bank in the railway project.

(ix) Route location and elevation in wide valley zone, which mainly means location and elevation selection of unfavorable geological subgrade and subgrade along river.

(x) Influence on natural riverbed exerted by the project, i.e., change made by construction to river hydrological environment and conditions.

(xi) Influence on riverbed exerted by project muck and watercourse collecting gravel, i.e., road cutting waste or tunnel muck and material borrowed for subgrade filling.

(xii) Flood-control project layout and plan related to route.

4.7.3 Railway Environment Location Based on Natural Environment Protection

The natural environment is the foundation of human survival and development. Natural environment protection is a basic state policy of China. The railway is a stripped structure passing through long areas that often passes through zones with rich natural resources and beautiful landscape environment. If railway location alternative is unreasonable, natural environment along the line will surely be damaged; natural landscape and original style and features will be impacted, and atmosphere, water sources, and noise pollution will increase. Protecting the natural environment along the railway aims to make railway coordinate with natural environment along it. The railway shall become a part of the natural environment and be integrated into it, so that to reduce natural environment damage and realize sustainable and harmonious development of railway and regional environment. Therefore, a “more safe, environmental-friendly and economic” overall designing and guiding concept shall be implemented during railway location.

A railway location concept based on natural environment protection means that railway route is more suitable for surrounding natural environment and social environment and is more conducive to protection of natural scenery, humanity history, beautiful landscape, and other social treasures under the condition that it satisfies traffic safety, smoothness and comfortableness; it emphasizes creative spirit, advocates flexible design and calls for multi-disciplinary participation, multi-department cooperation and multi-scheme comparison. During location design, it makes location design highlight the key point of impact on environment by regional location and at the same time gives consideration to general environmental elements on the basis of fully surveying and analyzing different

geographical conditions, geology and landform conditions, geographical characteristics, mineral resource distributions, natural and human landscapes, water resource protection and acoustic environment elements, etc. of the zones passed through by railway. Meanwhile, a location scheme which gives maximum protection to natural environment and can realize optimum utilization of natural environment shall be determined under the cooperation with, support and participation of local government, relevant department and residents. Key points of route selection are summarized as follows:

(1) Investigation and analysis on natural environment along the railway

Firstly, natural and human landscapes of zones along railway shall be investigated and classified. For the zone with abundant landscape types, railway shall be integrated into natural and human landscapes and become an organic composition of background by utilizing the design philosophy based on background. Interaction of route and environment shall be analyzed and thus to promote natural and human landscapes of zones along railway and give them maximum protection.

(2) Determination of route trend in natural environmental sensitive sites along railway

Advantages and disadvantages of a route scheme shall be reflected according to investigated and collected data, by combining with topographic map, based on background design concept, focusing on characteristics of each section, given impact exerted by route on natural and human landscapes, water source, vegetation, noise, exhaust gas, cultivated land occupation, demolition, natural resources, historical and cultural relics and urban and township

development plan, etc. In addition, current and long-term impacts exerted by the route on environmental factors of environmentally sensitive sites shall be comprehensively analyzed and predicted, so as to obtain the best route design scheme which has the minimum comprehensive impact though a repeated comparison with several schemes.

(3) Analysis and assessment of natural environment effects

Effects on natural environment and landscape exerted by the location scheme of the environmentally sensitive site and section shall be comprehensively assessed through using relevant technology and method and integrating natural environment protection concept into overall process of railway location design. Assessment indicators include: coordination between plan and longitudinal section technology indicator and environment and landscape; interference caused by route on natural watercourse; damage caused by route on flood land vegetation; proportion of high filling and deep cutting section; coordination between artificial protection and landscape along railway; engineering geologic condition; water resources protection; complexity of environmental protection engineering; and environmental protection investigation, etc.

4.8 Computer Aided Railway Location and Alignment Design

In computer aided location and alignment design, it mainly takes advantage of the technologies which uses computer and its peripheral equipment and graphical input and output equipment to assist engineer in railway routes selection and alignment design, and the computer aided location and design develops with the development of computer, its peripheral equipment and graphical equipment, software, modern survey technology and its equipment. Adoption of computer aided railway location and alignment design obviously benefits design quality improvement, manpower and capital saving, and design speed acceleration. In addition, it will be an effective method which can reform Chinese traditional location methods and promote modernization of Chinese railway survey and design.

The main contents of computer aided railway location and alignment design include:

- ① Establishing a Digital Terrain Model (DTM);
- ② Line strike-selection for partial scheme of route;
- ③ Computer aided design of route plane and profile;
- ④ Optimization design of route profile; and
- ⑤ Optimization design of space alignment.

4.8.1 Digital Terrain Model

The Digital Terrain Model (DTM) means a regular or disordered digital array expressing space distribution of terrain features. That is to say, it expresses terrain surface in the form of coordinates with point of x , y , and z . If a mathematic curved surface is established based on data points to simulate actual terrain surface, elevation or other terrain information of any points of the terrain can be figured out according this curved surface.

The main forms of Digital Terrain Model applied for the railway line design include: Square Grid Digital Terrain Model, Triangulation Network Digital Terrain Model, Fishbone Digital Terrain Model, Discrete Digital Terrain Model, and Partitioning Discrete Digital Terrain Model. A brief introduction to the relevant knowledge of Square Grid Digital Terrain Model and Triangulation Network Digital Terrain Model is given in the following section.

4.8.1.1 Collection of Digital Terrain Data (DTD)

Digital Terrain Data is the basic element forming Digital Terrain Model and the function of it is equivalent to that of detail points in the process of surveying and mapping the contour line during field work. There are four frequently-used methods to acquire and structure data of Digital Terrain Model, i.e., ground survey, topographic map digitization, aerial reconnaissance, photogrammetry data acquisition, and using satellite information to acquiring data.

Ground survey: A field ground survey is the main method used to acquire data information in engineering surveying work, especially in large-scale mapping. DTD acquisition methods can be divided into three kinds according to different field work methods and used instruments and equipment, i.e., general terrain mapping method, method using ranging theodolite and electronic notebook and method using total station electronic theodolite.

Topographic map digitization: The existing topographic map digitization also becomes one of digital computer aided mapping methods. Digital computer aided mapping has seen development in recent decades. Its production scale has formed gradually in the last ten years. With no exception, all of original topographic maps (including national basic map) of all departments are all drawn by applying computer. Application of plenty of original topographic maps is required for DTM establishment in engineering. Therefore, a digitalizer is adapted to complete digitization of original topographic maps.

Aerial reconnaissance: Modern location finds the airplane a useful aid. As a means of direct, personal inspection, the engineer may fly quickly and easily over the area, covering more miles in a day than could be covered otherwise in a month. Aerial reconnaissance enables the engineer to get an overall bird's-eye view of the terrain, relating each feature to the other in proper correlation. Not every detail can be readily observed from the air. Some ground survey may be required. Aerial reconnaissance indicates where those situations exist and saves time and effort by eliminating at once portions of the area that are clearly impracticable or which require no closer observation.

Certain geological features are more outstanding and recognizable from the air. Thus not only the terrain itself but its history and general soil characteristics may be determined.

Photogrammetry: The newly developed processes of photogrammetry bring several useful and time-saving tools to the location engineer. Aerial photographs are of great help in all stages of design. Not only may aerial photographs serve as a guide in planning reconnaissance, but, when combined with contour maps and properly presented, they may also serve as a substitute for all or portions of the reconnaissance and preliminary surveys. Photogrammetry, the science of obtaining reliable measurements from aerial photographs, can greatly shorten the time and costs involved in reconnaissance and surveys.

Aerial photographs give a reasonably true representation of the ground features in conventional terms and appearance. Distance, direction, routes, water courses and lakes, wooded areas, fields, and manmade works are all clearly discernible. There are three usual types of photographs: vertical, oblique, and composite. As the name implies, the vertical photographs are taken when the camera axis is perpendicular to the earth. When the scale is known, or can be obtained from horizontal control points a known distance apart, horizontal distances may be scaled directly.

Oblique photographs are taken with a tilted lens. The tilt is usually 30° or less with the horizon. Distances cannot be scaled with the same degree of accuracy on oblique photographs as on vertical photographs, but the oblique view enables the factor of elevation to be given some qualitative value in reading the photograph (Fig. 4.34).

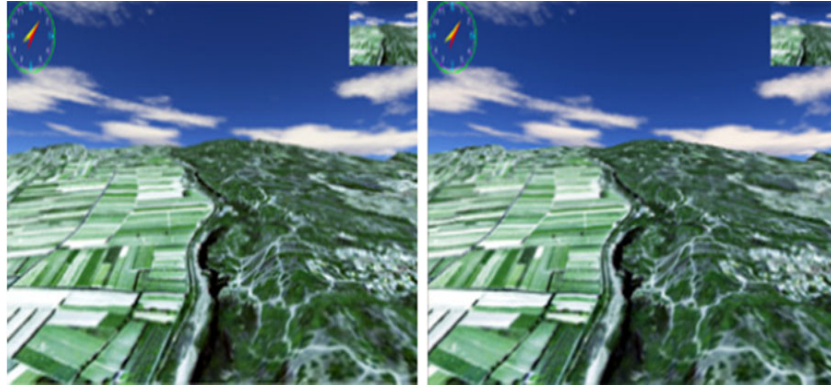


Fig. 4.34 Oblique aerial photograph.

A series of vertical photographs made successively in line during a flight over an area (such as reconnaissance area) are called strips. An overlap of about 60% in the direction of flight is usually allowed. For a wider area, parallel strips may be flown. A series of strip photographs joined together constitute a strip mosaic and permit most essentials of reconnaissance to be obtained in the office. Controlled mosaics are formed by adjusting aerial photographs to the plotted position of ground control points. (Ground controls are positions of known location and distance apart that can be readily identified in the photographs.) A certain amount of distortion occurs in a photograph, which is of no consequence near the center but becomes of significance toward the edges. Fig. 4.35 shows a strip mosaic.

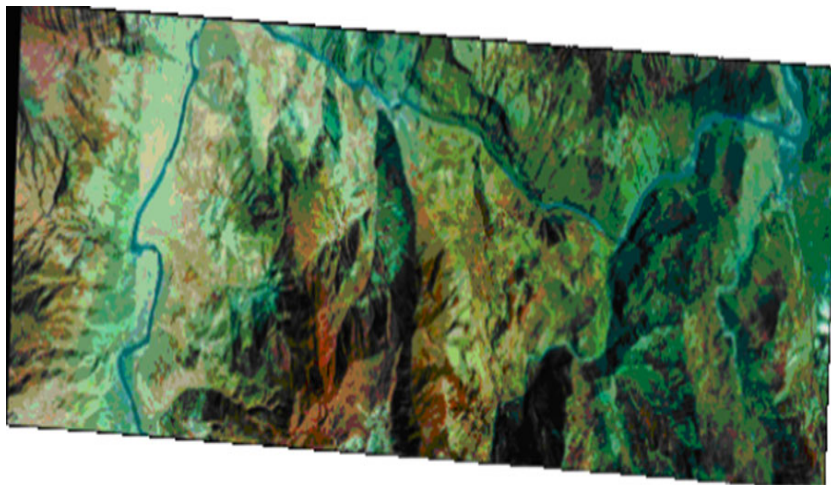


Fig. 4.35 Strip photographs showing use of aerial photography in planning a location.

Photomaps are reproductions of photographs on which grid or coordinate lines, marginal data, and names of places and objects have been added. Contours may, if desired, be drawn on the maps or placed on a transparent overlay. Translucent films with a matted surface can be used to take penciled names and notations. Prints are made from the film in standard blue-or white-printing equipment or by one of the several processes of reproduction and duplication now available. Fig. 4.36 shows such a map.

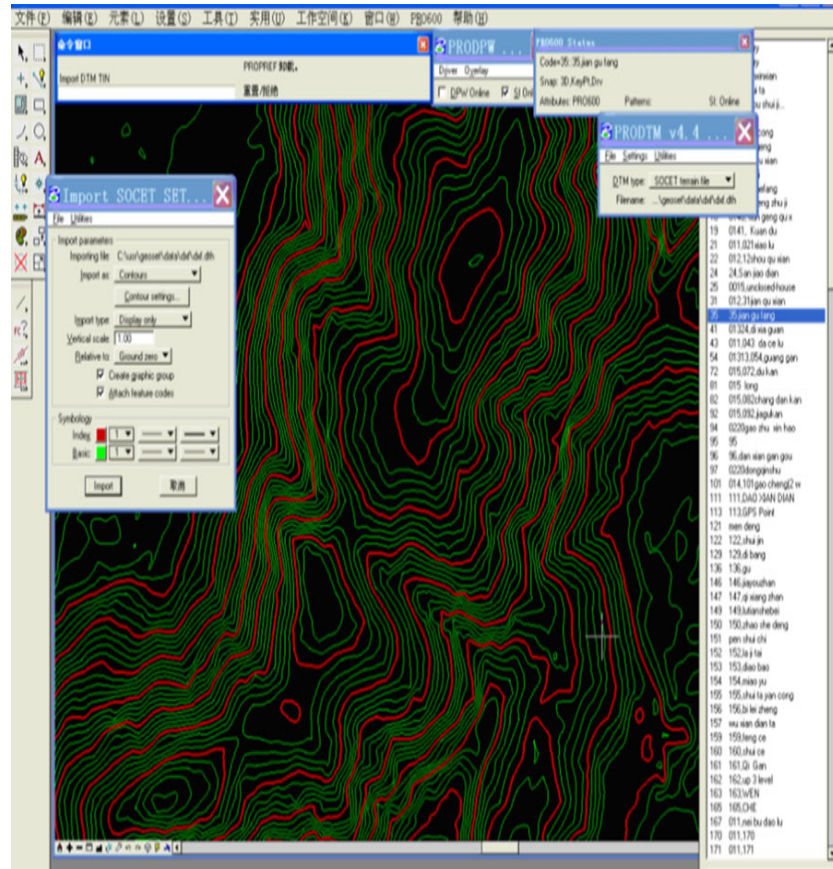


Fig. 4.36 Map fragment from aerial photographs.

Stereovision is a three-dimensional effect achieved by blending, through special eyepieces, the images of two photographs taken at slightly different points. Usually overlapping exposures are taken. The system permits a study of ground relief or topography, giving an indication of height, depth, and slope-the qualitative essentials of elevation. Relative orientation through stereo-plotter for all photos and absolute orientation according to established model scale are made. Then, use the space measuring mark to capture model points on the orientated model. By using these points, special linear structure or line of mathematical definition (e.g., contour line, longitudinal section line, etc.) will be depicted. Thus, point location or line map of surveying and mapping will be acquired. The elevation and annotation will be read out by using administration line and independent administration elevation point.

Another way in which aerial photography is used is to determine geological history and soil characteristics. Many types of soil deposits exhibit characteristic patterns when seen from the air (the oxbow lakes and channel changes of a “braided” stream channel or features of glaciation, for example). As suggested earlier, a survey of these features can be made while flying over the area. However, more study of the features is usually required than can be obtained during the flight of a plane. The aerial photograph permits such studies to be made at uninterrupted length.

Using satellite information to acquiring data is a new technology developing in recent 10 years. Main methods are to use photogrammetry and establish DTM through ground satellite picture. In recent years, great effort are being made to research a method which directly uses satellite information to obtain digital ground information and thus to establish DTM quickly in foreign countries.

Surely, the above mentioned digital terrain data acquisition methods are implemented by combining with survey and design task only when no existing topographic information database is available. Generally, Western developed countries have established the digital cartographic information database which can offer digital cartographic information in various measuring scales and storage formats. At present, China has established a topographic information database covering the whole country with scale of 1:250000, 1:50000, and 1:10000. Besides, topographic information databases with scale of 1:100000, 1:5000, and 1:1000 are under development. Once national central database is available, design units can directly obtain required topographic information from national topographic information databases according to construction project.

4.8.1.2 Types of Digital Terrain Model

The main types of Digital Terrain Model used for railway route computer aided design include: Square Grid Digital Terrain Model, Triangulation Network Digital Terrain Model, and Fishbone Digital Terrain Model.

(1) Square Grid Digital Terrain Model

1) Layout form of data points

The data points of square grid model form the grid through distribution in the regular form of square or rectangle is as shown in Fig. 4.37. For this model, it just needs to divide the railway land within a certain range into equal-sized square checker or rectangular checker, and then read the ground information of grid points in sequence. Used for railway design, the band-shaped Square Grid Digital Terrain Model always changes with different terrain types. In different sections, different grid step lengths are used in order to increase interpolation accuracy.

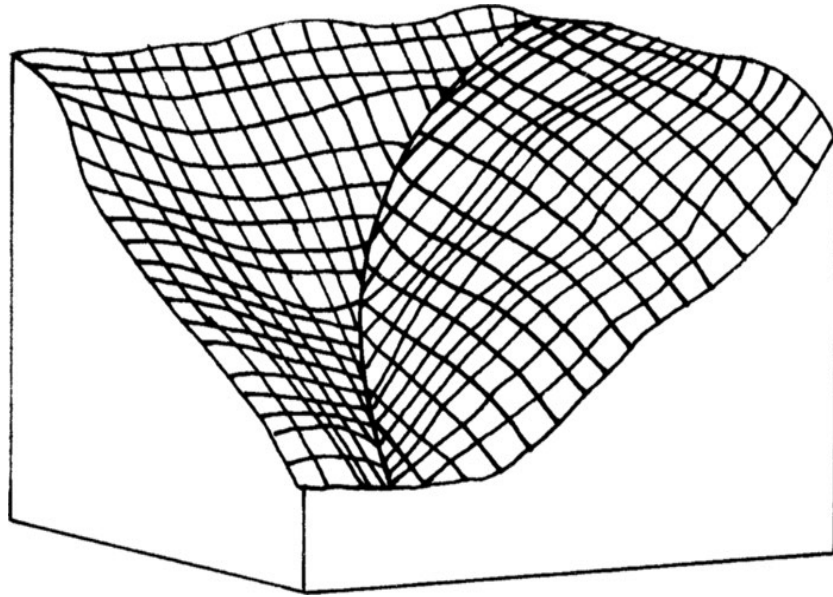


Fig. 4.37 Rectangular grid.

2) Exploration of interpolation points

Since the data of grid models are distributed in the form of square or rectangle, the horizontal coordinate increments of the square grid— Δx and Δy are constants. Horizontal coordinate of any point can be calculated according to origin of DTM (Digital Terrain Model) $-x_0, y_0, \Delta x, \Delta y$ and the row and column in the grid where the point is located; vice versa, if the horizontal coordinate of any point is known, the row and column in the grid where the point lies can be calculated, thus, ground information of the point is interpolated.

If the horizontal coordinate of any point P is known as (x_p, y_p) , the grid where point P lies and the horizontal coordinate (x_A, y_A) of point A in the bottom left corner of the grid can be calculated according to following formula:

$$(4.5)$$

where I, J are the row and column of point in the bottom left corner of grid mesh where point P lies; X_0, y_0 are the horizontal coordinate of DTM (Digital Terrain Model) origin; and L is the step distance of square grid.

The meanings of other symbols are the same as the above.

3) Ground information of undetermined interpolation points

The interpolation method selection of undetermined interpolation point in the Square Grid Digital Terrain Model has little influence on elevation accuracy; thus, a relatively simple method with higher operating rate may be used, such as the common bilinear interpolation method.

The four data points nearest to unknown point form a quadrangle, Z_p -the elevation of undetermined point is obtained according to the following formula:

$$Z_p = a_0 + a_1x + a_2y + a_3xy$$

Firstly, four coefficients— a_0 , a_1 , a_2 , a_3 are obtained by utilizing four data points, and then according to x , y —the coordinates of unknown point P , elevation Z_p of undetermined point can be obtained.

(2) Triangulation Network Digital Terrain Model

1) Layout form of data points

This Digital Terrain Model is formed by three-dimensional coordinates of all triangle vertexes. Data points are distributed at the vertexes of triangle, and connected into the triangulation network. This model is based on the assumption that there is a ground which is accurate enough to be represented by the finite number of plane. As to every plane, the linear equation is

$$Ax + By + Cz + D = 0$$

Thus, during the division of triangulation network, all contour lines within the three edges of the triangle shall be arranged into straight, parallel lines with the constant spacing wherever possible, as shown in Fig. 4.38.

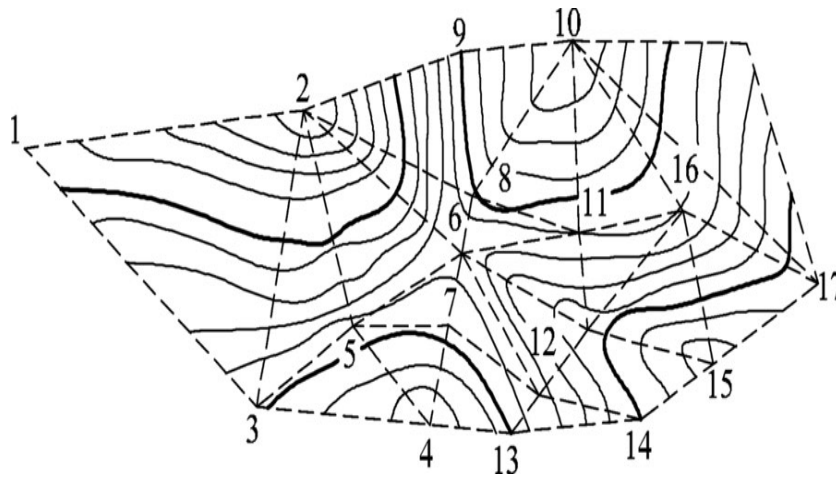


Fig. 4.38 Triangulation network.

2) Exploration of interpolation points

In order to facilitate to find out one triangle mesh and make interpolation, the information of Triangulation Network Digital Terrain Model shall be saved according to certain rules. The

preparation of original data is shown in Table 4.5.

Columns 1-4 are obvious and there is no need to make explanations; the fifth column shows the number of each triangle in the computer, which is formed by the vertexes of the triangle. If the three vertexes are represented by 1, 2, and 3, the number of the triangle is 123. By this method, there is no need to repeat the common vertexes of adjacent triangles for many times during information provision.

Triangle edges are found by checking all horizontal coordinates saved in the storage one by one. In order to judge whether the unknown point lies in a certain triangle, it is required to obtain the equations of three edges and barycenter coordinates of the triangle. The equation of each triangle edge can be deduced according to the linear equation of its corresponding triangle vertex:

Table 4.5

Model Information Storage List of Triangulation Network Digital Terrain

Vertex Number of Three Triangle Edges		Vertex Coordinate of Three Triangle Edges	Number of Three
x		y	z
1		2	3
1		35	44
2		45	55
3		47	52

$$\frac{y - y_1}{y_1 - y_2} = \frac{x - x_1}{x_1 - x_2}$$

through the organizing equations:

$$M \times x + N \times y + L = 0$$

$$f(x, y) = M \times x + N \times y + L$$

Barycentric coordinates of three triangle edges are obtained:

$$x_{gc} = \frac{x_1 + x_2 + x_3}{3}, y_{gc} = \frac{y_1 + y_2 + y_3}{3}$$

(4.6)

Plug the barycenter coordinate and unknown point coordinates into the equation of each edge of the triangle, and if the values and symbols are the same, it indicates that the unknown points and triangle centers of gravity lie in the same side of three edges, that is, in the same triangle.

3) Ground information of undetermined interpolation points

Each triangle in the triangulation network is considered as a plane, its plane equation is:

(4.7)

By solving the equation, interpolation information of undetermined points is obtained.

4.8.2 Object Model of Computer Aided Route Design

Object model refers to the data combination of represented objects and relationship among data, which reflects the mathematical expression of changes among variables in the design, and is used to describe the change rule among the design parameters, constraint conditions and objective functions.

In computer aided design of a railway route, the applied object model involved mainly includes route plan and profile pattern, cross section pattern, terrain model, objective function and mathematical expression of constraint conditions.

(1) Plan pattern

A route plan is formed by curves and their tangent straight lines. Plane curve includes circular curve and transitional curve. A plane design variable can be plane curve radius and plane turning point coordinate, and may also be the plane curve radius and length of every calculation section in the plane (straight-line section is the entire straight length of this section, and the curved section is the entire curving length of this section).

(2) Profile pattern

A profile includes ground line and design grade line.

For the ground line, the broken line pattern is employed and its digital structure is made up of ground elevation and length of grade section. A Digital Terrain Model is employed for the ground line which can be obtained according to interpolation of horizontal coordinates of 100 m marks and marked points in the known route plane.

A profile pattern includes two types, i.e., broken linear pattern and function curvilinear pattern. In the computer aided design of railway route, broken linear pattern is mostly used.

The broken linear pattern is formed by a series of straight-line sections. The design variables may be grade change point and design elevation, and may also be the gradient and the length of grade section. The broken line pattern in profile includes two types, i.e., unequal chain-like profile and designed profile satisfying the minimum grade requirement.

(3) Ground cross section pattern

In optimizing calculations, the design elevation of each grade change point changes with the route scheme. As sectional area calculation needs a long time through using ground cross-section lines of the broken linear pattern, ground cross section is processed to straight lines in advance in most optimization programs. In a domestic optimization program of a railway profile, ground longitudinal section is processed into left and right bidirectional cross slope lines.

(4) Constraint conditions

The route plane and profile design should meet the requirements of Railway Route Design Specification (hereinafter referred to as Route Specification). Route specification and other technical requirements should be constraint conditions of variables.

In optimization design of a profile, the following constraint conditions shall be met for the grade change point position: grade change point position constraint, i.e., gradient constraint on grade section, gradient difference constraint on adjacent grade sections, and elevation constraint condition, etc.

The following constraint conditions shall be met for the route plane:

- ① Constraints on plane curve radius, minimum intermediate straight line length, minimum circular curve length and station site length.
- ② Seriously unfavorable geology areas, historic reservation, reservoirs, and major project areas should be considered as location exclusion areas; the exclusion area is expressed by data substring of designated zone boundary.

- ③ The designated site location, bridge site should be considered as an area where route will pass through inevitably, which is expressed by the substring of zone boundary.
- ④ Intermediate station site constraint and route terminal constraint. In terms of plane and profile coordination, it shall be ensured that the vertical curve and transitional curve are misaligned.
- ⑤ Mathematical model of objective function.

In computer aided design of railway route, conversion of project operating costs is generally regarded as the objective function for analysis, calculation and optimization.

4.8.3 CAD Model of Route Selection

A CAD model of route selection is achieved by simulating artificial paper location process. Route selection process can be divided into control point selection and route plan generation.

- ① Control point selection;
- ② Route plan generation

(1) Control point selection

The control points in the route selection include initial control points and additional control points. Initial control points include route starting point, terminal point, large intermediate transportation center, etc. By connecting these control points with straight lines, general area where route may pass through can be determined. Task of railway location computer aided design system (hereinafter referred to as RLCAD) is to determine the river-crossing point, saddle back, mountain top, unfavorable terrain and geology area, and secondary traffic center, etc. in the planned passing area. On the basis of a CAD system, steps to determine control points are as follows:

- ① Analyze “electronic topographic map” and select possible control points.
- ② Get horizontal coordinates of selected points, and modify dynamic database.
- ③ Select properties of control points (such as control point type, information of existing objects around the selected control points).
- ④ Use dynamic database to obtain the information of corresponding control points (data and knowledge).
- ⑤ Adjust inference engine of control information, determine design parameter.
- ⑥ Modify knowledge base and dynamic database.

(2) Possible route scheme generation

By intelligent CAD method, make different combinations of initial control points and additional control points, and connect them into different chain-type broken lines by straight line, then several possible route selection schemes are generated; after

comparison and selection, the structure pattern of individual project, such as bridge, tunnel, retaining wall, etc., is determined.

4.8.4 Computer Aided Design of Profile

Firstly, determine route plane position on the topographic map (manual determine route plane on the paper or graphic interaction on computer graphic terminal), store the data such as plane turning point coordinate, plane curve radius, the related technical standard, vertical control point mileage and requirements into database; interpolate the information such as ground longitudinal section and ground cross slope according to the band-shaped digital terrain model of the area where design route passes through. According to interpolated ground longitudinal section, use computer to automatically generate one design route of longitudinal section which not only meets the constraint conditions and technical standard, but also gets close to the ground as far as possible, to serve as initial profile.

Based on the initial profile, adopt one optimization method to optimally design the profile thus, one optimal profile is determined on the selected plane with the minimum engineering cost; by the automatic analysis, calculation and interactive graphics technique, the optimal chain-like profile is arranged into a design profile. At last, draw route section diagram by the aid of the computer peripheral device-plotter.

The mathematic model of railway route optimization design can be summarized as follows:

When a group of design variables $x_1, x_2, \dots, x_n$ are available, solve the following questions:

Objective:

$$(4.8)$$

Constraint condition:

$$H_j(x) = 0, j = 1, 2, \dots, q$$

(1) Automatic generation of initial profile

Basically, there are two ways to automatically generate the initial profile.

1) Determine the design route composed of short grade section (chain-type grade section), find out the optimal scheme of chain-type grade section, and then arrange it into admissible straight-line grade section by Route Specification, such as initial value determination method adopted by the gradient projection method.

2) The curvilinear function is used to solve the undetermined coefficient by the least square method to obtain the initial solution, such as B spline method. By this method, the

initial value is determined. In railway longitudinal section optimization design, the relatively frequently-used method is to obtain the designed initial value composed of unequal long chain-type grade sections by adopting gradual exploration method on the basis of chain-type grade section. In the procedure, the intelligent simulation of artificial route selection is employed in this method. The restrictions of ① elevation constraint, ② maximum grade, and ③ allowable gradient difference are only taken into account in design, and there is no limit on the length of the minimum grade section. In the bridge and culvert place, the elevation control needs to be taken into account. The tunnel number, tunnel position, and tunnel length are determined by computer-automated design, and are adjusted if they are in violation of design standard and constraint conditions. If all constraint conditions are met, one initial profile is determined, which not only coordinates with ground line closely, but also satisfies the constraint conditions. This method is suitable to automatically determine the initial value of longitudinal section on general terrain, and better reflects the sufficient grade section and slight grade section.

(2) Profile optimization

There are many ways to design the optimal profile on computer, such as continuous analysis method, partial difference method, gradient method, conjugate gradient method, gradient projection method, etc. Differences among these methods lie in the questions raised and strict degree of optimization realization method; the degree of obtained solution approaching the optimal solution; main factors and sufficiency of the affecting design line location; and the calculating time of electronic computer, etc. The objective function of railway profile optimization design is close to the piecewise quadratic function, and may be deemed as a convex function, and its constraint is time. The gradient projection method is exactly applicable to solve the nonlinear programming problem with linear constraint. As for the first partial derivative of objective function, it may be obtained by numerical differentiation.

Basic principle of gradient projection method: use the projection of intersection between negative gradient of objective function- $\nabla F(x_q)$ and constraint surfaces where point x_q belongs to resolve the constraint minimization problem.

(3) Chain-like profile modification

Modification means to change the optimal chain-like profile into profile of long grade sections. Basic methods are as follows:

- ① by computer graphics technique, divide the optimal chain-like profile into sufficient and slight grade sections;
- ② by computer, automatically and respectively modify the sufficient and slight grade sections;
- ③ improve the automatically modified results by interactive graphics technique. Principles of automatic modification: on the premise that the generated long grade section after modification meets the requirements in Route Specification, the quadratic sum of elevation between the points of 50 m on the designed profile and its corresponding points on the optimal chain-like profile is minimum.

(4) Profile diagram drawing

The horizontal line on the route profile diagram expresses the route length, and the vertical line expresses the elevation. A profile diagram consists of two parts: route information and data, and profile diagram. As the final profile diagram, the figure produced shall be in

accordance with the standard format of Railway Route Schema; as the intermediate result after the interactive processing, simplification may be made on the basis of standard schema, such as only drawing route plane, design grade and design elevation of road shoulder.

4.8.5 Computer Aided Design of Route Plane

Based on the digital terrain model and “electronic topographic map,” the route plane design works shall be completed by combining interactive graphics technique and optimization technique.

4.8.5.1 Generate Initial Horizontal Alignment

For the purpose of optimization, an initial horizontal alignment should be generated for each possible route.

In order to obtain a reasonable initial horizontal alignment quickly, IRLCAD divides the procedure of generating initial horizontal alignment into two stages: first, from the centerline of selected route, find a chain-linked-fold-line by using optimizing method; then based on the chain-linked-fold-line, generate an initial horizontal alignment interactively.

(1) Generating chain-linked fold scheme of plane for a selected route

Comparing with natural gradient of terrain, a selected route can be divided into heavy gradient or easier gradient sections. For these sections with easier gradients, reasonable alignment can be located principally in tangent lines and avoid troublesome ground of any kind if possible. For heavy gradient sections, the major problem in alignment design is to overcome elevation. This can be realized automatically by emulating the “guideline location” method in human paper location. As the result of guideline location is a fold-line in different length, we call it as “chain-linked-fold-plane.”

On considering that the chain-linked-fold-line is only a very primary scheme of plane, we simplify the design procedure as follows:

- 1) Only consider these constraints related to earthwork calculation.
- 2) Classified constraints considered into two groups (1) vertical constraints conditions, including constraints of grade and constraints of difference of gradient; (2) horizontal constraints conditions, including constraints of difference of direction and minimum length of tangent.

Starting from the centerline of the possible route, by using the combination of gradient projection and the best linear approximation techniques, the optimizing of chain-linked-fold-line can be realized. The optimizing process is divided into two steps: first, considering the vertical constraints, find the optimal guideline scheme X1 by gradient projection method; then based on X1, considering horizontal constraints, find the approximate result X2 by the best linear approximation technique.

1) Find the optimal guideline scheme X1

For horizontal alignment, we take coordinates of X, Y at vertexes of guideline as design variables. For vertical alignment, we take elevations of points where gradients are changed to design variables.

The guideline in railway location is defined as the line on which the cuts and fills are all zero. Thus, the objective function to generate 'guideline scheme' may take the following equation:

$$(4.9)$$

where X,Y is the coordinates at point where vertical gradient changed; n is the total number to be calculated; h_i is the cut or fill height at point to be calculated; z_{si} is the design elevation at point to be calculated; and z_{di} is the terrain elevation at point to be calculated which is the function of coordinates X, Y.

Starting from the centerline of possible route and using the gradient projection, the optimizing of "generating chain-linked fold scheme of plane" can be realized.

2) Finding the best approximate solution X2

Although the optimal guideline scheme can fit the terrain very well, it is unsatisfactory in smoothness and curvature. In order to overcome these shortcomings and make the guidelines fit terrain formation well, it is necessary to smooth the optimal guideline scheme.

Based on the optimal guideline scheme X1, finding the approximate result X2 can be realized by following iterated steps:

1) Check the optimal guideline with constraints for difference of direction to find the place where the constraint is violated.

2) Establish the roof function by the best linear approximation method using of the coordinates of points on guideline between and .

The best linear approximation equations are

$$(4.10)$$

where x_i, y_i are the new coordinates at point to be calculated; x_j, y_j are the coordinates at and around the point to be calculated on optimal guideline; n is the number of points to be used; and p_j is the weight; p_j varied with the distance from point to be used to the point to be calculated on optimal guideline. It may take the first-order function of distance, or the second-order function.

The above process is repeated until all the constraints are satisfied and the approximation solution X2 is achieved.

(2) Generating initial horizontal alignment

After display the chain-linked-fold-line on 'electronic terrain map' an initial horizontal alignment can be generated with interactive CAD method. The contents of design include the following:

1) With contour background, move the cursor to determine intersecting points (IP, include initial terminate point IP₀ and final terminate IP_n). Then select the radii of curves, and the length of transition curve. Draw lines and arcs between IPs and compute the deflecting angles of straight lines.

2) Compute the major elements such as length of tangent, length of curve, the X and Y coordinates of the beginning and ending points of curves, etc.

3) Check the constraints on horizontal alignment (such as direction constraints, L_{min} and L_{max}). If some constraint is violated, the system will give error information and prompt the engineer to improve the design.

4) Determine the sites of bridges and tunnel and select the form of bridge and culvert.

5) Design the horizontal plan near the restricted area. For the bad geological conditions or other reasons there are some restricted areas for the projected line. These areas can be gone around by setting curves. This can be easily to be realized by man-machine interaction on the contour line background. To protect the line from moving into the restricted areas during optimizing, we construct the binary constraints and add very large data to digital terrain data around the border of restricted areas.

6) Run the initial profile sub-system to check the feasibility of the plan. If the plan is feasible an initial profile is obtained; then the system will give necessary prompt information to indicate the designer to revise the design.

The initial vertical alignment can be generated by using a successive heuristic algorithm (Sirong Yi, 1985).

4.8.5.2 Optimization on Considering Route Plane and Profile

Based on the initial scheme of route plan, the combination of route plane and profile is made to provide a basis for comprehensive selection of schemes.

When the design elevation of the grade change point-Z acts as design variable on the longitudinal section, when the horizontal radius R and the turning points X, F act as the design variables on the plane, the mathematic model of combination of route plane and profile is:

$$\left. \begin{array}{l} \min f(X, Y, R, Z) \\ \text{s.t. } g_j(X, Y, R) \geq 0, j = 1, 2, \dots, p \\ h_k(Z) \geq 0, k = 1, 2, \dots, q \end{array} \right\}$$

(4.11)

In the formula, design variables of plane—X, Y, and R are all m-dimensional vectors, m is the number of plane intersections, Z is n-dimensional vector, and n is the number of grade change points on the longitudinal section.

When the principal railway standards are given and the initial and final terminals and any intermediate traffic centers are fixed, the purpose of railway location is to find the most reasonable route of railway line, in view of the most economical combination of construction costs and operating expenses, within a strip of land between the control points. We take the annual conversion cost as the economical objective function of railway location. In the annual conversion cost method the investment costs are reduced to an annual basis and combined with annual operating expenses to give a combined total annual cost. In equation form:

$$(4.12)$$

where E is the annual operating expenses, F is the capital investment, Δ is the coefficient of investment effect, and K is the annual conversion cost.

When the principal railway standards are given and the initial and final terminals and any intermediate traffic centers are fixed, it is thought that the cost of rolling stock and power supply system is not vary or has little difference for every alternative. Only the construction cost of permanent way must be taken into account. The construction cost F consists of sub-grade cost, retaining wall cost, bridges cost, culverts cost, tunnels cost, cost in proportion to the length of line, and cost of railway right of way. F may be expressed as follows:

$$(4.13)$$

where f_1, f_2, f_3, f_4 represent construction costs of sub-grade (including retaining walls), bridges, culverts, and tunnels, respectively. f_1, f_2, f_3, f_4 are all the functions of gradient and can be calculated with numerical methods discussed in reference. f_5 represents the cost of facilities which are proportional to the length of line

$$(4.14)$$

where L is the total length of projected railway line, in meters.

f_6 is the cost of railway right of way and it can be achieved by means of Digital Model of Land Price as discussed in reference.

The operating expenses include the annual consumption cost varying with the volume of traffic (E1), and the maintenance expense of permanent way (E2), that is:

$$(4.15)$$

where E1 is computed based on the balance speed method. First, the operating expense per train meter is fitted into the second-degree function of gradient, that is,

$$(4.16)$$

In this formula, constants a, b, and c vary with the price index of operating expense.

The operating expense in proportion to the volume of traffic may be derived as follows:

$$E_1 = N_1 \sum_v V_j \times \{ (1 + \mu) [a(i^2 + (600/R_j)^2 + (700/R_j)b + c] \\ + (1 - \mu) \times i_j \times [1200/R_j)a + b] \}$$

$$(4.17)$$

On straight, $1/R_j=0$, where represent the annual conversion number of trains in forward and backward direction respectively, V_j is the length of jth straight or curve, in meters, R_j is the radius of jth curve, in meters, and n is the total number of straight and curves.

$$(4.18)$$

where QEL is the unit operating expense per meter of line.

The objective function may be expressed as

$$K = \Delta(f_1 + f_2 + f_3 + f_4 + f_5 + f_6) + E_1 + E_2$$

$$(4.19)$$

Optimization of route plane and profile is made by taking minimum conversion of project operating costs as objective junction. At this time, the plane curve radius is served as continuous variable, and longitudinal grade is served as chain grade.

According to the composite function differential method, the gradient-VF of objective function with respect to the independent variable can be directly calculated. The generalized gradient projection method is used to create the optimization design of route plane and profile.

As the combination of design standards are often not unique, and there are always more than one possible proposal at river crossing and troublesome regions, several feasible local optimal results will be obtained from the optimization of alignments. Thus, in order to find the most feasible alignment, it is necessary to evaluate the local optimal result synthetically. For scheme synthetic evaluation of engineering problems, we adopt the method of conversion annual cost to make the scheme synthetic evaluation for technical design of railway location.

4.8.5.3 Drawing of Route Plan

When the hypsographic map is available, drawing of design route plane means to paint design route of plane on the hypsographic map. Firstly calculate route feature points and 100 m marks, and transfer the marked plane coordinate into graphic coordinate by the transformation of coordinates, then call the painted linear function and painted curve subprogram, respectively, to draw the route plan in which symbols and notes are marked. The data structure used for drawing route plan includes: horizontal coordinates of route origin-destination, length of station site, range of bridge and tunnel origin-destination, sign of station type (such as intermediate station, district station, etc.), coordinates of turning points on the route plan, circular curve radius, length of transition curve, sign of left and right transfer curve, curve turning angle, principal point coordinate and mileage, etc.

Chapter 5

Technical and Economic Comparison of Schemes

Abstract

This chapter starts by discussing the basic concepts of technical and economic comparison. It then moves on to consider basic data of economic comparison. These include investment, operating expenses and so on. These data are the basis of economy analysis and have decisive influence on scheme comparison conclusion. The criterion of proposals must be done well on the basis of reliable investigation and survey data. Economic criterion methods are used, and can be divided into two categories: static and dynamic. The comprehensive criterion of schemes is based on various technical and economic evaluation indexes to carry on the comprehensive analysis, identify the most reasonable scheme. The basis for the comprehensive evaluation of schemes depends on the various technical and economic indicators, mainly including indicators relating to the technical features, operating characteristics, the quantity of works, engineering conditions, economic evaluation, and indicators of several other aspects.

Keywords

Technical comparison; Economic comparison; Data; Economic criterion methods

5.1 Basic Concepts of Technical and Economic Comparison

5.1.1 The Role of Technical and Economic Comparison in Schemes

The overall goal of railway design is to realize the required transport capacity with a relatively low investment, at the same time creating good operating conditions and reducing operating expenses. In addition, railway construction should still pay attention to reducing pollution and beautifying the environment along railway lines, providing convenience services to meet the public's need for passenger and cargo transportation, and creating good social benefits. To realize a design goal, several proposals of technical decision could be put forward for comparison; each proposal is a possible scheme. For example, different ruling grades, the proposals of valley side in location at river valley area, etc., constitute different schemes for comparison. In railway line design, it is necessary to propose all alternatives according to the actual conditions to study and compare so as to identify the best proposal.

With different technology measures adopted, various design schemes will have different engineering characteristics, operating characteristics, and economic benefits. As each proposal has its advantages and disadvantages, a comprehensive analysis and comparison need to be carried

out to find out the most reasonable solution. This is the role of technical and economic comparison of schemes.

In order to ensure the proper orientation of a railway investment, the technical and economic comparison should follow the following principles:

- (1) The railway must complete the specified transportation.
- (2) There must be no missing of possible scheme, no matter whether the work is in the name of alternative selection or feasibility study with its official formulation.
- (3) Schemes should be compared on the basis of the same precision.

The railway location engineers, in addition to their responsibility of making high-quality detailed designs, should also have a clear view of the economical principle of alternative selection and the nature of the work they are designing.

5.1.2 Index in Technical and Economic Criterion

In railway location, possible proposals should usually be evaluated and compared from the technical characteristics and engineering conditions, operating conditions and economic effect. The basis of selection is the technical index and economic index, which reflect the characteristics of the scheme.

1. Technical index

Technical indexes reflect the technical characteristics of route proposals, which have an important influence on the engineering conditions and operating conditions of the route.

Technical indexes reflecting engineering conditions include: construction length of railway, coefficient of extension line, maximum gradient, minimum curve radius, the number and length of unfavorable geology sections, number of stations, quantity of cut-fill, quantity of bridge and tunnel engineering, labor input, area of right of railway and construction period, etc.

Technical indexes reflecting operating conditions include: operating length of railway, length of control section, times of train running forward and back in the line, lifting height, carrying capacity, traction tonnage, traffic capacity, the travel speed, number of locomotives and vehicles, Locomotive and vehicle running hours, working hours of locomotives and train crew, energy consumption of locomotives and trains, fuel consumption, etc.

2. Economic index

The economic indexes of the route scheme include construction cost, operating expenses, converted annual costs, repayment period of capital cost, net present value, internal rate of return, etc.

Construction cost refers to the sum of civil construction cost and purchase expense of locomotives and vehicles, which reflects the overall amount of capital invested in construction period, expressed as construction cost (10,000 yuan). Operating expenses refers to the expense incurred in operation period, to a certain extent it reflects the merits of

operating conditions of the scheme, expressed as the expenditure of operation per year (10,000 yuan).

In order to reflect the economic efficiency of the schemes in terms of engineering and operation comprehensively, a certain conversion method can be utilized to convert the engineering and operation cost within a certain period into an average annual cost, namely converted annual cost. The index reflects the scheme expense in construction period and operation period, and the scheme which possesses a lower value is the optimal one.

When different proposals lead to different traffic volume and transport income, the economic indicators of a scheme should also take income into consideration. The investment payback period reflects the years which the railway transport income offset various expenditures including construction costs, operating expenses, and other required costs.

The net present value is the sum of the discount difference between the annual cash inflows and cash outflows (that is the net cash flow), which should take into account the time value of money in railway construction project economic life period. The higher the net present value of route scheme is, the better for the economy it is. Comparing route proposals by means of financial criteria uses a financial net present as value (FNPV) indicator; comparing proposals by means of national economic evaluation uses an economic net present as value (ENPV) index.

Internal rate of return is the discount rate when the net present value equals to zero. It represents the real rate of return, by which a construction project has reached actually, using it to measure project profit is high or low, the higher its value, the better on the economy. Comparing route

proposals by financial criterion use financial internal rate of return (hereinafter referred to as FIRR) indicator to comparison; comparison, by national economic evaluation, use economic internal rate of return (EIRR) index to comparison.

5.1.3 The Classification of Schemes

In the early stages of the project work and the stages of railway survey design, there are schemes with different properties, different scale needing comparison. These schemes can be divided into three categories as follows.

1. Network scheme

Network scheme is the scheme which has an important influence on the national economy development and the composition of transportation network, such as line strike selection among the initial terminal, ending terminal, and major control points; the comparison of building diversion line with building the second line, etc. These schemes have significant differences on regional service level of national economy, project investment, and economic benefit. The comparison of proposals is a problem of investment decision, and should be solved by a pre-feasibility study and feasibility study.

2. Overall scheme or principle scheme

These schemes have roughly the same level to meet the national economy needs of the region; the major difference lies in the selection of main technical standards (ruling

grade, kind of traction energy, and locomotive routing, etc.), or different partial strike through the local area. The comparison result has a decisive influence to the main technical standards of railway, engineering conditions, operating conditions, investment, and economic benefits. The principle scheme comparison general is done in the feasibility study and preliminary design stage.

3. Partial scheme

This only refers to a scheme which has different engineering measures at local area, including proposals for detouring unfavorable geological barriers of local area, plane barriers and height barriers; proposals for improvement of the plane and profile design and type selection of small bridge and culvert, etc. The comparison results have a certain influence on the construction costs, operating expenses, construction conditions, operation conditions, etc. The study of a local scheme is generally done by means of social/economic comparison at preliminary design stage and improvement of alignments before construction design.

The above classification is just for discussing the problem. In the practical projects, schemes often cannot be divided into different kinds easily. For example, a network scheme must be studied together with a selection of main technical standards; and a principle scheme comparison has a certain impact on the industrial and agricultural development of local area and the construction of the transportation network. The process of alignment also needs to take into account the problem of partial plans, etc.

5.1.4 Brief Process of Technical and Economic Comparison of Schemes

In summary, the whole process of railway route selection also is the process of scheme comparison. According to the characteristics of the scheme comparison, a project technical and economic comparison can be summarized as the following process:

- (1) Identify tasks.
- (2) Plan schemes and start design.
- (3) Calculate and process appraisal index.
- (4) Compare schemes and make a choice.

In the economic comparison of schemes there are some specific design problems, on the premise of meeting the constraint conditions, according to specified evaluation indicators to establish the objective function, using electronic computer to solve the optimal solution from multiple schemes.

In general, the scheme comparison in railway route selection, which leads to important decisions, shall involve a set of very complex factors, in addition to all kinds of natural conditions, policy factors, and social factors have great influence on scheme evaluation. This has made the problems of seeking an optimal solution complex. Only limited schemes proposed in design shall be evaluated in an affordable way, and from them, the most reasonable solution shall be identified, customarily known as the optimal one.

In order to eliminate the possible engineering deficiencies resulting from the unreasonableness, the “synthetic optimization” process is suggested.

The idea of synthetic optimization involves: collecting the governing factors of major railway elements, for instance, kind of traction energy, locomotive characters, and alignment standards together as design variables, and treated simultaneously. The method of solution may be qualitative or quantitative. In the case of selecting tractive energy and number of main tracks, the traditional alternative selection or qualitative method is still useful. For the locomotive characteristics and alignment standards which can be expressed numerically, a quantitative method with mathematic models and computer aided optimization will be applied.

The main feature of synthetic optimization is that the solution of all the design variables of the different related specializations is accomplished in a single process. Therefore the resultant selected alternatives of functional element are automatically in coordination.

Any optimization design without the coordination of related functional elements, no matter how complicated its mathematical model is, should not be regarded as a synthetic one. That is, mathematic modeling is one of the characters of quantitative synthetic optimization, but it is not the sufficient condition. On the contrary, if an engineering project is analyzed and selected from alternatives composed of different combinations of related element parts but without mathematic modeling, it is also a coordinated or synthetic optimal decision.

This chapter will briefly introduce the contents about calculation and scheme criterion, etc. in relation to the

economic appraisal index formerly mentioned.

5.2 Basic Data of Economic Comparison

The basic data of scheme comparison include investment, operating expenses and so on. These data are the basis of economy analysis and have decisive influence on scheme comparison conclusion. The criterion of proposals must be done well on the basis of reliable investigation and survey data.

5.2.1 Investment

5.2.1.1 Classification of Investments

The investment of railway construction project, in accordance with the constitution and the purpose, can be divided into two categories: direct investment and related investment. In technical and economic comparison of schemes, usually only direct investment is considered, namely only calculating construction cost and purchase expense of rolling stocks.

(1) Civil engineering investment: including civil engineering, transportation facilities, construction preparation and

management fees, etc. These are the main part of the project investment.

(2) Purchase expense of rolling stocks: including purchase expense for passenger locomotives, freight locomotives, vehicles, and motor units.

5.2.1.2 Civil Engineering Investment

Computation of construction investment for scheme technical and economic comparison has different requirements for accuracy and depth in different design stages. In common, firstly calculate the quantity of engineering construction and equipment, then adopting corresponding analysis of the comprehensive unit price or unit price, and calculate engineering investment according to the following formula.

$$\text{Engineering investment} = \sum (\text{unit price engineering quantity}) (10^4 \text{ yuan})$$

Railway engineering include demolition engineering, subgrade engineering, bridge and culvert engineering, tunnel engineering, track engineering, communication and signal engineering, power supply equipment of electric traction railway, buildings, other operating production equipment and buildings, other indirect fees, etc.

1. Demolition engineering

This includes removing building, reconstructing roads, moving communication lines and power lines, etc. These engineering quantities can be summarized respectively.

2. Subgrade engineering

a. Earth work: generally, first compute earth work volume by employing average cross-section method, then estimate the subgrade engineering cost according to the comprehensive unit price per cubic meter. In detailed design, it is necessary to distinguish the composition of the stone and soil based on the geological data, and compute the quantity of earth and stone respectively by means of a subgrade cross-section, then calculate the cost according to the corresponding comprehensive unit price or unit price.

b. Auxiliary engineering of subgrade: including subsidiary earthwork of subgrade, reinforcement engineering, protection engineering, etc. Their costs can be estimated by means of corresponding quantity and comprehensive unit price.

c. Retaining wall: first, statistics the length of retaining wall according to its type and height, or the quantity of retaining wall masonry, then compute the cost according to the corresponding unit price.

3. Bridge and culvert engineering

a. Bridge: the construction cost of bridges can be computed by means of number of beams, abutment masonry quantity and the corresponding unit price according to its type and beam span.; it can also estimate the length of each bridge (taking into account the bridge height when necessary) to statistics of the number and total length of bridge by means of the hydrological data and plane and profile, and then

estimate the cost according the comprehensive unit price per linear meter to.

b. The culvert: to calculate the cost of culvert by the length according to the type and aperture.

4. Tunnel engineering

From design data to obtain the length of the tunnel and tunnel without cover, classification statistics extension meter according to the length, adopting the corresponding unit price to calculate the cost.

5. Track engineering

Track engineering includes main line track and station line track.

Construction cost for laying out main line track could be compute according to the length of the main track and the unit price of corresponding track type.

Engineering cost for layout out station line track could be computed according to the track type, track-laying length, number of switch sets, and the corresponding unit price.

6. Communication and signal engineering

Communication engineering includes communication lines, communication equipment, etc. Its engineering quantity can be computed by means of kilometer, station, and department.

Signal engineering includes traffic command equipment, block equipment, interlocking equipment, etc. The quantity can be computed by means of kilometer, group and station.

7. Power supply equipment of electrified railway

Power supply equipment of electrified railway is composed of power engineering and traction power supply engineering.

Power engineering includes power lines, power equipment, etc. The quantity can be computed by means of kilometer, place, and station.

Electric traction power supply engineering includes catenary, traction substation, power supply depot, etc. The quantity can be computed by means of main line kilometer, track kilometer, and place; and the engineering cost can be computed by means of engineering quantity and comprehensive unit price.

8. Buildings

Buildings in railways include production and office buildings, residential and public buildings, etc. The quantity of buildings can be computed in square meters.

9. Other equipment for operating production and buildings

Other engineering should be taken into consideration in computation of cost, including water supply and drainage, locomotive, vehicle, passenger and freight transportation, track, and other building and equipment, etc. The quantity can be computed by means of mainline kilometer and place.

10. Other indirect fees

Other indirect fees include temporary facility cost, labor insurance fund, fees for construction team transfer, etc. This kind of quantity can be computed in mainline kilometers.

11. Other fee

Other fee includes material price difference, plan profits, taxes, purchase expense of appliances and production

furniture, other fees, etc. The quantity can be computed in mainline kilometers.

12. Budget reserve

Budget reserve refers to the unpredictable project fee in investment estimation, general estimate, or investment check at feasibility study stage, preliminary design stage, and construction drawing stage. Generally, it can be calculated according to the percentage of the sum of the above fees.

13. Reserve fee on considering project cost growth

Due to the rise in materials price, equipment cost, and labor standards in construction period than design period, and other expenses standard adjustment in the whole period from the year of compiling design budget to the year of construction completion, the total amount of investment may increase. It is necessary to draw some reserve fee, and listed generally according to average growth rate.

Comparison of partial proposals need computing item 1-5 above project costs, thus is main works. Comparison of other scheme only calculate these indicators with difference each scheme, and don't need to calculate the construction cost of all the projects one by one.

5.2.1.3 The Purchase Expense of Rolling Stocks

The purchase expense of locomotives and cars are estimated chiefly according to the traffic volume and the mechanical relation of train movement.

1. The purchase expense of locomotives

$$A_L = (1 + \gamma_L) \frac{\frac{t_1 + t_2}{\beta_{TS}} + (t_{ls-ls} + t_{ls-td} + 2t_{lwt}) \times n_l}{1440} (N_F + N_P) \times a_l$$

(5.1)

where A_L is the locomotives purchase expense (10^4 Yuan), when the type of cargo and passenger locomotive is not the same, it should be calculated separately; t_1 , t_2 are the runtime of train going forward and backward, not including start or stop additional time (min); β_{TS} is the travel speed coefficient; single track take 0.7-0.75, double-track take 0.85; t_{ls-ls} is the work time of locomotive servicing in locomotives depot (min); t_{ls-td} is the work time of locomotive servicing in turnaround depot (min); t_{lwt} is the time for locomotive waiting for a train (min); N_P , N_F are the pairs of passenger and freight train (to/d); N_L is the locomotive routing number; γ_L is the locomotive maintenance spare coefficient; diesel locomotive take 0.35, electrical locomotive take 0.30; and a_L is the locomotive price (10^4 yuan).

2. Purchase expense of assisting locomotives

When the whole tractive district adopts double locomotive traction, purchase expense of assisting locomotive is the same as that of leading locomotives. When adopting

assisting locomotive at partial district, the purchase expense of assisting locomotives can be calculated using Eq. (5.2).

$$A_{al} = \frac{T_{al}}{1440 - t_{ls}} N_F \gamma_l a_l \quad (10^4 \text{ yuan})$$

(5.2)

where A_{al} is the purchase expense of assisting locomotives (104 yuan) and T_{al} is the required time of assisting locomotive turnover.

(5.3)

$t_{al'}$, $t_{al''}$ are the running time of assisting locomotive go backward and forward, not including start-stop additional time (min); and t_{ls} is the time needed for assisting locomotive servicing operations per day and night, estimated according to the required times of servicing work and time per servicing work(min).

The meaning of other symbols are the same as former.

3. Purchase cost of cars

Car purchase expense is calculated using Eq. (5.4).

$$A_{car} = M \times a_{car} \times (1 + \gamma_{car}) \quad (10^4 \text{ yuan})$$

(5.4)

where A_{car} is the purchase expense of passenger car, freight cars, motor train unit (104 RMB); γ_{car} is the maintenance spare coefficient of passenger car, freight cars, motor train unit, 0.23 for freight car, 0.16 for passenger car, 0.16 for motor train unit; a_{car} is the average price of passenger cars, freight cars, cars of motor unit (ten thousand yuan/m); and M is the total number of passenger cars, freight cars, cars of motor unit in use.

$$\text{Freight car } M_F = (1 + \gamma_{car}) \frac{\frac{t_1 + t_2}{\beta_{TS}} + 2t_{ds}n_{ds}}{1440} N_F n \quad (\text{car})$$

(5.5a)

where t_{ds} is the stop time of cars at district station(min); n_{ds} is the number of district station; and n is the number of cars of a train (cars/train).

The meaning of the rest symbolic is the same as the former.

$$\text{Passenger car } M_P = \frac{\frac{t_1 + t_2}{\beta_{TS}} + (t_{s-s} + t_{s-t})}{1440} N_P n \quad (\text{car})$$

(5.5b)

where t_{s-s} , t_{s-t} is the passenger train stop operation time at starting station and terminal station (min).

The meaning of the rest symbolic is the same as former.

$$\text{Motor Unit } M_{\text{mu}V} = \frac{\frac{t_1 + t_2}{\beta_{\text{TS}}} + \sum_{n_{\text{mu}}} t_{\text{mu-s}}}{1080} N_{\text{mu}V} \text{ (car)}$$

(5.5c)

where $t_{\text{mu-s}}$ is the Motor Unit servicing work time at motor unit train depots (workshop) (min); $M_{\text{mu}V}$ is the vehicle number of high-speed train which speed is V (m); $N_{\text{mu}V}$ is the pairs of high-speed train which speed is V (to/d); n_{mu} is the vehicle number of EMU; and 1080 is the operating time of high-speed rail every day, usually calculated on 18 h (min).

The meaning of the rest symbolic is the same as the former.

5.2.2 Operating Expenses Calculation

In the conventional calculation, the operating costs are divided into many items. For the convenience of scheme comparison, these items may be grouped into two

categories, they are: cost relating to the traffic amount (E_1), costs relating to the maintenance of permanent way (E_2).

5.2.2.1 The Operating Cost Relating to the Traffic Amount

1. Calculation principle

The operating consists relating to traffic amount can be computed using Eq. (5.6).

$$E_1 = 365N_T \left[N(e_1 + \Delta e_4) + A_T e_2 + A_R e_3 + (e_5 + e_6 + e_7 + e_8 + e_9 m) \frac{T}{\beta_{TS}} \right] 10^{-4} (10^4 \text{ yuan/year})$$

(5.6)

where N_T is the train pairs (pairs/d), calculate according to the annual passenger and freight volume (excluding fluctuation coefficient); e_1 is the maintenance expenditure quota related to energy consumption of locomotive, vehicle, the motor vehicle unit (RMB/kW h or yuan/ton oil); e_2 is the maintenance expenditure quota related to traction power of locomotive, train (yuan/kN km); e_3 is the maintenance expenditure quota related to resistance work of locomotive, vehicle, train (yuan/kN km); e_4 is the electricity or fuel price (RMB/kW h or yuan/ton oil); e_5 is the maintenance expenses

quota related to time dependent of locomotive, trailer upkeep (RMB/h); e_6 , e_7 are the hour wage of locomotive, train crew (RMB/h); e_8 is the train's operation expenditure quota (yuan/hour); e_9 is the maintenance expenditure quota related to the time dependent of vehicle, train (yuan/hour); n is the vehicle number of train; β_{TS} is the coefficient of travel speed; Δ is the unit conversion factor: for electric power, internal combustion traction $\Delta=1$; and N , AT , AR , T are the train energy consumption of two direction (kW h tons and tons of oil vapor), traction work (kN km), resistance work (kN km), running time (h), according to traction calculation method to calculate the passenger train and freight train, respectively.

2. Energy consumption calculation

a. Electric traction

In the case of electric traction, the operation energy consumption N include traction operation power consumption (kW h) and idle running, braking and stop power consumption N_0 (kW h).

Power consumption of traction operation

$$(5.7)$$

where UW is the voltage of pantograph, take 25,000 V; I_p is the average active current in each speed interval (A), according to the average speed on the curve of $V=f(s)$ in each speed interval to check the active current figure; I_{p0} is the electricity active current traction locomotive running for its use, four axis and six axis locomotive take 6 A, eight shaft

locomotive take 7.5 A; and t is the traction operation time in each speed interval (min), it can be checked in curve $t=f(s)$, or with several solution is obtained.

The power consumption N_0 of idle running, brake and stop can be calculated using Eq. (5.8).

$$(5.8)$$

b. Diesel traction

When using diesel traction, the operation energy consumption N includes traction operation fuel consumption N_Q (kg) and diesel engine idling fuel consumption N_0 (kg).

Traction operation fuel consumption:

$$(5.9)$$

where e_y is the traction operation fuel consumption in unit time (kg/min), according to the handle and the average speed of the calculation period to determine; and t is the running time corresponding to the average speed of the calculation period (min).

With a diesel engine idle running, brake run or stay in the station, the fuel consumption are calculated according to the diesel engine idling fuel consumption, namely

(5.10)

where e_0 is the fuel consumption in unit time of diesel engine idling (kg/min); it is related to the diesel engine rotating speed. When computing, one can check for the corresponding form.

3. Calculation of traction mechanical work

Traction mechanical work is the work done by locomotive traction force (motor train) at running time; it is equal to the average traction force multiple operation distance. Traction mechanical work A_Q used to overcome mechanical work A_Z of resistance and accumulate the potential energy and kinetic energy of the train, so there is

$$\begin{aligned} A_Q &= \sum (F \times \Delta s) \\ &= A_Z + 1000 \times (P + G) \times g \times (H_2 - H_1) + 41.7 \times (P + G) \times (V_2^2 - V_1^2) \end{aligned}$$

(5.11)

where A_Q is the traction mechanical work when trains running between station A and station B (J); F is the average traction of each calculate period (N); Δs is the distance of each calculation period (m); A_Z is the resistance mechanical work (J); H_2 is the center height of B station (m); H_1 is the center height of A station (m); V_2 is the speed when the train through B station (km/h); and V_1 is the speed when the train through A station (km/h).

4. Calculation of resistance mechanical work

Resistance mechanical work A_Z is converted into heat energy, it is harmful for locomotive, vehicle, motor train and track abrasion, it does work when overcoming the basic resistance, curve resistance and braking force of the train, etc., it is obtained by using drawing mechanical work minus potential energy and kinetic energy of the train, namely

$$A_Z = A_Q - 1000(P + G) \times g(H_2 - H_1) - 41.7(P + G) \times (V_2^2 - V_1^2) \text{ (J)}$$

(5.12)

For high-speed motor unit trains, use M instead of $P+G$.

5. Number of train

a. Number of passenger train N_P

Pairs of passenger train according to the need of passenger transport capacity and transport to calculate and determine the various number of passenger trains. This is usually achieved by passenger traffic survey and forecast results. The number of passenger trains can be calculated using the following equation:

$$N_P = \frac{\beta_P A}{365 \gamma_P}$$

where N_P is the fluctuation coefficient of month passenger flow; A is the single direction (up or down) annual passenger volume (person); and γ_P is the average fixed number of persons in a train.

b. Number of freight train N_F

Number of freight train can be calculated according to the requirements of the annual freight volume and in different directions respectively.

Let CH , CL as annual freight volume of heavy traffic direction and light traffic direction, GH , GL as full loaded traction tonnage of heavy traffic direction and light traffic direction (t), then

i. If $CH=CL=C$, $GH=GL=G$, then

$$N_F = \frac{C \times 10^6}{365G \times K_{\text{net}}} - (\text{Excluding freight fluctuation coefficient}) \text{ (pairs/d)}$$

(5.13)

where C is the annual freight volume (Mt/a); G is the traction tonnage in tons (t); and K_{net} is the net load coefficient.

ii. If $CH \neq CL$ (or $GH \neq GL$), then,

Heavy traffic direction:

(5.14)

Light traffic direction: if the train is all empty and the number of the two directions is the same, then,

(5.15)

(5.16)

If a train is composed of empty trucks and heavy trucks, then

$$N_{L(E-F)} = \frac{C_L \times 10^6 + 365 G_H (1 - K_{net}) \times N_{HF}}{365 G_{L(E-F)}} (\text{train/d})$$

(5.17)

where NHF, NLF are the number of loaded trains in heavy traffic direction and light traffic direction (train/d); Nempty is the number of empty truck train in light traffic direction (train/d); NL(E-F) is the number of mixing train in light traffic direction (train/d); and GL(E-F) is the traction tonnage of mixing train in light traffic direction (t).

6. Computation of operating expenses relating to the traffic amount by using train-kilometer method

In the preparation stage of project construction, or where the accuracy is not high, usually, the train-kilometer method is used to calculate operating expenses related to the amount of traffic. Because this method is based on equilibrium

velocity method, the expenses should be added as additional fees for a train starting and stopping.

a. Cost relating to train running

Costs relating to train running can be computed using the train kilometer method.

i. Costs of train running which freight train operate one time in one direction are computed using Eq. (5.18).

$$\varepsilon_1 = \sum e_i \times l_i + 0.0105 \sum \alpha \times (P + G) \times a \times 10^{-3} \text{ (yuan/train)}$$

(5.18)

where e_i is the expense of train running per kilometer (RMB yuan/km) on various grades (according to the design gradient of profile); l_i is the corresponding length of various grades (km); a is the comprehensive expenditure of mechanical energy consumption per ton-km (RMB/t km); SS1 locomotive takes 0.53, SS3 locomotive takes 0.55, SS4 takes 0.54, SS7 is 0.5, and DF locomotive is 0.75; and is the sum of curve deflection angle of locomotive tractive operation section in one direction ($^{\circ}$).

ii. The annual expenses relating to train running

When the traffic volume and the traction tonnages are the same for upward and downward direction, the annual expenses of train running for both directions is

$$\varepsilon_{\text{run}} = 365 \times (N_F + \vartheta \times N_P) \times \sum \varepsilon_1 \times 10^{-4} \text{ (104 yuan/a)}$$

(5.19)

where ε_{run} is the sum of the annual expense of train running in two directions; is the sum of the train running fee for a freight train go forward and backward (RMB/column); and ϑ is the converted coefficient of expenses of passenger train running, related to the traction tonnage of passenger and freight train and locomotive type.

The meaning of the rest symbolic is the same as former.

When the transport volume of two directions is not the same, the annual expenses relating to train running of heavy and light traffic direction should be calculated separately.

Heavy traffic direction:

$$\varepsilon_{\text{H-run}} = 365 \times (N_{\text{F}} + \vartheta \times N_{\text{P}}) \times \varepsilon_1 \times 10^{-4} \quad (10^4 \text{ yuan/a})$$

(5.20)

Light direction:

The whole vehicles are empty

$$\varepsilon_{\text{L-run}} = 365 \times (N_{\text{LF}} + \mu \times N_{\text{empty}} + \vartheta \times N_{\text{P}}) \times \varepsilon_1 \times 10^{-4} \quad (10^4 / \text{a})$$

(5.21)

when a train is composed of loaded cars and empty cars

$$\varepsilon_{L-run} = 365 \times (N_{L(E-F)} + \vartheta \times N_P + E_S \times N_S) \times \varepsilon_l \times 10^{-4} \text{ (10}^4/\text{a)}$$

(5.22)

where E_S is the running expenses for single locomotive in one direction (yuan/times); and N_S is the number of travel for single locomotive every day.

The annual travel fee for both directions is $\varepsilon_{run} = \varepsilon_{H-run} + \varepsilon_{L-run}$ (10^4 yuan/a).

b. Additional expenses for the train starting and stopping

The expense relating to a train running are computed by means of balancing speed against the operating costs when trains don't stop at the station. Actually, the train running on a route needs to stop at some stations for the purpose of passing, overtaking, technical operation, and business operation. The additional expenses is these costs relating to increasing amount of consuming time and energy when the train stopping at some stations.

The annual additional expenses relating to train start-stop is calculated using Eq. (5.23).

$$\varepsilon_{ss} = 365 e_{ss} K_{ss} (N_{HF} + N_{LF} + \mu \times N_{empty} + \vartheta \times N_P) \times 10^{-4} \text{ (10}^4 \text{ yuan/a)}$$

(5.23)

where e_{ss} is the additional fees of freight train stopped one time (yuan/times), can consult relevant manuals; and K_{ss} is the average number of freight train starting and stopping (time/pair), can consult relevant manuals.

The meaning of the rest symbolic is the same as former.

5.2.2.2 Costs Relating to Maintenance of Permanent Way (Including Depreciation Cost)

Costs relating to maintenance of permanent way E_{per} includes cost relating to main track maintenance, station track maintenance, station maintenance, maintenance of signal and communications equipment and power supply equipment, it can be calculated using Eq. (5.24).

$$E_2 = [(e_{mt} + e_{sc} + e_{ps}) \times L_{mt} + e_{rdt} \times L_{rdt} + e_{st} \times L_{st} + e_o \times L_o + \sum e_s \times N_s + e_{ts} \times N_{ts}] \times 10^{-4} \text{ (10}^4 \text{yuan/a)}$$

(5.24)

where e_{mt} , e_{sc} , e_{ps} are the annual maintenance cost ratio of main track, signal and communications equipment and

catenary (yuan/km); L_{mt} , L_{rdt} , L_{st} , L_o are the length of main track, reception-departure line, sorting track and other track (km); e_{rdt} , e_{st} , e_o are the annual maintenance cost ratio of reception-departure track, sorting track and other station track (yuan/km); N_s , e_s are the number of all kinds of station and their annual maintenance cost quota (yuan/station); and N_{ts} , e_{ts} are the number of traction substation and their annual maintenance cost quota (RMB/substation).

5.2.2.3 Annual Operating Expenses

Annual operating expense is the sum of E_1 and E_2 :

$$(5.25)$$

5.3 Economic Criterion Methods

The analysis may be separately for Chinese national railways, for private railways and for government enterprises.

5.3.1 Classification of Economic Criterion Method

For calculating economic benefit, according to time factors, the economic criterion methods can be divided into two categories, the static method and dynamic method.

5.3.1.1 Classification Based on the Time Factor

(1) In the static method, the value representing by a certain currency amount does not change with time.

The static method neither reflects the economic loss causing by taking up funds for the extending construction period of a project, nor exactly calculate economic benefit of putting into production in advance. But due to omit the time factor, static method is simple in computing and suitable to eliminate obviously unreasonable scheme from multiple schemes comparison and selection.

(2) In the dynamic method, the value representing by a certain currency amount will change with time.

Dynamic methods take the time value of money into consideration, and reflect the value rules of economic society. These methods can convert costs and benefits of different time into the same reference time value to calculate and compare, so it can correctly reflect the economic benefits.

5.3.1.2 Classification Based on Evaluation Indexes

According to the economic evaluation indexes, economic criterion methods can be divided into the minimum cost method and cost-benefit methods.

(1) Methods cratering schemes by means of minimum cost include annual converted engineering and operating costs, staged investment economic comparison method, etc.

(2) Cratering schemes by means of cost-benefit, including investment payback period method, net present value method and internal rate of return method, etc.

5.3.2 Criterion Economic Methods Used in Chinese Railway Design

Economic evaluation of schemes, according to the characteristics and scale of scheme, could employ one of following methods.

1. Method of payback of investment balance

When comparing two schemes, usually the larger the investment, the less the annual operating expenses. This method works on the basis that the extra investment of the larger investment scheme can be compensated by the savings of annual operation expenses. The year length of compensation required is called balance investment payback period T .

Let A_1 and A_2 denote the capital investments of two alternatives 1 and 2 of location designs, respectively; E_1 and E_2 are the annual operating expenses of the corresponding alternatives. Alternative 1 may be taken as an original design and 2 as the revised design which requires higher investment in order to save a certain amount of constant operating expenses. Suppose the revenues of the designed lines are the same. The payback period of the additional investment $A_1 - A_2$ is

$$(5.26)$$

where T is the payback period of investment balance (a); A_1 , A_2 are the investment of scheme 1, scheme 2, $A_1 > A_2$; and E_1 , E_2 are the annual operating expenses of scheme 1, scheme 2, $E_1 < E_2$.

A standard payback period T_{base} should be stipulated to justify the additional investment $A_1 - A_2$ is being preferable, that is, when $T > T_{base}$, alternative 2 is preferred; when $T < T_{base}$, alternative 1 is better.

This method thinks that if payback period T is less than the benchmark payback period T_{base} of the project, then the alternative with larger investment is preferred.

It may be seen that some factors influencing railway economy are not involved in criterion expression, they are: (1) the length of construction period, (2) the rate of railway charges, and (3) the saving due to delayed investment.

Therefore, this static method may only be used when railway revenue and construction periods of all the alternatives are the same or nearly the same and the delayed investments do not much influence the economic calculations. In addition, it may be used in some research works in which the above listed details are uncertain or basically the same and do not affect the results of the analyses.

Considering traffic capacity is increased year by year after railroad operating, annual operating costs will also change year by year. To reflect the characteristics, another method of economic criterion involves use of the dynamic formula. The balance investment payback period can be calculated using Eq. (5.27):

$$(5.27)$$

where E_{1t} , E_{2t} is the annual operating expense in t year of alternative 1 and alternative 2.

Further considering the time value of money, the balance investment payback period can be calculated using Eq. (5.28).

$$(5.28)$$

where T is the payback period of differential investment (years); i_{by} is railway benchmark yield, or the rate of discount for the delayed costs; A_1 , A_2 are the investment cost of alternative 1 and alternative 2, $A_1 > A_2$; E_1 , E_2 are the annual operating expenses of alternative 1 and alternative 2 of designed year, $E_1 < E_2$; and m is the construction time limit for a project (a).

2. Conversion annual costs method

In the investment payback period method, if $T = T_{base}$, then

$$\frac{1}{T_{base}} \times A_1 + E_1 = \frac{1}{T_{base}} \times A_2 + E_2$$

Investment of A_1 , A_2 multiplied by the coefficient of $1/T_{base}$ is the conversion annual expenditures, and added transportation expenses E_1 , E_2 respectively, obtaining the annual conversion costs of alternatives.

Coefficient $1/T_{base}$ can be expressed by Δ , known as the effective coefficient of investment, also known as the benchmark yield. The if using A to expressed project investment, K to annual conversion cost, then

$$K = E + \Delta \times A$$

Among several alternatives, the design with the minimum annual conversion costs K is the most economic one. This is also the static method.

The effective coefficient of investment Δ is related to the profit and investment policy of national economy department. It is one of the key figures in Chinese railway engineering. If Δ is stipulated on the side of smaller value, the decision will be made in favor of the alternative with expensive capital cost and lower operating costs. Otherwise, for a higher

value of Δ , the alternative of less cost of investment and higher expenses of operation will be favorable. Thus, the stipulation of Δ will widely influence the railway economy and development.

As $\Delta=1/T$, the rational stipulation of payback period or standard effective coefficient of investment Δ is one of the basis of economic policy. In Chinese engineering design, T is taken from 6 to 12 years, and that is Δ - from 0.06 to 0.12, according to the nature of the railway. In the past, the Chinese railway design comparison commonly used $\Delta=0.10$, the current “railway construction project economic evaluation method” (second edition) of 0.06.

3. Minimum conversion cost method

Comparing alternatives which line length and transport revenues are basically the same, for simplify the calculation, the minimum conversion cost method is adopted for comparison. The conversion costs include the total investment cost of various alternatives and various costs of each alternative in the project life period (mainly the annual operating expenses). The alternative with the lest total cost is taken as the best, the basic equation is:

$$(5.29)$$

where K_i is the total conversion cost of alternative i ; A_i is the total investment cost of the alternative i ; E_{it} is the annual operate cost in t year of the scheme i ; and n is the years of calculating period.

Further considering the time value of money, the calculating equation for the total conversion cost is:

$$(5.30)$$

where A_{it} is the capital investment at t year of the alternative i ; E_{it} is the operating expenses in t year of the alternative i ; i_{by} is the railway benchmark yield; and n is the years of calculating period.

If at the end of calculation period, some schemes have residual value of fixed assets, the calculating equation of the total cost can be modified as follows:

$$K_i = \sum_{t=1}^n \left(\frac{A_{it}}{(1+i_{by})^t} + \frac{E_{it}}{(1+i_{by})^t} \right) - \frac{A_{rv-i}}{(1+i_{by})^n}$$

(5.31)

where $Arv-i$ is the residual value of fixed assets of scheme i at the end of calculation period.

4. The difference investment internal rate of return method

It is a method with the criterion index of economic comparison. Differential investment internal rate is the discount rate that the sum of net cash present value equal to zero. It can be calculated using Eq. (5.32).

$$\sum_{t=1}^n [(CI - CO)_{2t} - (CI - CO)_{1t}] (1 + \Delta FIRR)^{-t} = 0$$

(5.32)

where CI is the cash inflows; CO is the cash outflow; $(CI - CO)_{2t}$ is the net cash flow of bigger investment scheme in t year; $(CI - CO)_{1t}$ is the net cash flow of smaller investment scheme in t year; $\Delta FIRR$ is the balance investment financial internal rate; and n is the calculating period.

From the perspective of national economic benefits

$$\sum_{t=1}^n [(B - C)_{2t} - (B - C)_{1t}] (1 + \Delta EIRR)^{-t} = 0$$

(5.33)

where B is the benefit; C is the cost; $(B - C)_{2t}$ is the net benefits flow of larger investment scheme in t year; $(B - C)_{1t}$ is the net benefits flow of smaller investment scheme in t year; and $\Delta EIRR$ is the balance investment economic internal rate.

When doing a scheme comparison, according to the above equation, to calculate the balance internal rate of return of investment, and compare with financial internal rate i_C (from the point of enterprise benefit comparison) or social discount rate i_s (from the point of national economy benefit comparison), when $\Delta FIRR \geq i_C$ or $\Delta EIRR \geq i_s$, with large investment scheme is the best scheme. On the other hand, the small investment scheme is the best scheme.

This method is suitable for comparison of two or three schemes. When the number of schemes is large, to avoid increased workload when comparing scheme two relatively, the net present value method is used in the comparison.

5.3.3 Methods Used in Other Countries

5.3.3.1 Methods Used in Private Railway and Other Projects

There are several methods for economic criterion of engineering projects of private enterprises, such as: the method of rate return, payback period method, present worth method, annual cost method, and other similar formulas of comparison.

An approximate formula of rate of return method introduced by W. W. Hay for alternative selection of railway lines is as follows:

$$\text{Rate of return } P=\frac{R-E}{A}$$

where R is revenue, E is operating expenses, and A is investment.

The alternative with the highest value of P is regarded as the best.

This calculation based on a zero interest rate is only a rough estimation primarily for comparison. The actual rate of return will depend on the reality in operation and whether there is any interest for the bank loan.

The payback period method without consideration of interest is the reciprocal of the above rate-of-return method.

$$\text{Payback } m=\frac{A}{R-E}$$

If the variation of R–E in different year can be predicted, the equation may be written as

$$\sum_{i=0}^m (R_i - E_i) \geq A \text{ or } \sum_{i=0}^m A_i$$

If both the bank loan interest and the yearly varying values of revenue and operating expenses can be estimated, the rate-of-return calculation may be put in a table form. For example, assume the investment cost A of a short projected railway is ¥200 million at 5% interest of bank loan. The values of R–E of different periods and the payment condition may be expressed as Table 5.1, in which payback of each year=(R–E)–yearly interest.

Table 5.1

Unrecovered Investment=Unrecovered Investment of Previous Year—Payback of This Year

Year	Investment A (Thousand)	R–E (Thousand)	Interest 5% (Thousand)	Payback (Thousand)
0	¥200,000			
1		¥20,000	¥10,000	¥10,000
2		¥25,000	¥9500	¥15,500
3		¥30,000	¥8725	¥21,275
4		¥35,000	¥7661	¥27,339
5		¥40,000	¥6294	¥33,700
6		¥45,000	¥4609	¥40,391
7		¥50,000	¥2590	¥47,410
8				

Note: Synthetic optimization in engineering decisions with railway example.

The above indicates a rate of return or payback period of 7-8 years in which beside the 5% interest payment, all the initial investment is paid back. This is, of course, the payback period may be much longer because of: 1, expensive investment, 2, long construction period, 3, slow growth of traffic amount, i.e., the slow increase of R-E and possibly 4, high rate of interest of bank loan.

That is why private enterprises and foreign investors show much less enthusiasm in railway construction than in light industries.

The present worth method is a dynamic process used widely in engineering and industrial projects in western countries. In this method, the time factor, i.e., the cash flow discounted at any future year is considered, all the revenue, capital investment and constant expenses are converted to a single sum equivalent to the value of present time. The PW is expressed by the following equation:

$$PW(n) = \sum_{t=0}^n (R - A - R)/(1+i)^t$$

where n is the planning horizon (number of years of the planning decision taken according to the nature of the project by the owner of the enterprise); R is the revenue in the year t; A is the capital investment in the year t; E is the operating expenses in the year t; and i is the interest rate.

For private enterprises, i is specified as the minimum attractive rate of return (MARR). MARR may be compared with the discount rate cash flow in the governmental projects in the discussion of railway construction economy.

The alternative with the greatest PW is taken as the most economic selection.

It may be seen from the above example methods that for the railway construction in this and other developing countries, if private and foreign investments are encouraged, or when any national railway is aided by the World Bank or other international loan of low interest rate, several requirements have to be fulfilled:

- (1) The prediction of traffic amount and its growth should be dependable.
- (2) The investment operation costs should be kept to a minimum under the condition of safety and qualified construction standard.
- (3) An adequate railway rate is required.
- (4) The construction period should be as short as possible.
- (5) A low rate of interest is required.

Otherwise, the payback period will be very long and the railway subjects to a long-term situation with debtors. These requirements are much more important than in government railway construction, because they involve the question whether the channel of private and foreign investments are possible, not only the problem of economy.

The private investment may be of different cases and different patterns. In the case of a private enterprise with its ownership of the railway, the owners will be impossible to endorse super high standard of alignment and in cooperation of equipment with alignment. If the design of the private road is clearly more economical than that made by the government railway, that will be a disgrace of the national civilization.

5.3.3.2 Methods Used in Government Enterprises of Western Countries

Government-operated engineering projects are usually of the nature of exploitation and public service. Natural resource protection and exploitation, cultural promotion, public transportation development, municipal establishments, hydraulic and irrigation works and other projects for social development are to be considered from longer and broader views. So the methods of economic criterion should somewhat differ from those used for private projects.

John A. White, Marvin H. Agee, and Kenneth E. Case introduced in their “Principles of Engineering Economic Analysis” in detail the benefit-cost analysis and cost effectiveness analysis used for judging the projects in “public sector” (Wang Di).

Benefit-cost analysis at the rate of interest i may be indicated by the following equation:

$$B/C(n) = \frac{\sum_{t=0}^n B(1+i)^{-t}}{\sum_{t=0}^n C(1+i)^{-t}}$$

where B is the social benefits relating to the project in the year t , in which disbenefits have been deducted; i is the interest rate; n is the planning horizon in years; and C is the government expenses for the project in the year t .

Practical benefits to society include extensive range of public merits of all the related firm, organizations, agents, and individuals, such as industries, agriculture, mines, power generation, other public works, and private enterprises. Disbenefits include all losses and expenditures which caused by the establishment of the project, for example, the loss of land production, compensation to migrants, forest loss, disturbance of irrigation systems, etc.

C includes the construction costs and running operating expenses.

The planning horizon may be taken as the period before a large scale reconstruction. For private invested equipment planning horizon may be taken as the life of the project, but

most of public works have very long life; only reconstruction or reformation sometimes happen. If the period before reconstruction or reformation exceeds thirty years or more, the present worth by the end of planning horizon will be very small, and further consideration of the financial values will be insignificant.

When the B/C ratio of a project is greater than one, it is regarded as feasible. The project with the greatest B/C ratio among all the alternatives will be the most economical one.

A benefit-cost analysis may be made between two feasible designs a and b. The project with less cost and net benefit may be regarded as an existing construction or original design, and the other project (with greater cost and net benefit) the additional cost to produce an additional net benefit $\Delta B = B_b - B_a$. The items B&C in the above expression are then replaced by ΔB , and ΔC .

The final results of the B/C ratio and the $\Delta B/\Delta C$ ratio will be the same, but the use of ΔB and ΔC will eliminate the common items and values of the two alternative and thus, serve to save the time of computations.

Another form of the analysis is the B–C criterion, which is expressed as

$$B - C = \sum_{t=0}^n (B_t - C_t) / (1 + i)^t$$

This is similar to the present worth method used in private projects and is comparatively suitable in railway project criterion. In comparison with B/C ratio analysis, the B–C criterion has the advantage of indicating the amount of profit or deficit at any time.

5.4 Comprehensive Criterion of the Proposals

5.4.1 Traditional Comparing Methods

The comprehensive criterion of schemes is based on various technical and economic evaluation indexes to carry on the comprehensive analysis, identify the most reasonable scheme.

The basis for the comprehensive evaluation of schemes depends on the various technical and economic indicators, mainly including indicators relating to the technical features, operating characteristics, the quantity of works, engineering conditions, economic evaluation, and indicators of several other aspects.

The comprehensive criterion of schemes should be carried out according to the differences between schemes, and select an index system with an appropriate breadth, list for comparison. Taking an example of a new railway, the commonly used indicators are listed in Table 5.2.

Table 5.2

Technical and Economic Index of New Railway Line Project

Serial Number	Index	Name
I	II	
1	Track length	Building
2	Coefficient of extension line	
3	Traction quality	
4	Running time for a round trip	Control
5	Carrying capacity	
6	Traffic capacity	

7	Maximum grade	Ruling g
8	Length of maximum grade	Ruling g
9	Lifting height	Up/down
10	Minimum radius of curve	
11	Bad geological location	Number
12	Station	District
Intermediate station		
13	Cut-fill	Fill
Cut		
14	Bridge	Total number
Among them, the seat number/total length of the large bridge		
15	Culvert	Total number
16	Tunnel	Total number
Among them, number of long tunnel/total length		
17	Construction labor	
18	Land occupation	
19	Investment	Construction
Expenditures on rolling stock		
20	Operation price	
21	Operating costs of design annual	
22	Conversion project operating costs	
23	Profit-tax rate of capital of design year	
24	Payback period	
25	Net present value	
26	Internal rate of return	

5.4.2 Criterion Method With Optimization Models

Up to now, the static method of criterion is still widely used in Chinese railway projects without tendency of revision, especially for the projects of exploiting nature. In this text, this traditional formula will be used as the objective function of optimization, i.e.,

$$D = \Delta A + E = \text{minimum}$$

where D is the effective coefficient of investment=0.08-0.12, according to the nature of the project; and A and E are the capital investment costs and annual operating expenses of the designed year, respectively.

In the case of private owned enterprises, when railway revenue is considered, the factor of revenue rate may be put in the criterion function. When a dynamic formula is used, the interest rate and time factor may be applied. Both variations of criterion method do not give much difficulty to the optimization.

In short, the only essential items of any method of criterion are the capital investment A and the annual operating expenses E.

5.4.2.1 Objective Functions

The objective function model of optimization of the three most important design variables F (rated tractive force), G (ruling grade), and R (minimum radius of curves) for undeveloped sections (basic model) may be summarized as follows:

$$D = \underbrace{\left(\frac{a}{G-c} + b \right)}_{(A)} \underbrace{\left(p + qR + rR^2 \right)}_{(B)} \underbrace{\left[\frac{F}{f} \left(\frac{d-eG}{g+G} \right) + h \right]}_{(C)} + C_t \underbrace{\left[\frac{p_1}{2980F \left(\frac{d-eG}{g+G} \right) V_t} + \frac{p_2}{4380q_n V_t} \right]}_{(D)}$$

$$+ \underbrace{\left(k_1 + lG + mG^2 \right)}_{(E)} \underbrace{\left(\frac{s}{R+t} - \mu \right)}_{(F)} \underbrace{\left(\frac{n_f F (d-eG)}{g+G} \right)}_{(T)} \quad (\text{RMB/km/year})$$

(5.34)

where D is the effective coefficient of investment; (A) is the construction cost as a function of ruling grade; (B) is the influencing factor of curvature standard; (C) is the influencing factor of passing siding length; (D) is the cost of rolling stock; (E) is the operating expenses as a function of ruling grade; (F) is the influencing factor of curve standard on operating expenses; and (T) is the designed railway traffic capacity.

In the case of sections of steep natural longitudinal slope where the development is necessary, the objective function of optimization will be

$$D = \left\{ \left(\frac{d}{G-c'} + b' \right) (p+qR+rR^2) \left[\frac{F}{f} \left(\frac{d-eG}{g+G} \right) + h \right] \frac{d_1 S_n}{0.8G} + C_t \left[\frac{p_1}{2980F \left(\frac{d-eG}{g+G} \right) V_t} + \frac{p_2}{4380q_n V_t} \right] \right\} \\ + (k_1 + lG + mG^2) \left(\frac{s}{R+t} - \mu \right) \frac{n_f F (d-eG)}{g+G} - \frac{d_2 S_n}{0.8G} \text{ (RMB/km/year)}$$

(5.35)

For clearness, in the above functions, only the three critical independent variables F, G, and R are involved. Factually, the length of siding platform is already included as an influencing factor depending on the freight train length, i.e., the tractive force. The consideration of this length is not conformed to the given figures of effective siding length without reasonable basis in the design specification. The length of platform should be kept enough for the development of freight train by adequate regulating the constant h.

The rated locomotive speed V of the same type of traction varies only slightly. The spacing distances of passing sidings L are frequently governed by local demands. The detailed treatment of these and other variables are left for the research engineers of the design institutes and not included in the basic models.

The construction cost items have constants a, b, c, a', b', c', p, q, and r depending on the natural condition and constants d, e, f, g and prices p1 and p2 relating to rolling stock investment. Constants k1, l, m, nf, s, t, and u varying with operating condition, type of profile, and prices of current norm. These constants can be obtained from statistics.

For very long railway projects in China, it is generally impossible to have uniform topographic condition and the same required traffic capacity throughout the entire line. The optimization of the design variables F, G, and R is reasonably analyzed separately for various divisions. It has been a good tradition in Chinese railway in arranging the divisions according to topographic features, combined with the required capacity and engine terminals.

In each division, there may be sections of different topographic categories and types of profile. The mathematic model of the entire division may be obtained by taking the weighted means of the constants of individual models as the model constants for the division.

Evidently, for very steep sections, especially the sections on both sides (or one side) of the cross-ridge tunnels, the resultant optimal value of tractive force F and the ruling grade G

will definitely be much higher than those of ordinary undeveloped sections. That means double or multiple engine driving on steep grades and sharper curves is necessary.

After the pure mathematical solutions of design variables are obtained, there should be an overall adjustment of practical engine type and alignment standards to facilitate the uniform freight train weight through the entire line.

The optimization analyses are common in the stages of planning and preliminary design. The only thing is that the constants in the mathematic models may have different degrees of accuracy. Factually, the optimization process in preliminary design serves only for an examination, if necessary, to the solution obtained in the planning stage.

5.4.2.2 Constraining Factors

1. Railway capacity

The required line capacity, in one sense, is a condition of design, just like the natural condition to face, and is also a constraining factor. The available freight capacity is

$$C = \frac{n_f F (d - eG)}{g + G} \geq \text{required capacity } C_r$$

(5.36)

where n_f is the saturate number of freight trains per day with adequate reservation; and d , e and F are the conversion constants, obtained from statistics.

The limiting effect of railway capacity on the optimization of F and G may be illustrated by the graph.

2. Tractive force

The minimum value is the tractive force of the weakest engine of the given kind of energy supply. It often does not affect the designs of national railway. The maximum F is practically determined by the technical standard of the railway. If the long freight trains are provided with multiple engine driving, strong enough coupling devices, electric breaking and computer controlled operation, the item F practically has no limit. Otherwise, the total tractive force applied will depend on the current equipment standards. In Chinese railways today, triple engine-driven trains have been used in some mountain railways. The research in dynamic characteristics and computer control of super-long freight trains is carried on in laboratories. The limitation of tractive force might be gradually relaxed.

3. Ruling grade

The designed grade standard of 6‰ widely is used in trunk lines, and 4‰ is the limiting flat ruling grade. Because any grade standard flatter than this will approach the train

resistance of starting. In other words, in case on any flatter grade trains might not be able to start from a halt.

The steepest ruling grade is limited from the view of security and the requirement of railway. The degree of safety depends on the degree of advancement of technical facilities. The maximum grade of standard gauged mountain railway of light capacity in Switzerland goes up to 50–60‰. The railroad of the USA across the Rocky Mountains has a maximum grade of more than 40‰.

The steepest grade in Chinese trunk line railways designed and constructed in the 1950s is 30‰. The first mountain line, completed nearly 100 years ago by Mr. Zhan Tianyou, has a maximum grade of 33‰. The maximum grade designed in the late 1940s is only 20‰. With the marching onto tire road of more and more difficult regions and increase of motive power, the designed grade, on the contrary, steps back its steepest value. In very steep natural slope districts, the designed line has to be greatly developed. According to past lessons, it has brought about excessive construction cost and latent ecological disasters. The reasonable upper limit of grade will never be reached on the condition of present tardy state of technical innovation, and especially the current practice in grade design habituated in the last 40 years.

4. Curvature standard

The minimum radius of curves is often governed by the required train speed rather than economical factor. But the economic consideration should not be entirely omitted. In mountain regions, especially at the spots of steep cliffs and high piers in deep valleys, the safety speed should not be expected very high. According to the mechanical relation, the speed of 80–100 km/h of standard gauge trains requires a 400–500 m radius. These standards already form the constraining factor in the optimization analysis.

In the developed sections, the longer the curve radius is, the greater amount of construction work and, consequently, higher the probability of calamities will be. Therefore, the problem of curve radius induces a basic question, that is, whether the excessive line development caused by insufficient utility of railway grade and motive power is a risk-taking measure.

In plain regions, the railway construction cost is less affected by the variation of curve radius than that to mountain area. For the sake of allowing the increase of train speed, the curve radius should be made relaxed. The old specified minimum radius of 800 m for trunk lines is evidently too short and the related regulation is to be revised.

In most cases, the economically optimized minimum radius of curves is shorter than the above discussed values both for mountain and plain districts. Therefore, very often, the factor R becomes a constant in the objective function of optimization. Thus, the optimization analysis often involves only two chief design variables: F and G .

5.4.2.3 Graphic Example of Coordination of Locomotive Tractive Force and Railway Grade Standard

According to the above discussion, among all the factors of technical features, the locomotive tractive force and the ruling grade standard are the most important ones

controlling the railway economy and efficiency. Fig. 5.1 shows the effect of F and G on the economic index and railway capacity in curve forms.

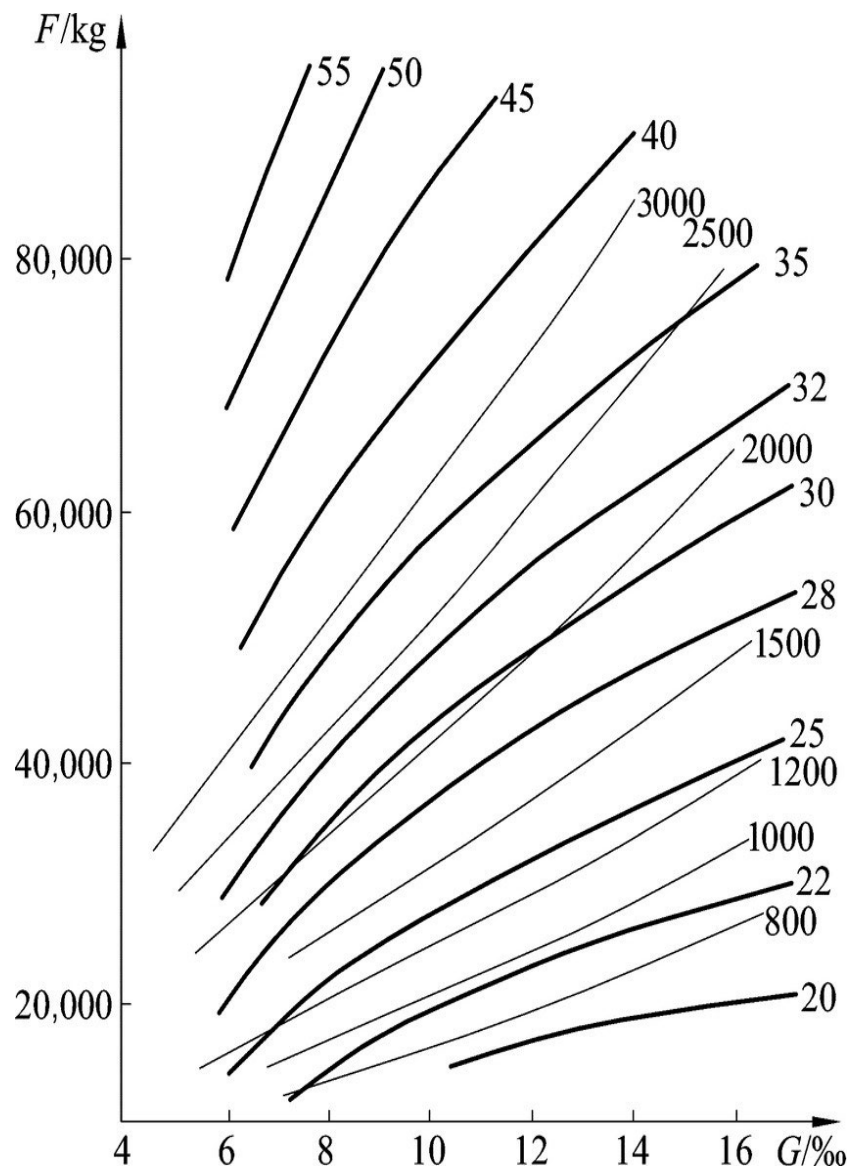


Fig. 5.1 Effects of tractive power and grade standard on economy and railway capacity. Economic index (objective function), ; railway capacity (constraining function), .

In the graph, the ordinate denotes the locomotive rated tractive force and the abscissa—the ruling grade of the projected line.

The heavy lines are the contours of economic index (value of objective function). The fine curved lines show the constraining function of traffic capacity.

Example: In the case where the required capacity is 20 Mt in the designed year, a corresponding minimum expenditure contour line tangent to the 20 Mt capacity curve may be drawn by interpolation between the heavy contour lines ¥ 28 and 30 million per year. The expense value is approximately ¥29.6 million per year. The point of the tangent shows the theoretical optimal tractive force of 40,000 kg (i.e., 40 Mg) and an economic ruling grade of 9.5‰.

The practical adopted F and G may be determined by adjustment of the results of different sections and selecting the practical locomotive tractive force in coordination with the ruling grade of round number.

This example graph is for undeveloped sections of electric railway in mountain regions of ordinary difficulty. For other topographic conditions, different graphs of the same type may be constructed. The economic contour lines and the constraining radius of curvature, spacing distance of stops, and the number of passenger trains of the projected lines. For the same kind of line in a very similar environment, the corresponding graph may be drawn for convenient use.

The graph may also be used in predicting the strengthening schemes in the future development of railway traffic. If the designed ruling grade is 8‰ for an electric driven single track railway, SS7 may be used up to the required traffic of 18 Mt/a. Beyond this load, SS4 will go on service until 28 Mt/a.

Another function of graph is to examine the economic efficiency of designs. For instance, when the required traffic C is 10 Mt/a, the combination of F 18 Mg and G of 6‰ shows an economic waste of 11% in comparison with that of F 21 Mg and G 10‰. When the required C is 20 Mt/a, the corresponding loss of F 28 Mg and G 6‰ in comparison with F 42 Mg and G 10‰ is 5%. When C=3 Mt/a, the loss of F 42 Mg and G 6‰ combination will be 2.5% in comparison with that of F 47 Mg and G 9‰. These roughly show the degree of waste of excessively high standard of alignment. The losses do not include the delay of operation and possible disasters due to excessive construction work.

In the case of more difficult topographic conditions, the loss due to inadequate decisions will be shown still evidently, especially in the sections of line development with double (or multiple) engines driving on steep natural slopes.

5.4.2.4 Implementing of Railway Project Optimization

1. Eqs. (5.34), (5.35) and the graph in Fig. 5.1 are only explainable examples in which the numerical constants vary with different categories of topography and operating conditions. The design variables F and G are the most important and constantly dealt with. The graph is very useful to facilitate the bird's-eye view of wide selection of locomotive and grade standard and also the further consideration for perspective traffic development.

For the solution of functions including reconstruction project, with more design variables (such as, beside R, the spacing of train stops, train weight and speed, etc.), mathematic optimization methods are to be used. In the last several decades, facilitated by computer technique, optimization methods have been widely applied in mechanical, structural designs and large-scale systems engineering. If necessary, the readers may refer to any of

the books with titles such as “Applied Optimal Design (Control)” or “Optimization Methods for Engineers.”

2. The topographic and geological conditions are very different in various regions of our country. Therefore, the research work of establishing the optimization models of all the regions will be enormous. It should preferably be taken by the research engineers of regional design institutes where abundant surveyed materials are available and the engineers are more familiar with the local natural conditions. It is convincing that much more rational and practical models and graphs than the author's examples will be obtained.

3. The research work, indeed, will be very heavy. However, once it is soundly done, the reasonable coordinate optimization of motive power and alignment standards can be obtained reliably for the planning stage. Based on these data, favorable working condition of design institutes can be provided as follows:

- The institutes may have a clear idea of adequate technical standards and scale of construction for the perspective railway network.
- A clear view of required types of locomotive can be foreseen and these data serve as good reference for the engine manufacturers without uncertainty of production.
- The optimal standards obtained in the planning stage will be the guide or channel for the design stage with deeper study and economy.

Chapter 6

Station Design

Abstract

A station is a basic production unit of railway transportation, and various types of technical equipment related to transportation are concentrated there. Investment on station construction takes up a great part in the total investment of railway construction. Stations may be classified into several types. This chapter starts by discussing passing stations, which are set on single-track railway for mixed passenger and freight trains, and overtaking stations. Proper design of intermediate stations is very important for railway completing required transportation and strengthening links with urban and rural areas. District stations are train spacing points to divide tractive districts in railway network. In order to deal with the disintegration and marshaling operation of many freight trains, a station equipped with hump shunting equipment is called a marshaling station. Finally, the chapter considers the essentials of high-speed stations.

Keywords

Passing station; Overtaking station; Intermediate station; District station; Marshaling station; Junction terminal; High-speed station

A station is a basic production unit of railway transportation, and various types of technical equipment related to transportation are concentrated there. Various passenger traffic service and freights traffic service, such as passengers' boarding and alighting, consignment, freights' loading and unloading, delivery and safekeeping of goods, etc., can only be realized at the station. Various technical operations of railway transportation, such as train arriving and departing, passing through, overtaking, disassembly and marshaling, shift of locomotive and train crew, train and freight examination, are all done at stations.

Investment on station construction takes up a great part in the total investment of railway construction. At present, there are about over 5700 stations all around China railway network, all with station track lengths occupying approximately 40% of railway traffic kilometers. To use the national fund effectively, lower the cost, and occupy less farmland, great importance must be attached to the planning and design of stations.

According to the characteristics of technical operation, the stations may be classified into three types in high speed railway, i.e., overtaking station, intermediate station, and terminal station; while in mixed passenger and freight railway, they may be classified into five types, such as crossing station, overtaking station, intermediate station, district station and marshaling station. According to the passenger and freight traffic volume, they may also be classified into four types for passenger traffic lines, i.e., super-large station, large station, medium station, and small station; and six types for passenger and traffic lines, i.e., superclass station, Class I, II, III, IV, and V stations.

6.1 Passing Station and Overtaking Station

6.1.1 Passing Station

6.1.1.1 Operation and Equipment at Passing Station

Passing stations are set on single-track railway for mixed passenger and freight trains. There, railways will handle reception-departure, and meeting and passing of trains. In addition, they may also deal with a little passenger and freight traffic service. To meet the requirements of operations, arrival-departure tracks shall be laid in passing stations, and facilities for communication, signal, and passenger alighting and boarding as well as technical offices shall also be equipped.

6.1.1.2 Passing Station Layout Diagram

Passing station layout diagram can be classified into transversal type station and longitudinal type station according to the relative position of arrival- departure tracks.

A transversal type passing station layout plan is shown in Fig. 6.1A. It is featured by the transversal arrangement of arrival- departure tracks. Therefore the station site is short; the engineering investment cost is small; the attendant on duty can watch the two throats with better horizon so that the management is very convenient. With transversal type, station tracks can be used flexibly and yards are laid very tightly.

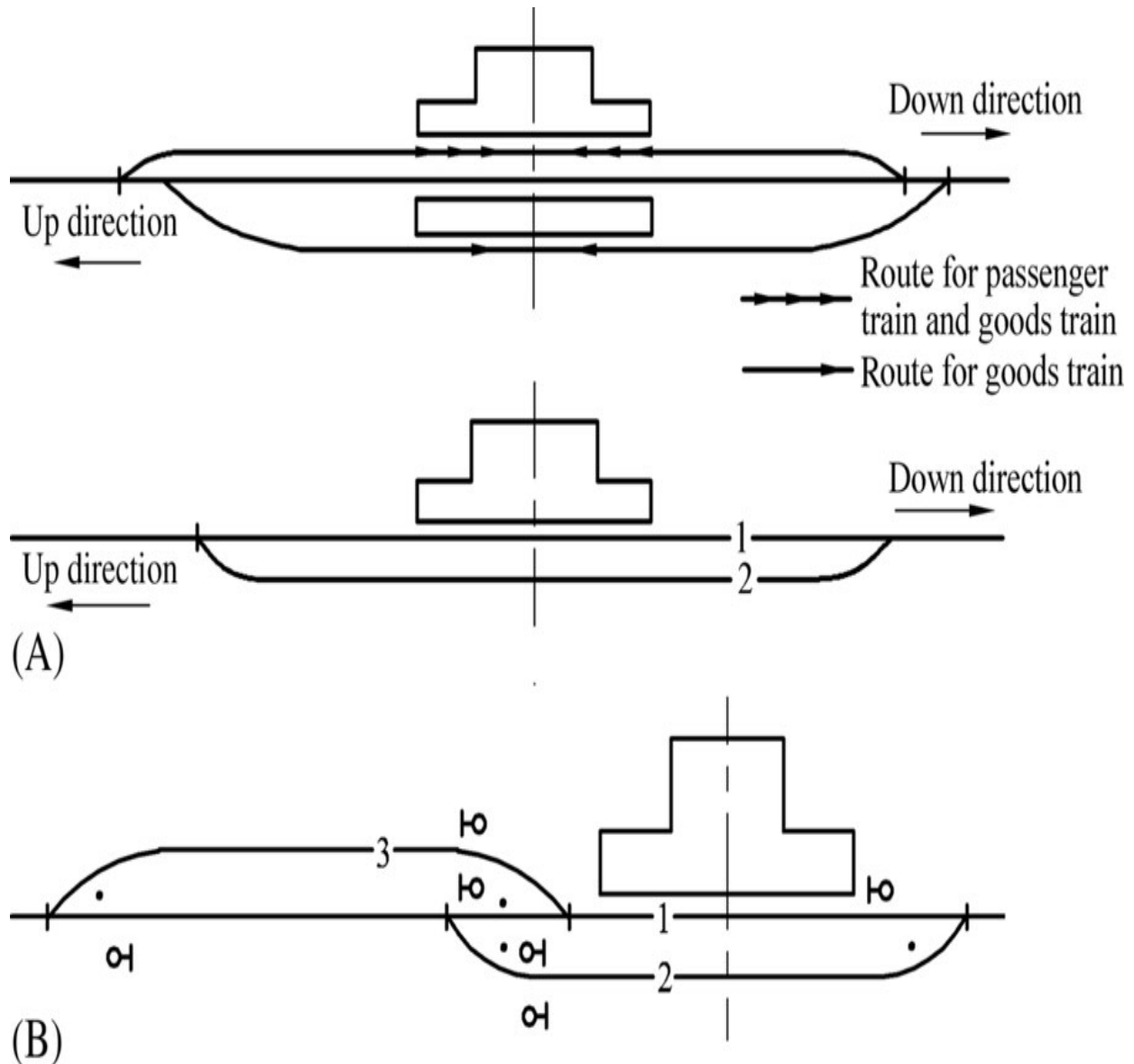


Fig. 6.1 Passing station layout diagram. (A) Transversal type passing station. (B) Longitudinal type passing station.

For a longitudinal type passing station, the two arrival-departure tracks are end-to-end arranged with one effective length staggered, as shown in Fig. 6.1B. The arrival-departure tracks staggering layout is beneficial for

organizing passing without requiring trains to stop, and is convenient for over-long train meeting and passing, and convenient for communication between the attendant on duty and the train driver. As the width of station site is narrow, work amount can be reduced at narrow topography area. However, comparing with transversal type, longitudinal layout has some shortcomings, such as the station site is longer than, line may be extended at section of sufficient grade, path of shunting service for attaching and detaching of the cars may be longer and the turnouts may be dispersed so that station management is inconvenient. Therefore, this type can only be adopted in sections where the terrain is narrow and through capacity requirement is high, or nonstopping passing is required for train as well as on over-long trains operating section.

(a) Transversal type passing station

(b) Longitudinal type passing station

Two arrival-departure tracks shall be laid in a passing station so that the station can offer three-train-passing conditions. When traffic volume is relatively small, one track scheme can be used. Two stations with only one arrival-departure track shall not be set consecutively so as to ensure that, the influent region is not wide and the train working diagram can be adjusted easily under abnormal transport order conditions.

When only one arrival-departure track is set, it shall be set at the opposite side of the operation office. The advantage of this layout is that main line can be applied for train arrival and departure. In this case, attendant on duty may handle the train passing-through on the main line at main platform, without being separated by other trains on the arrival-departure track and nor crossing the tracks. The passenger trains received and departed from main line may stop by the

main platform, no needing to run through the side turnout, therefore the train may run smoothly and passengers may feel more comfortable.

Usually an intermediate platform is not set in passing station. In cases where the amount of boarding and setting down of passengers is large and long-term development is very rapid, an intermediate platform may be set, located between arrival-departure track and main track opposite to the passenger building.

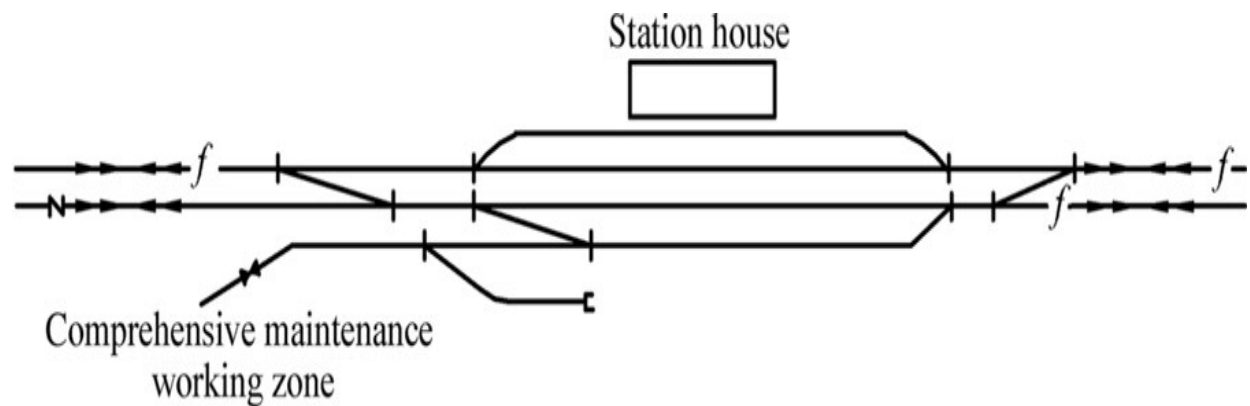
6.1.2 Overtaking Station

6.1.2.1 Operation and Facilities at Overtaking Station

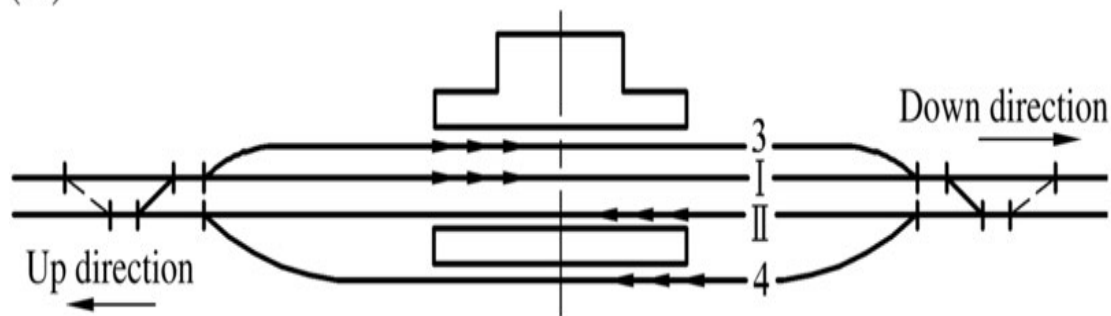
Overtaking stations are set on double track railways and responsible for dealing with the overtaking of trains in the same direction. The main works include dealing with the passing-through of the trains on the main line, entering and exiting the arrival-departure track of waiting trains and stop-and-waiting of trains. When necessary, overtaking station on mixed passenger and freight railway may deal with changing track for the train in opposite directions, and also handle a little passenger and freight business. Arrival-departure tracks shall be laid in passing stations, and facilities for communication, signal, and passenger alighting and boarding as well as technical offices shall be provided.

6.1.2.2 Overtaking Station Layout Diagram

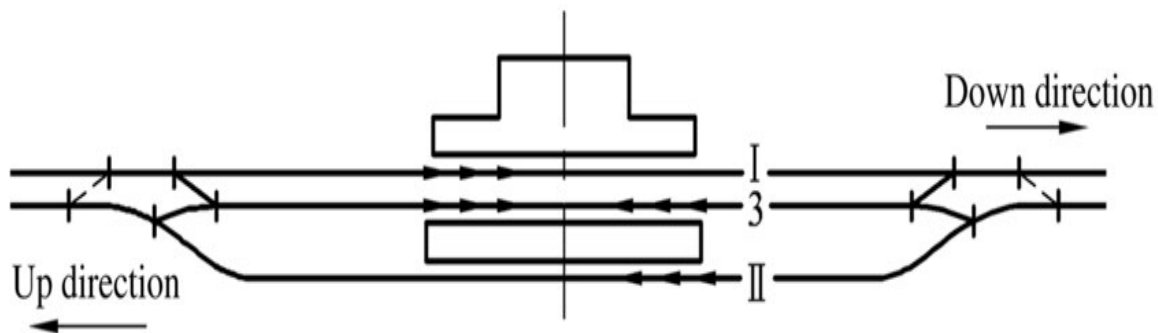
Generally, transversal type layout is adopted in overtaking stations (see Fig. 6.2). The advantages of transversal layout are: the station site is short, construction cost is low, labor cost is saved and management is convenient, arrival-departure track application is flexible and the station layout is tight. Usually two arrival-departure tracks shall be set on the two sides by the main line so that the trains in the two directions can wait simultaneously (see Fig. 6.2A and B). When conditions are extremely difficult, one single arrival-departure track may be set between the two main lines for the passenger and freight railway (see Fig. 6.2C).



(A)



(B)



(C)

Fig. 6.2 Overtaking station diagram. (A) Overtaking station on passenger dedicated line. (B) Overtaking station with two arrival-departure tracks on mixed passenger and freight line. (C) Overtaking station with one single arrival-departure track for mixed passenger and freight line.

Two crossovers shall be set between the two main lines at the two throats of the overtaking station, arranged as facing crossover. When conditions are extremely difficult, and one single crossover is set at each end, the crossover shall face to the operation offices and spaces shall be reserved for laying the second crossover. As maintenance of scissors crossing is inconvenient, it is only used when station site length is restricted.

(a) Overtaking station on passenger dedicated line

(b) Overtaking station with two arrival-departure tracks on mixed passenger and freight line

(c) Overtaking station with one single arrival-departure track for mixed passenger and freight line

6.2 Intermediate Station Design

Due to the huge number and very important role in railways, a proper design of intermediate stations is very important for railway completing required transportation and strengthening links with urban and rural areas. For a reasonable design, engineers should comprehensively understand stations' functions, operations and requirements for facilities. This section mainly introduces design problems about intermediate stations of passenger and freight railway lines. Knowledge about intermediate station on passenger dedicated railway will be discussed in Section 6.5 of this chapter.

6.2.1 Plane Layout Diagram of Intermediate Station

6.2.1.1 Operations of Intermediate Station

There are two types of operations: commercial operations and technical operations.

Commercial operations include ticketing, passenger alighting and boarding, luggage receiving and distributing, freight consignment storage, and handover.

Technical operations include dealing with the train passing, overtaking and passing, detaching and attaching of cars for less-than-wagon-load train, taking-out and placing-in of cars and loading-unloading operations, etc. Intermediate stations may also handle changing track of trains in opposite directions on double track railway. These intermediate stations, which are also turn-around points of locomotives and starting and final point of assisting locomotives, still need to handle attaching and detaching of assisting locomotive, waiting, turn-around, and servicing work.

6.2.1.2 Intermediate Station Layout Diagram

Intermediate stations usually employ transversal layout plans. Common layout diagrams of intermediate station for single-track railway and double-track railway are as shown in Figs. 6.3 and 6.4. Both types are better for guaranteeing passengers' safety, convenient for loading and unloading of less-than-carload cars, convenient for attaching and detaching of cars, good for train waiting, and conducive for maintenance of facilities, modification and expansion of equipment.

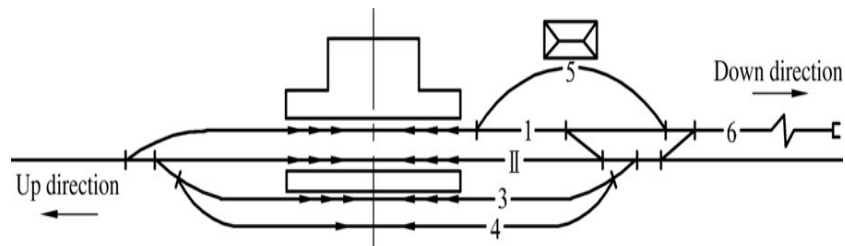


Fig. 6.3 Single-track intermediate station diagram.

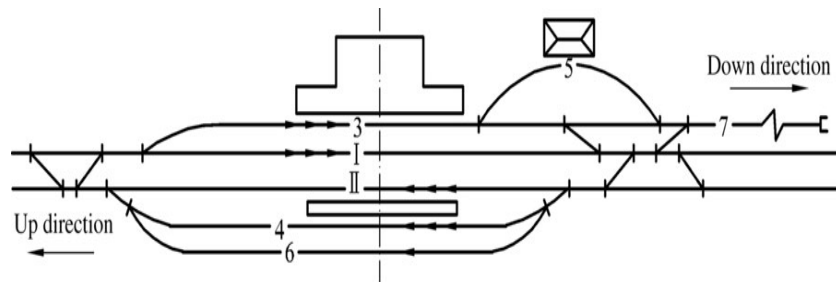


Fig. 6.4 Double-track intermediate station diagram.

Two crossovers shall be set at the throat areas at the two ends of the station to meet requirements of shunting, train running in reverse direction running, and receiving and departing trains in two directions. Sometimes, due to major repairs of section track, temporary failure of track, and other abnormal conditions, the train running schedule may need to be adjusted to make a train running on one main track change to another main line to run continuously. For this reason, the intermediate station needs also to set two crossovers at the two ends.

The following, with Fig. 6.3, introduces the technical operation process of various trains in intermediate stations. (Note: Chinese railways adopt a left-side running system.)

- (1) Receiving and departure of nonstop passenger and freight train: After handling blocking with neighboring station, station attendant on duty open track 1 of main line for trains passing through.
- (2) Receiving and departure of stopping passenger and freight train: after handling blocking, the passenger train is received to track 1 or 2; when track 1 and 2 are occupied, train may be received to track 3; freight train can be received to track 1, 3, or 4.
- (3) Handling attaching and detaching operation: when cars needing to detach and attach at head of the train, downward pick-up and drop train shall be received to track 1. After the set of cars is detached, the locomotive haul the train arrived at the station to track 6, then run reversely and place cars into loading and unloading track 5 for dealing with the loading and unloading operations. If there are already downward cars on track 5, the two sets of cars shall be attached together and dragged out by a locomotive then place into track 1 through lead track 6 for detaching, then the locomotive will send the arrived train to track

5 for detachment through lead track 6, then the locomotive will return to track 1 through lead track 6 and the train shall be attached and preparing for departure.

Most upward pick-up and drop trains shall be received on track 4. After being detached, the locomotive will run along an idle track to the end of the detached train, drag the cars to be detached into lead track 6, and place in loading and unloading track 5 for loading and unloading operations. The locomotive will then drag the guard's van to lead track 6 and place the guard's van to track 4 for attachment. After it is detached, the locomotive will run along the idle track to the head of the train and get attached to the train and then waiting for departure. If there is already a downward train in track 5, then the pick-up and delivery process is similar to the downward trains.

(4) Loading and unloading without detaching: to handle loading and unloading of cars by workers and facilities prepared in advance during the train stopping for passing and water adding operations.

From the basic operation process above, we understand that detaching and attaching operation is still influenced by train formation. Other operation methods are also not a fixed procedure. Each station can formulate a pragmatic operation rule and provide the process of each technical operation as per its specific condition.

6.2.2 Major Equipment Layout of Intermediate Station

6.2.2.1 Facilities for Passenger Transportation

Passenger traffic facilities include passenger station building, platform and flat aisle or cross line facilities.

Passenger Station Building

Passenger station building shall coordinate with urban planning and the general layout diagram of the station and shall be convenient for passenger passing. The station building shall be placed near residential area and shall be better erected at the middle part of the station so that the passengers alighting and boarding is convenient as possible. The passenger station building shall keep a certain distance from the central line of the nearest track, so more tracks may be added at the building side. Generally, distance between outer wall of the building ledge and platform edge should be 8–20 m. While under difficult condition, a shorter distance can be adopted, but it shall never be shorter than the main platform width.

The ground of station (building site) shall be kept at the same elevation with the main platform surface or at least the difference shall be as minor as possible (track-level Model, Fig. 6.5A). When the topography is difficult, the station building site may be higher (track-

above model, Fig. 6.5B) or lower than the main platform surface (track-below model, Fig. 6.5C).

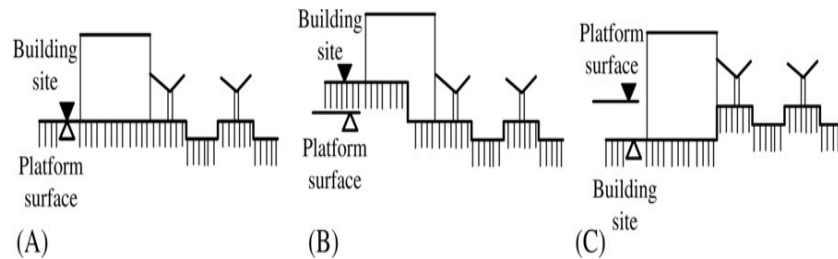


Fig. 6.5 Difference of height between bottom of station building and top of platform.

The scale of station building is subject to the largest number of the passengers waiting for trains at one time. Intermediate station building scales are mostly medium or small, and generally a fixed design is adopted. Common capacities of small station building are 50, 100, 200, and 400 persons.

Passenger Platform

There are two types of passenger platforms: basic and intermediate platforms, as shown in Fig. 6.6. An intermediate platform shall be set between tracks 2 and 3 and two tracks away from the main platform, so that application may be more effective and maintenance may be more convenient (if it is set between tracks 1 and 2, sleeper change may be very difficult). When the passenger amount is not very large, an intermediate platform is not required temporarily.

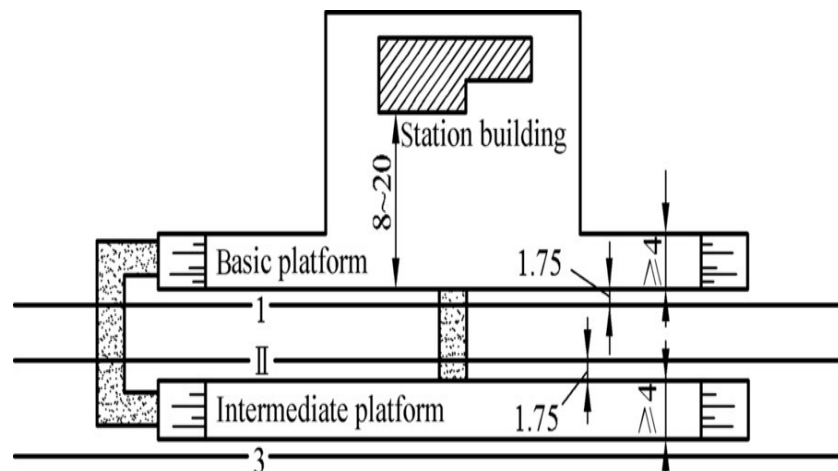


Fig. 6.6 Passenger traffic equipment of intermediate station.

Generally, the length of the platform shall be set as 300–550 m, subject to the recent passenger flow volume, train length, and enlargement needs. When passenger flow volume is relatively small and the train is relatively short, the platform length may be reduced properly.

The width of the platform shall be determined subject to the peak volume of alighting and boarding, luggage car type, size of buildings and facilities set in the platform. The main platform width within the range of station building from the outer wall edge of the building ledge to the platform edge shall be no less than 6 m, and other part shall be no less than 4 m. Single-track railway intermediate platform widths shall be no less than 4 m and double-track railways shall be no less than 5 m. When overpass facilities are provided, the platform shall be widened as needed.

The height of passenger platform can be divided into three types based on its relationship with neighboring line and requirement of the passing trains, they are high platforms, middle platform and low platform. Limited by the gauge, platforms next to the main line and line for overload freight trains shall be 300 mm higher than the rail top (low platform), other platforms may be 500 mm higher than the rail top (middle platform). High platform that is 1100 mm higher than the rail top, which is only required under special circumstance. For water drainage, the surface of platform shall be designed as a traversal slope with slope no bigger than 2% toward the platform edge.

Level Passageway and Overpass (Bridge) Facilities

Level passageway shall be provided between the main platform and intermediate platform for passage, the width shall be no less than 2.5 m. When needed, overpass and underground tunnels may be constructed in large and medium station where the traffic volume (i.e., the alighting and boarding persons) is large.

6.2.2.2 Freight Traffic Equipment

Generally, at an intermediate station of mixed passenger and freight lines, a freight yard should be set up, including warehouse, freight platform, freight-storing yard, freight track, loading and unloading facilities and freight offices, etc.

Freight Yard

The site of freight yard at intermediate station shall be determined according to freight distribution direction, freights traffic volume, terrain and geologic conditions, and local town planning. In most cases, the freight yard should be located on the same side with the station building, as shown in Fig. 6.3. In this case, there is no need to cross the railway, which can make freights delivery more convenient and is favorable for station management. When freight distribution direction is at the opposite side of the station buildings or at the same side but the upward moving freight amount is very large and the layout at the same side is restrained by the terrace or urban development planning, the freight yard may be placed at the middle of opposite side or a third quadrant of the station building, with necessary safe and convenient passage.

According to the freight track type, the freight yard can be classified into three modes, thus, through-type freight yard, stub-end type freight yard and hybrid (mixed-type freight yard), as shown in Fig. 6.7.

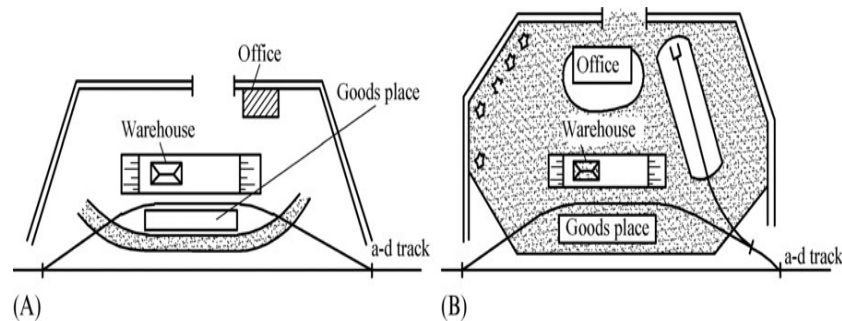


Fig. 6.7 Layout of intermediate station freight yard. (A) through type freight yard of intermediate station. (B) Hybrid freight yard of intermediate station (mixed-type freight yard).

(a) Through type freight yard of intermediate station

(b) Hybrid freight yard of intermediate station (mixed-type freight yard)

Freight Platform

There are two types of freight platform: ordinary platform and high platform.

An ordinary platform shall be 1.1 m above the rail top; the height shall be at the same level with the train floorboard which is favorable for loading and unloading. A platform more than 1.1 m higher than the rail top is called a high platform, which is designed according to the freight loading and unloading requirements. When there is a warehouse, the width of platform shall be subject to the sum of warehouse width and the two passageways. The width of a warehouse may be 9, 12, 15, and 18 m. The two passageways shall be wide enough for convenient loading and unloading. It is recommended that the width by the railway side be 3.5–4.0 m and the width by the yard side be 2.5–3.5 m as shown in Fig. 6.8.

Width of open stock without warehouse should be 12–15 m while manual operation, the width should be wider while mechanical operation.

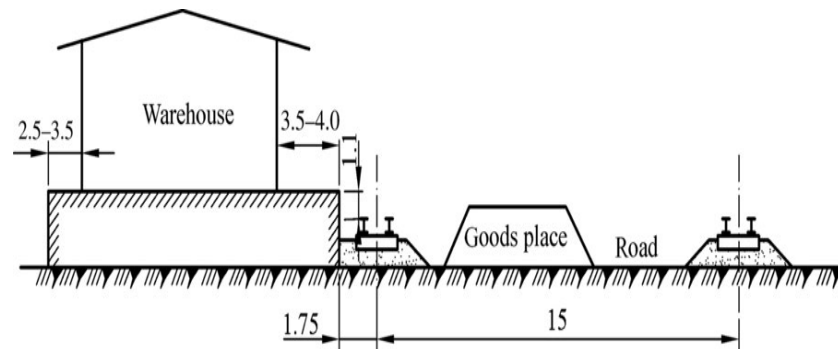


Fig. 6.8 Cross section of intermediate station freight yard.

Freight Warehouse

An LTL warehouse of intermediate station for transshipment of less-than-wagon load goods is generally located on main platform near the station building. When the volume of less-than-carload freight is not very great, the warehouse may be incorporated into the luggage room.

6.2.2.3 Station Sidings

Besides the main line, track facilities at intermediate station include sidings (arrival-departure track, lead track, freight track, storage siding), spur track (branch line, private sidings and industrial line) and tracks for special purposes line (catch siding and refuge siding).

Arrival-Departure Track

Arrival-departure tracks are sidings used to receive and departure passenger trains or freight trains.

(1) Quantity of arrival-departure track

The quantity of arrival and departure tracks shall be decided according to the carrying capacity, working amount of trains, and transportation characteristics. For mixed passenger and freight railway line, the quantity of arrival-departure track should be two for intermediate station on single track line, so that the station can deal with three-train rendezvous (three trains crossing) or meet the requirements of some special trains stopping. When local freight working amount is very large, e.g., intermediate station where attaching and detaching operation amount is large, 3 or more tracks may be laid. Generally two or three arrival-departure tracks are set for double track lines which are laid out by the two sides of upward and downward line, so trains on both lines can wait and overtake simultaneously. Besides, more tracks may be adopted at intermediate stations where technical operation takes relatively long time, e.g., water supply stations, banking locomotive starting and terminal stations, train technical inspection station before long and steep down-grade, stations before junction terminals and junction station of dedicated line. The quantity of arrival-departure track is also relevant to the organizing mode of trains. In sections with train tracking running, the quantity of arrival-departure tracks should be increased appropriately.

(2) Train route of arrival-departure track

Arrival-departure track can be designed as single route or either route. An arrival-departure track with single route can be only used with one direction (up direction or down direction) and that with either route may be used with both up and down direction moving. Either route is very flexible; however, signal interlocking devices shall be added.

For mixed passenger and freight lines, arrival-departure track of intermediate station on single track should generally be designed as either route so that good flexibility for handling train operation can be ensured and the service efficiency of station track may be higher.

In order to ensure passing-through and crossing of out-of-gauge freight trains, 3-5 intermediate stations (including water supply station) in each district shall be selected, in which, in addition to the main line, there should be another arrival-departure track in single-track railway (two in double-track railway with one on each direction) to ensure out-of-gauge freight trains passing through. Distance between track for out-of-gauge freight trains and adjacent tracks shall be a little larger. Intermediate stations which have more arrival-departure tracks may be selected for out-of-gauge freight trains passing through. This is favorable for passing and overtaking of out-of-gauge freight trains and other trains. In these intermediate stations, an arrival-departure track near the intermediate platform is generally selected as route for out-of-gauge freight train so that the large distance between the two tracks is taken advantage of (Fig. 6.9).

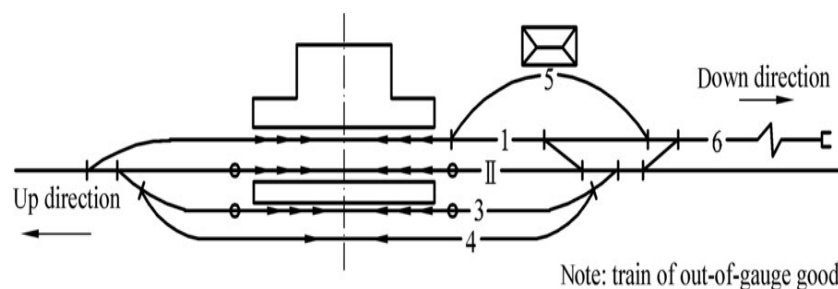


Fig. 6.9 Layout of arrival-departure track for out-of-gauge freight train.

Lead Track

The lead track shall be designed according to number of main lines, train traffic density, as well as freight yard position.

Dedicated lead track shall be set for shunting service at intermediate stations with much detaching and attaching service and higher traffic is density. Lead track shall be set at these stations where carrying capacity in the section computed on the basis of parallel train working diagram on single-track railway is more than 24, on double-track with semi-automatic block is more than 54, or with automatic block is more than 66 and shunting services amount is large, or those intermediate stations with fewer pairs but large shunting operation work amount as shown in Figs. 6.3 and 6.4. When carrying capacity is not very large or the service work amount is rather small, a main line or special line may be used for shunting service. In this case, its plane and profile and the line of sight shall be adjusted to meet the requirement of shunting services, and the arrival signal should be moved outward to a distance no more than 400 m. The effective length of the lead track shall meet the requirement of shunting working, generally no less than half of the freight train. When conditions are unfavorable or service amount at the station is not very large, the effective length may be shorter but no less than 200 m. The lead track shall be set on the straight line; when conditions are restrained, it can be set on a curve with a radius no less than 1000 m; when conditions are extremely poor, the radius shall be no less than 600 m. The lead track shall be set on a flat slope or on a downward slope with gradient lower than 2.5‰ toward the shunting track.

Freights Track (Goods Track)

For managing loading and unloading work of goods, freight tracks should be laid in the intermediate station of the passenger and freight railway line. Freight lines in the freight yards can be designed as through, stub-end, and mixed track. As both ends of the through track are connected to the arrival-departure track, shunting working of trains on both of up and down direction is flexible and easy to manage, as shown in Fig.6.7A. For a stub-end track, only one end is connected with reception-departure line, and another end extends into the freight yard, so train switching is not flexible as that of through type. But line arrangement can be diverse, the interval between tracks can be large and there are many effective freights allocations. It is suitable for the station where there are large amount of freight working and freight tracks. At intermediate station where the volume of freight is large, the mixed-type track is often used. According to property of freights, freight tracks are arranged as passing-through type and stub-end type. Common freights are operated on the through track and mass freights and special freights are operated on the stub-end track, as shown in Fig. 6.7B.

The effective length of freight track should be determined by freight volume, time interval of taking-out and placing-in cars. However, the shortest length should not be lower than length of five cars, i.e., 70 m.

The space between goods line and receiving-departure track should allow for demands of goods stacking and loading and unloading work on both sides of the goods line. When there is loading and unloading work between tracks, the space should not be less than 15 m, and when there isn't any loading and unloading work, the space should not be less than 6.5 m.

Catch Siding (Safety Siding)

The catch siding is one of the separating equipment of train route. The catch siding is set to prevent trains on sidings or spur tracks from conflicting with trains on main lines without passing through the open approach road. Effective length of the catch siding should not be less than 50 m, the profile should be designed as near level grade or an up grade facing to bumper post. Catch siding need to be laid out in following places:

(1) Joints where spur tracks (include dedicated line and branch line) are connected to the main line in section, as shown in Fig. 6.10A.

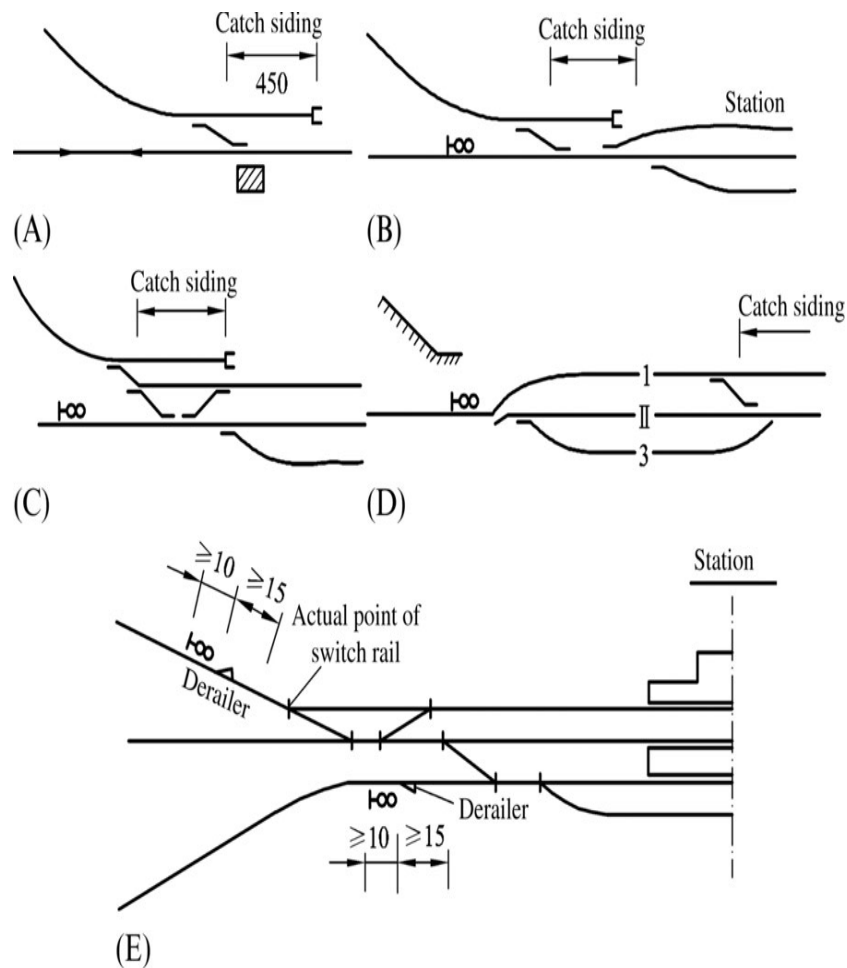


Fig. 6.10 Layout of catch siding and derailer. (A) Catch siding connected to special sidings in the section. (B) Layout of the catch siding with special sidings connected to the main line in the station. (C) Layout of the catch siding with special sidings connected to the arrival-departure track in the station. (D) Catch siding layout of the station before abrupt downslope. (E) Derailer setting.

(2) Joints where private sidings are connected to the main line or arrival-departure track at stations, as shown in Figs. 6.10B and C.

(3) When the external braking distance outside the home signal is on down grade toward to station direction with gradient exceeding 6‰, in order to simultaneous receive trains in the opposite direction and simultaneous do arrival and departure work in the same direction, the catch siding should be arranged on the end of the arrival track. As shown in Fig. 6.10D. This can prevent trains arriving on the downgrade from crashing with other trains.

The end of the catch siding should avoid high fill, the end of the bridge or the building, preventing more loss when derail of rolling stocks occurs.

When the special siding is connected with the main line or the arrival-departure track, if it is limited by topographic conditions or arrival direction of special siding is level or upgrade, the derailer can be set instead of catch siding. The arrangement of the derailer is as shown in Fig. 6.10E.

(a) Catch siding connected to special sidings in the section

(b) Layout of the catch siding with special sidings connected to the main line in the station

(c) Layout of the catch siding with special sidings connected to the arrival-departure track in the station

(d) Catch siding layout of the station before abrupt downslope

(e) Derailer setting

Refuge Siding

When descending a long steep grade, to prevent trains from overturning and conflicting with other trains in the front station by losing control because of brake device failure, it is necessary to set refuge sidings.

In section out of sites of two adjacent stations, only when the average profile gradient is 15‰ or over is the refuge siding necessary. Whether it is necessary to set a refuge siding should be determined after checking the out of control speed of trains by means of traction calculation according to the condition of plane and profile. At the same time, the position and the length of refuge line are also determined by traction calculation.

When checking the out of control speed of trains, it is considered that the first brake works and the second brake fails. If the brake machine fails in descending a long steep grade, the train will speed up rapidly under gravity. When the locomotive is braked, the train reaches

the turnover speed in the section or can't stop sliding after reaching the front station, it is necessary to set a refuge siding.

The turnover speed refers to one of three speeds, thus, 100 km/h, turnover speed of curve and turnover speed of turnout.

The turnover speed of curve is (km/h).

The turnover speed of turnout is (km/h).

In the above turnover speed equations, R , R' are the radius of curve and the radius of turnout lead curve (m), respectively.

The refuge siding has several types, such as stub-ending track, loop track, and sand path. Because the stub-ending track has many advantages such as simple structure, convenient construction and convenient maintenance, almost all refuge sidings in Chinese railway employ stub-ending tracks. To ensure the out-of-control train can be stopped at the end of the refuge siding, the sand path is laid in the 30–50 m region to the end of stub ending refuge siding by sanding evenly on the rail surface, to increase the running resistance.

The position for setting stub-end refuge siding shall be determined by means of checking speed of out of control trains. If the speed of a train reach to the turnover speed in section or before entering the station, the refuge siding should be laid in the section or in before the home turnout, as shown in Fig. 6.11. If the train has not reached the turnover speed in the section, the refuge siding can be laid at the departure end of station site, as shown in Fig. 6.12. The advantages of setting the refuge siding at the departure end are to avoid trains in descending a long grade to stop at the signal before the refuge siding and at the same time to use the gentler slope of the station site to make the out of control train speed down so that reduce the length of the refuge siding. Whenever the trains come from descending a long steep grade, the block system can be conducted only when the track connected to the refuge siding is free. Therefore, this layout scheme of refuge siding may influence the use of station sidings, and operation safety in stations become worse. Thus, the busy stations should lay out the refuge siding at the arrival end.

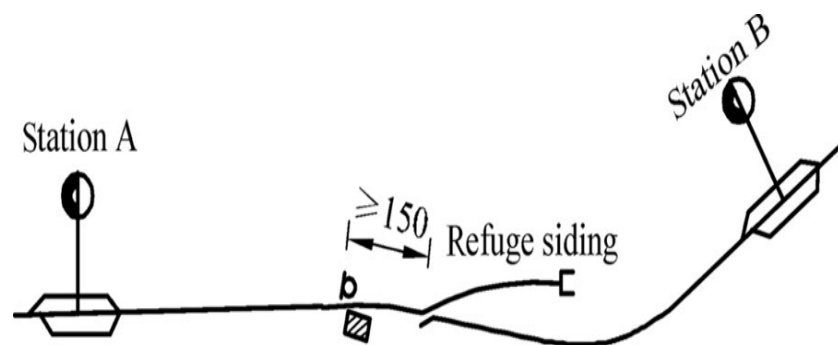


Fig. 6.11 Layout of refuge siding in the section or at the arrival end.

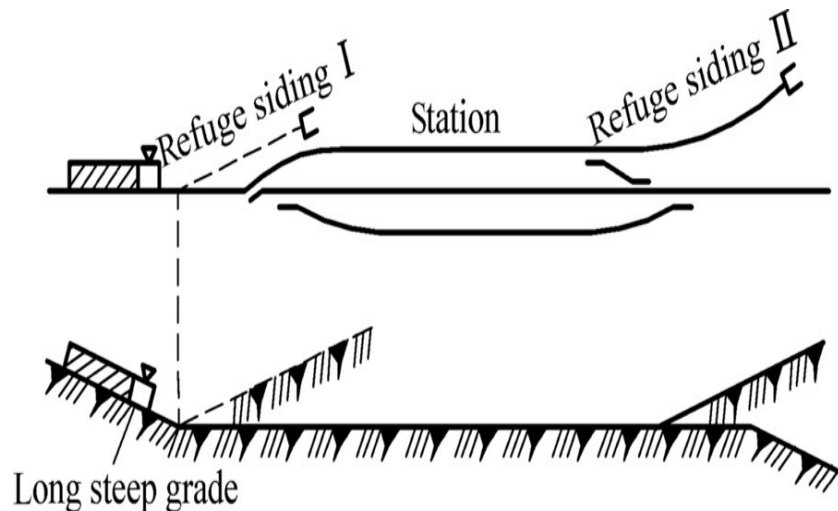


Fig. 6.12 Layout of refuge siding at the departure end.

When the refuge siding is set in the section or at the arrival end of a station, a signal (see Fig. 6.11) should be set at the place no less than 150 m before the stock rail of turnout. In this design, if a normal train overruns the signal, it will not run into the refuge siding to avoid the difficulty of getting back on the steep slope.

The profile of refuge siding should be designed according to the speed of out of control trains entering the refuge siding, with graphical method or analytical method, grade section by grade section until the train stops. The profile of refuge siding is generally consisted of short grade sections with a gradually increased gradient. The algebraic difference between adjacent gradients is not more than 15‰, and the maximum gradient of the last grade section is usually not more than 100‰.

Industrial Line Linking to the Station

When an industrial line is linked in the station, it should be easy to take out and place in cars by the industrial line, and make the best to reduce the interference for train running and shunting services. When the industrial line is linked to the intermediate station, they are usually linked in the throat area at two ends of the station. When there are several industrial lines linked in the station, to make the shunting service easy and reduce the train running interference, it is best to concentrate them into one area, generally in the same quadrant with goods yard. In the intermediate station where passenger trains often stop, the special line should not be linked to the arrival-departure line, which is at the same side with the station building, to prevent trains from interfering with each other. In addition, town planning, location of industrial enterprise, freights flow direction and topographic conditions also affect the linking position of the special line. Therefore, the special line linking scheme in the intermediate station should be determined after technical and economic comparison according to specific circumstances.

There are several arrangement plans of linking scheme shown in Fig. 6.13. When the industrial enterprise is located at the same side of the station building and topographic conditions are favorable, linking scheme I or II can be adopted, and scheme I is better. When the industrial enterprise is located at the other side of the station building, linking scheme III or IV can be adopted.

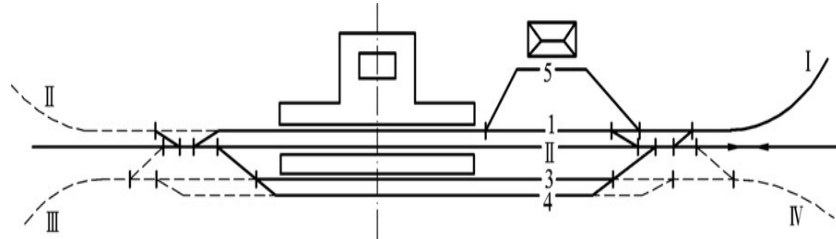


Fig. 6.13 Junction scheme of intermediate station and industrial line.

6.2.3 Calculation of Intermediate Station Plan

After determining the facilities and layout diagram of intermediate station, engineer need to calculate the station plan to further locate the positions, and determine the specific dimension of facilities and their relationship.

6.2.3.1 Numbering Tracks and Turnouts

The tracks and turnouts shall be numbered to meet following rules.

(1) Tracks numbering: for single-track railway, the tracks are numbered from station building to the other side. For double-track railway, the tracks are numbered from main line to two sides, up direction tracks are numbered in even number, and down direction tracks in odd number; and roman number are used for the main line, Arabic numbers are used for the station sidings, as shown in Fig. 6.14.

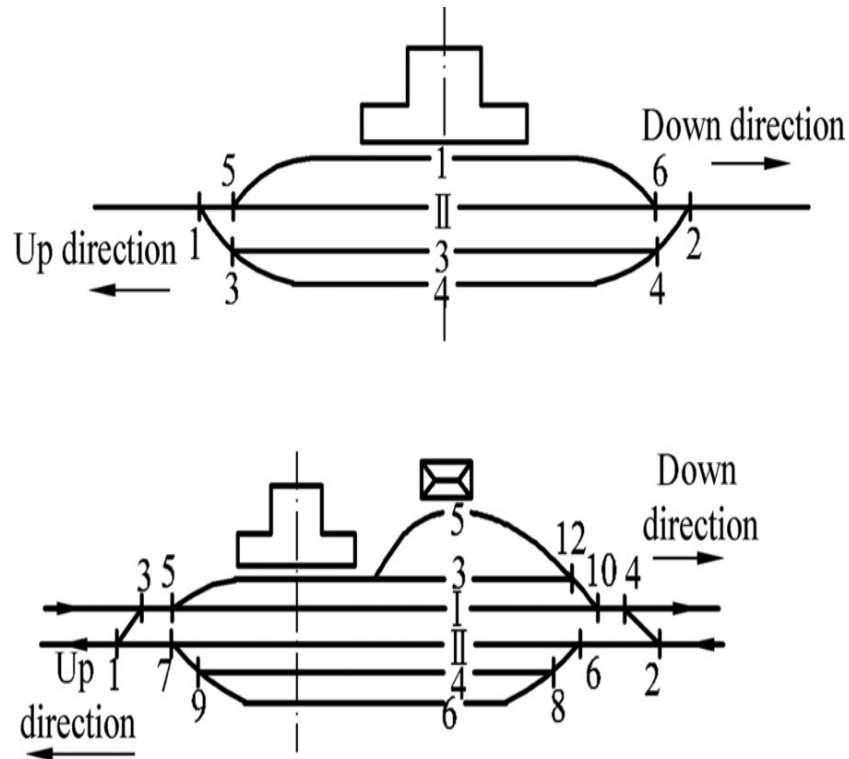


Fig. 6.14 Tracks and turnouts numbering.

(2) Turnouts numbering: taking the station building as the center, turnouts are numbered in sequence as even number for the arrival end of up direction trains, and odd number for the arrival end of down direction trains. Train routes are to be numbered at first, and then other routes. Crossover turnout and its connected turnout should be numbered in consecutive numbers, as shown in Fig. 6.14.

6.2.3.2 Distances Between Tracks Inside Station

1. Distance between centers of lines in a straight line

In station, the distance from the center of track to the building or facilities and distance between center lines of two nearby tracks should ensure the driving safety and station staffs' safety and convenience in carrying out works. The influenced factors include, rolling stock clearance limit, fundamental construction clearance, out-of-gauge freights clearance, aerodynamics, and wheel-rail contact geometrical relation, etc. (see Figs. 3.18-3.20), and the type of operation between nearby tracks.

For example, the distance between main lines should be

$$2 \times (1700 + 100) + 1400 = 5000(\text{mm}) = 5.0(\text{m})$$

where 1700 mm is the half width of rolling stock clearance limit; 100 mm is the width of train signal; and 1400 mm is the safety distance for workers operation.

On a straight line, the distance from buildings (facilities) shall meet the requirements in Table 6.1, and distance between tracks shall meet the requirements in Table 6.2.

Table 6.1

Distance From the Main Buildings (Facilities) to the Center Line of the Track (mm)

No.	Name of the Buildings and Equ
1	Edges of overpass bridge column
Located at the outside of the outermost line of the station and yard	≥1100
Located at the outer side of the ladder track or lead track in the station and yard	≥1100
2	Edges of signal and water crane
Located at the siding side of non-out-of-gauge freight train line	≥1100
3	Edge of freights Platform
High platform	≥4800
4	Edge of passenger Platform
Normal platform	500
Located at the main line side or siding side of out-of-gauge freight train line	300
5	Edges of garage door, washing fr

Note: If it is difficult to reconstruct the station, the distance to the edge of high signal can be reserved as 2100 mm, and the distance to the center of receiving-departure track can be reserved as 1950 mm.

Table 6.2

Distance Between Station Tracks (mm)

No.	Name of Tracks
1	Between main lines or main line and its ne
2	Between arrival-departure tracks or shunti
3	Other secondary station tracks (apart from
4	Lines with height signal
Only one of two nearby tracks can pass freight train out-of-gauge goods	5000
5	Lines with water crane
Only one of two nearby tracks can pass freight train out-of-gauge goods	5200
Two nearby tracks cannot pass freight train out-of-gauge goods	5000
6	Passenger train storage tracks
7	Passenger cars servicing siding
With poles for lighting or communication	7000
8	Between freights interchange loading trac
9	Lead track and nearby sidings
10	Tracks in shunting yard
11	Ladder tracks and its neighbors

Notes: (1) Between the main line passed by passenger trains and freight trains and the near line with train checking operation, the distance should be widened to 5500 mm. When the station is reconstruct and extended or under difficult conditions, 5000 mm can be adopted.

(2) In an intermediate station where there is no shunting locomotive, distance between the lead track and the near main line can adopt 5000 mm. In intermediate station where there is shunting locomotive, if it is difficult to reconstruct or extend, distance between the lead track and the near lines can adopt 5000 mm. But where the high signal is installed between tracks, the distance should not be less than 5300 mm.

2. Distance widening in curve sections

In curve sections, the construction clearance and distance between centers of lines may be reduced as the change of geometric relation between car and track. In order to ensure the safety of operation, the distance between centers of lines may need to be widened.

(1) Reasons for widening

(i) Geometry deviation of cars from center of track

When the train is negotiating the curved track with radius R , the middle part will protrude toward the inside of curve with W_1 , and the two end parts protrude toward outside with W_2 , as in Fig. 6.15A.

If the length of a car body is L , distance between bogie pivot centers is Z , according to the geometric relation of curve, the protruded volume can be calculated as follows.

As

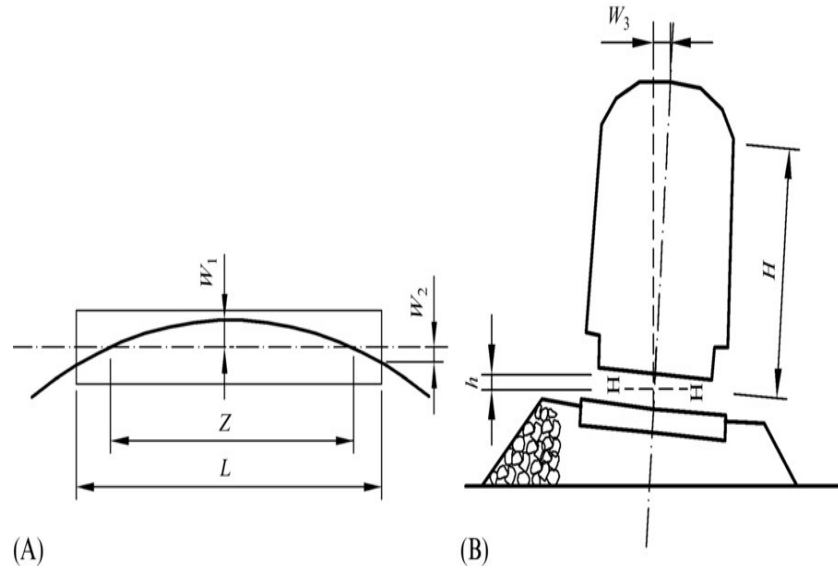


Fig. 6.15 Geometric relation between car and track on curve section. W 1 is the middle part protruded toward the inside of curve; W 2 is the end part protruded toward outside; W 3 is the deviation from the center line toward the curve center; L is the length of a car body; Z is the distance between bogie pivot centers; H is the height of calculated point.

$$(R - W_1)^2 + (Z/2)^2 = R^2$$

we have

$$R^2 - 2RW_1 + W_1^2 = R^2$$

From the above equation, and omit the infinitesimal item with two times, we get:

$$W_1 \approx \frac{Z^2}{8R}$$

where R is the radius of curve, m; L is the length of a car body; and Z is the distance between bogie pivot centers.

Similarly, W2 can be obtained using the following equation:

As

$$(L/2)^2 + [R - (W_1 + W_2)]^2 = R^2$$

Then

$$L^2/4 + \left[R^2 - 2R(W_1 + W_2) + (W_1 + W_2)^2 \right] = R^2$$

From the above equation, and omitting the infinitesimal item two times, we get

$$W_2 \approx \frac{1}{8R}(L^2 - Z^2)$$

In China, the maximum length of car body get $L=26$ m, distance between bogie pivot centers is Z , get $Z=18$ m, then

(6.1)

(6.2)

(ii) Deviation of car body caused by superelevation

When a car is negotiating the curved track with a superelevation of h , the body of car may have a deviation from the center line toward the curve center, as shown in Fig. 6.15B. at the point with height of H above rail surface, the volume of inclination W_3 as follows (distance between centers of rail is 1500 mm):as then

(6.3)

where h is the superelevation, mm; H is the height of calculated point, $H=3850$ mm.

(2) Value of widening calculation

① If the outer track has no superelevation, or superelevation of outer curve (hW) is smaller than or equal to that of inside curve hN , the widening value of distance between centers of curve is as follows:

$$W = W_1 + W_2 = \frac{40\,500}{R} + \frac{44\,000}{R} = \frac{84\,500}{R}(\text{mm})$$

(6.4a)

② When the outer track has no superelevation or its superelevation is less than or equal to the inner side.

③ if superelevation of outer curve (h_W) is larger than that of inside curve h_N, the widening value of distance between centers of curve is as follows:

$$\begin{aligned}
 W &= W_1 + W_2 + W_3 = \frac{40500}{R} + \frac{44000}{R} + \frac{H}{1500}(h_w - h_N) \\
 &= \frac{84500}{R} + \frac{3850}{1500}(h_w - h_N) \approx \frac{84500}{R} + \frac{2}{3}h_w
 \end{aligned}$$

(6.4b)

④ When the outer side track has superelevation h while the inner one has no superelevation, the widening value of distance between centers of curve is as follows:

$$W = W_1 + W_2 + W_3 = \frac{84500}{R} + \frac{H}{1500}h \approx \frac{84500}{R} + \frac{4}{3}h$$

(6.4c)

According to the above method, we can get the widening value of track distance and widening value of fundamental construction clearance at curve station, as shown in Table 6.3.

Table 6.3

Widening Value of Distance Between Tracks and Widening Value of Fundamental Construction Clearance in Curve Station



Note: In the table, 0.6h stands for the relative reduced value of platform height caused by the superelevation of curve outer orbit.

(3) Widening method

Widening method of track distance in curve station: the center line of each track in the curve station is designed as a concentric circle curve. As the main line has superelevation of outer rail and the transition curve must be set. While the station track has no superelevation of the outer rail, the transition curve can be either set or not. Therefore, to meet the widening requirements of the above mentioned curve, the station curve can adopt the following different setting methods.

When the superelevation is not set on station tracks and when the siding is at the outer side of main line, through adjusting and extending the main line transition curve length, to make the inner shift volume p of transition curve of the main line meet the requirements of widened track distance W . At this moment, the track distance of straight line part is not widened. When the station track is at the inner side of the main line, inner shift volume p of the outer main line transition curve will reduce the track distance in curve. To make the track distance in curve be widened for W , track distance in the straight line should be widened for $\Delta D = p + W$, to make the track distance of curve part just be widened for value W .

When transition curve is set on the sidings, either between the sidings and the main line or between two sidings, the length of station track's transition curve can be adjusted to make the inner shift value meet widening requirements of track distance.

6.2.3.3 Layout in Throat Zone of the Station

The layout in throat area of the station shall meet the requirements of defined arrival and departure routes for trains and the use of arrival-departure tracks.

1. Selection of turnout type

The number of turnout linking tracks shall be selected according to transportation mode and design speed. The selection of turnout number shall meet the following requirements:

- (1) The straight passing speed of turnout in main line shall not be lower than the design speed in the section.
- (2) The number of turnout used for train running through laterally with speed over 80 km/h should not be less than No. 30.
- (3) The number of turnout used for trains running through laterally with speed over 50 km/h should not be less than No. 18.

(4) The number of simple turnout used for trains running through laterally with speed of 50 km/h or lower should not be less than No. 12.

(5) The number of simple turnout used for train arrival and departure laterally should not be less than No. 12. In particular, symmetrical double curve turnout of number 9 can be used for nonmain tracks.

(6) In the section with straight passing speed of 100 km/h or lower, the number of simple turnout in main line shall not be less than No. 12, in other lines, No. 9 can be used.

(7) Slip turnout should not be used in the main line. Under difficult condition, if necessary, the number should not be less than No. 12 and shall meet the requirements of design speed in the section.

(8) The number of simple turnout or slip turnout in other lines shall not be less No. 9.

(9) Turnout in super long continuous welded rail tracks shall adopt gapless turnout.

[Table 6.4 shows the parameters of commonly used turnouts.](#)

Table 6.4

Major Parameters of Commonly Used Turnout

No.	Frog Angle α (°)	Central Radius of Lead Curve R (mm)	Distance a Between Beginning a
9	6°20'25"	180,000	13,839
12	4°45'49"	330,000	16,853
18	3°10'12.5"	800,000	22,667
PDR 60-18	3°10'47.4"	1,100,000	31,729
PDR 60-42	1°21'50.13"	5,000,000	60,573
PDR 60-62	0°55'26.56"	8,200,000	70,784

Note: PDR=passenger dedicated railway.

2. Connection between turnouts

The layout in throat area of the station shall meet the requirements of defined arrival and departure routes for trains and use for the arrival-departure tracks. The layout in throat area shall be tight and make the distance between centers of adjoining turnouts shortest under the prerequisite to ensure the running speed and service safety. And the quantity of turnouts in main track shall be reduced. In this way, this layout mode can shortened the length of throat or the connection track, reducing the running distance of rolling stocks, so as to reduce investment cost and operating costs. In order to ensure the smooth and safety of train running and reduce the wear and tear of turnout, it is necessary to insert a short rail between adjoining turnouts. For class I and clas II railways, the length of the rail inserted between adjoining turnouts shall meet the requirements in Tables 6.5 and 6.6.

Table 6.5

The Minimum Length of Rail Inserted Between Two Adjoining Turnouts (Two Face-Passing Simple Turnouts) (m)

Turnout Arrangement	Track	Where There are Trains Passing Two Sidings at the Same Time	No
Normal			Pa
	Main line	12.50	6
Arrival-departure tracks	6.25	6.25	0
Other station tracks	—	—	0

Note: When normal trains pass through two side tracks, the distance between two No. 18 single-turnouts should not be less than 25 m.

Table 6.6

The Minimum Length of Rail Inserted Between Two Adjoining Turnouts (Two Simple Turnouts Back-Passing Point) (m)

Turnouts Arrangement	Track	Turnout With Wooden Sleeper	Turnout W
	Main line	The straight passing speed ≥ 120 km/h	12.50
Straight passing speed < 120 km/h	6.25		
Arrival-departure track	4.50		
Other station tracks	0		
	Other station tracks	4.50	
Other station tracks	0		

The turnout should be set in a straight line. To adapt to the change of gauge, a straight line must be inserted between the turnout and the connecting curve, as shown in Fig. 6.16. The length of the straight line should be determined according to the gauge widening and its declining rate, as shown in Table 6.7. For a connecting curve with a transition curve, there is no need to insert a straight line between turnout and adjoining curve.



Minimum Length of the Straight Line Between Turnout and Connecting Curve (m)

Number	Radius of Connecting Curve (m)	Length of Straight Line (m)	
Front Part of Turnout	Rear Part of Turnout		
1	$R \geq 350$	0	2
2	$350 > R \geq 300$	2	4
3	$R < 300$	5	7

The connecting curve radius behind the turnout shall not be less than the lead curve radius of the adjoining turnout, generally, takes 500, 400, 300, or 200 m, and the larger one is better to improve train running conditions.

The turnout should avoid being set in the area of vertical curve. When conditions are difficult and it must be set in the zone of vertical curve, the radius of vertical curve on the main line and the receiving-departure track should not be less than 10,000 m, and those on other tracks should not be less than 5000 m.

6.2.3.5 Length of Station Tracks

The length of station tracks is expressed by three means: total length, rail-laying length, and effective length.

The total length is the length from the stock rail joint of turnout in one end to stock rail joint of turnout in the other end of the computed station track. If it is a stub-end route, the length is from the stock rail joint of turnout to the bumper post, as shown in Fig. 6.17.

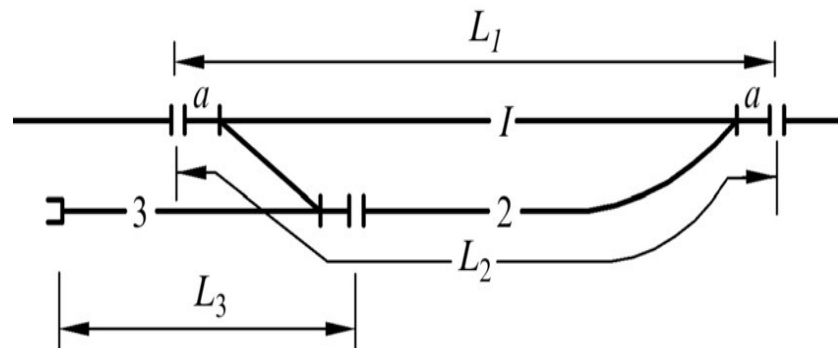


Fig. 6.17 Schematic diagram of total length of track.

The total length minus the length of all turnouts in the computed track equals to the length of rail-laying.

The effective length of a receiving-departure track or other station tracks is the length where trains or cars can stop without interfering neighbor train running route. The effective lengths are controlled by: departure signal, fouling post, tip of switch rail (when trackless circuit) or track insulation gap of stock rail joint (when track circuit), and bumper post.

The effective lengths of the track are calculated according to the up-direction route and the down-direction route, respectively. As shown in Fig. 6.18, track 1's down direction effective length $l_1(s)$ is from down departure signal to fouling post of the other end, while the up effective length $l_1(x)$ is from the up direction departure signal to turnout stock rail joint of

the other end (track circuit). The effective lengths of track 2 and track 3 are from departure signal of relevant direction to fouling post of the other end. In the figure, the departure signal of every track is set on the left side of the departure direction. When both sides of the track have a fouling post, it is controlled by the nearest one.

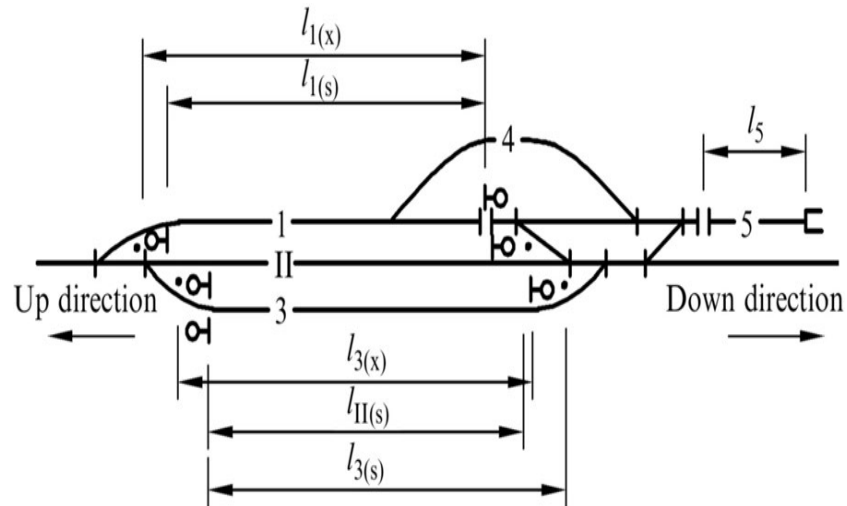


Fig. 6.18 Schematic diagram of effective length of tracks.

Preliminary design has determined the effective length standard of arrival-departure track in the short term and long term. For intermediate station design, the track and the throat of turnout should be arranged according to the chosen effective length of short-term, to make the actual length of every arrival-departure track be not shorter than the chosen effective length in long term. The length of station site is set according to the effective length of arrival-departure in long term, and this ensures the probability of track extending in the future from the plane and profile perspective.

6.2.3.6 Layout of Fouling Post and Signal

Fouling posts and signals are not only important traffic indication facilities to the station, but also markers to delimit the effective length of tracks. Therefore, when designing the station, it is necessary to determine the distance between the fouling post/signal and the center of turnout, and mark out their location in the figure. Layout of fouling post and signal are also related to the track circuit.

The Basic Positions of Fouling Post and Signal

1. Position of fouling post

A fouling post should be located in the same place as the jointing area of two tracks, ensuring when the rolling stock stops inside the fouling post, other trains can pass safely via the adjacent track. As shown in Fig. 6.19A, when set up in the straight section, the fouling post should be located in the place that is 2 m away from the center of the adjacent lines, which takes the half clearance limit for rolling stock 1.7 m and the spare gap 0.3 m into consideration. When the fouling post is set up in the curve part, the clearance limit widening of the curve track should also be considered, so the distance between the fouling post and the center of the curve line should be $2+W_1$ (W_1 is the widening value of the inner side of the curve), just as shown in Fig. 6.19B.

The distance between the fouling post and the center of turnout is affected by frog number, distance between centers of tracks, radius of the connect curve and so on; usually the calculation result will be made into a table for future reference, as shown in Table 6.8.

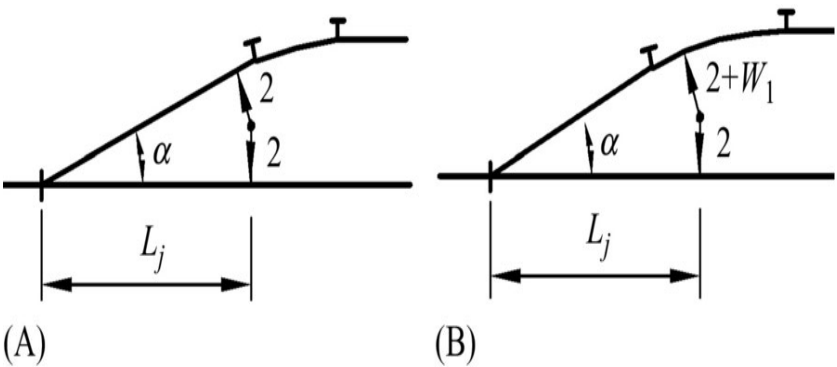


Fig. 6.19 Position of fouling post. α is the frog angle of turnout; W_1 is the clearance limit widening of the curve track; L_j is the distance between fouling post and the center of turnout.

Table 6.8

Distance Between Fouling Post and the Center of Turnout L_j (m)



2. The position of home signals

Home signals should be set up in all stations. Home signals should be set up at least 50 m away from the actual point of switch (turnout) rail for reverse-passing the point of turnout or the fouling post for back-passing the point of turnout, as shown in Fig. 6.20. When the main line is used in shunting, the signal should be moved outward, and the distance moved should not be more than 400 m. The movement should still be restricted within 600 m in spite of poor signal display.

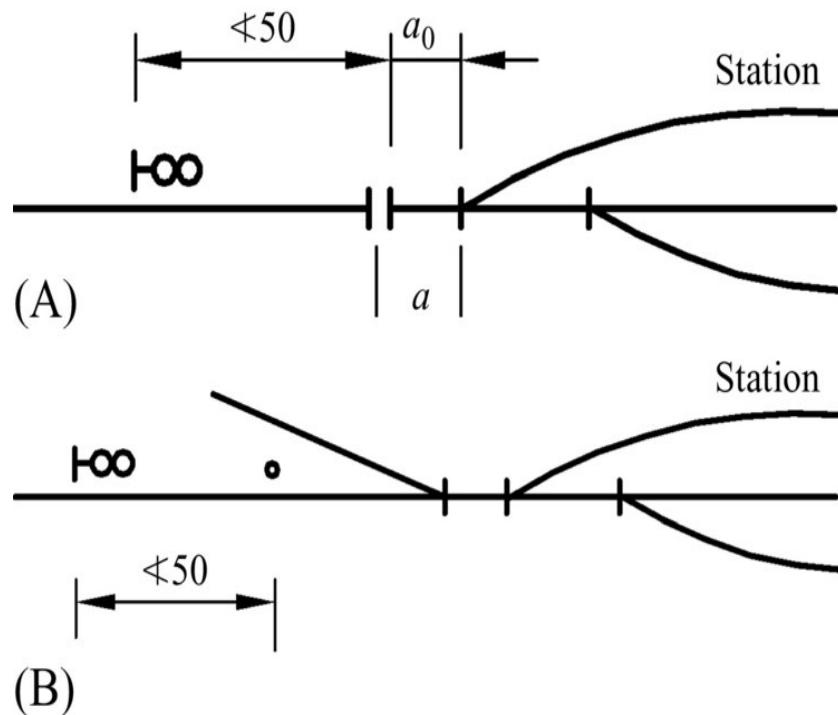


Fig. 6.20 Position of home signal.

3. Position of starting signal

Starting signals should be located appropriately on the left side of each running direction of departure tracks. Apart from the requirement of railway clearance, the position of the starting signal is also affected by the direction of turnout. Where there is a turnout back-passing the point ahead, the signal should be set at the actual point of switch rail of the turnout, as shown in Fig. 6.21A; while turnout face-passing the point ahead, the signal should be set inside the fouling post; the distance between the signal and the center of turnout should comply with the requirement of construction clearance and be determined according to the perpendicular distance between the signal and the center of adjacent track.

As shown in Fig. 6.21, when there is a free switch in front, the allowable vertical dimension between the high signal and the center of tracks in both sides is $P=0.5b+B$ in straight and $P=0.5b+B+W_1$ in curve track, in which W_1 is the curve widening value. b is the basic width of signal, for high signal it takes 380 or 410 mm; B is the construction clearance of signal, when of out-of-gauge freight train passing through the line, $B=2.44$ m, otherwise, $B=2.15$ m.

The distances between the signals and the center of turnout can be calculated out and made into a table such as Table 6.9 for future reference.

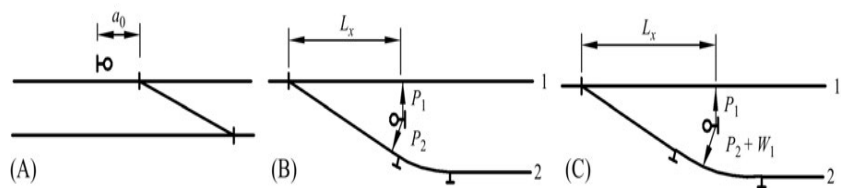


Fig. 6.21 Location of starting signal. (A) Back-passing switch. (B) Face-passing switch in the straight line. (C) Face-passing switch in curve track.

Table 6.9

Distance Between High Signal ($b=380$ mm) and the Center of Turnout L_x (m)



Positions of Fouling Post and Signal Under a Track Circuit

Sections with semi-automatic block, automatic block and stations with electric interlocking are all installed with track circuit. In these sections and stations, positions of the signals and the fouling posts should not only comply with the above requirements, but also cooperate with the rail insulation gap, and the specific requirements are as follows:

(1) It is best to set up the signal at the same coordinate with rail insulation gap, as shown in Fig. 6.22A and B. As the insulation gap is restricted by the length of standard rail, when the signal and the rail insulation gap cannot be at the same coordinate, it is allowable to set up the rail insulation gap nearby home signal within 1 m in front of or behind the home signal; the rail insulation gap adjacent to the starting signal can be in the area of 1 m inside the signal and 6.5 m outside the signal, as shown in Fig. 6.22C and D. When the rail insulation gap is in the inside of the signal, the signal can be moved inward to the same coordinate with the insulation gap.

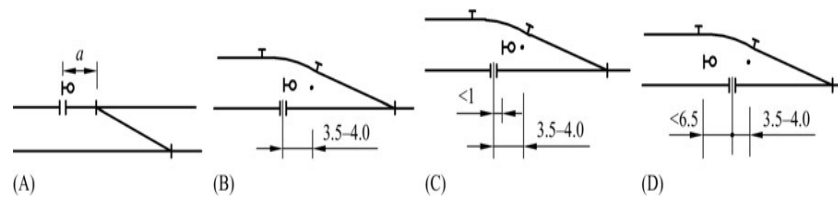


Fig. 6.22 Starting signal and fouling post with track circuit. a is the length of front part of turnout.

(2) The distance between the fouling post and the rail insulation gap should comply with the requirements of safe running and track circuit using state. A fouling post should be located 3.5–4.0 m away from the inner rail insulation gap, as shown in Fig. 6.21B–D, which ensures that when the train wheel stops inside the insulation gap, the front end of coupler will not run over the fouling post, the tail of the train will stop inside the fouling post, and the train wheel still occupies the turnout circuit to prevent the adjacent line from opening.

When designing the starting signal with track circuit and the fouling post, look out the distance between the fouling post/signal and the center of turnout separately in Tables 6.8 and 6.9, and then determine the location of insulation according to existing rail insulation gap. If the above requirements cannot be met with the existing rail gap, it is optional to adjust the location of insulation gap by moving the signal inward or laying short rails, and then move the fouling post inward to the place that is 3.5–4.0 m away from the insulation gap.

Example 6.1

As shown in Fig. 6.23, track 1 and track 2 are connected by No.12 turnout, and the radius of connect curve at the rear of the turnout is 400 m. Track 2 allows out-of-gauge freight train to pass, and the distance between centers of lines is 5 m.

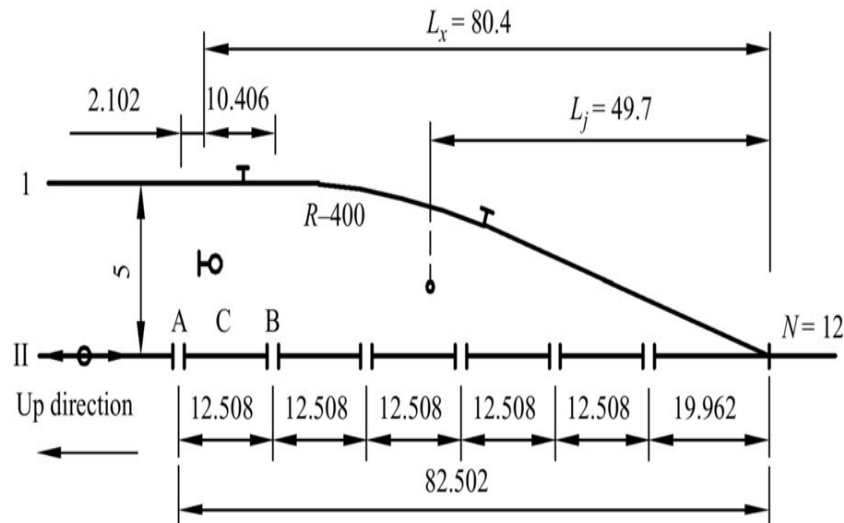


Fig. 6.23 Arrangement of signal and fouling post.

Solution

Basic position of fouling post and starting signal: From Tables 6.8 and 6.9, we get the basic position of the fouling post and the starting signal as $L_j=49.7$ m and $L_x=80.4$ m separately.

(2) Position of track section insulator: check the distance between rail gap to basic position of fouling post and starting signal one by one from the stock rail of turnout to the rational track section insulator. It can be seen from Fig. 6.23 that, with the existing rail gap, the distance between the signal and the inner rail gap A is about 2.1 m, and the distance between the signal and the outer rail gap B is about 10.4 m, which is not in compliance with the above requirements; the signal and the fouling post can be adjusted using the following two schemes.

Scheme A: The distance between the signal and the rail gap A is about 2.1 m, which is a little greater than the required 1 m; the signal can be moved inward to rail gap A; set track section insulator at A and move the fouling post inward to 4 m away from rail gap A. As tracks 1 and 2 are either-route tracks, to move fouling post inward makes the reduction of effective length in up direction is $(82.5-4)-49.7=28.8$ (m).

Scheme B: If the effective length is restricted, then a 6.25-m-long short rail can be used for section BC, which will keep the signal in the calculated position ($L_x=80.4$ m); the rail insulator is set at rail gap C that is 76.25 m away from the center of turnout, and 4.15 m away from the outside of the signal. This position complies with the requirements above.

6.2.3.7 Calculation of Coordinates of the Major Points and the Effective Length of Tracks I

[illegible]

According to the given distance between center of tracks, the number of frogs and the major elements of connected curves, etc., and the coordinates of freight yard and a practice results are shown in Fig. 6.25.

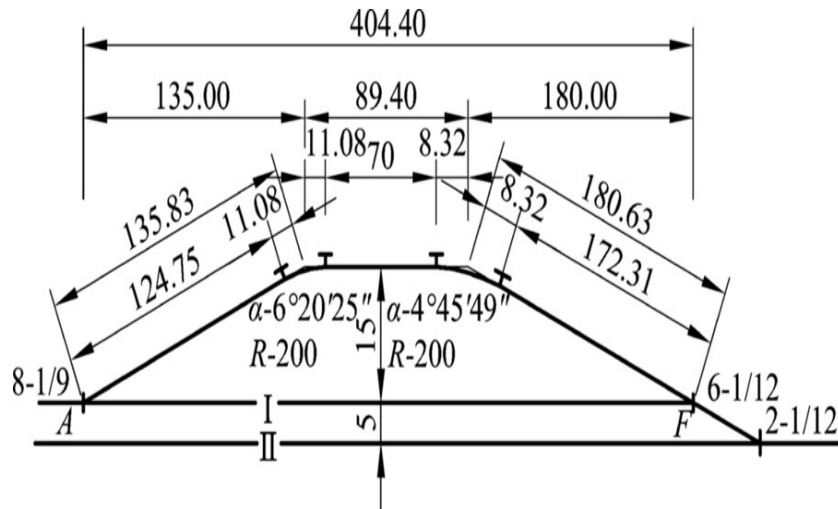


Fig. 6.25 Parameters of freight yard plane.

(2) Determination of signals and fouling posts

Down direction:

Track 1: starting signal is set between track 1 and track 4, and the distance of the two tracks is 15 m, the radius of connecting curve is 200 m. As curve is located outside of the designed area of starting signal and fouling post, the distance between centers of lines can be determined according to the construction clearance of straight line. In calculation, the distance from the center of turnout to starting signal $L_x=56.3$ m, to the fouling position $L_j=48.1$ m. As rail is used as part of track circuit, rail insulator can be set at the fourth gap, the distance to the center of turnout $LF=57.49$ m. Then move the starting signal inward to stand side by side with the track section insulator, and move fouling post inward to 53.49 m from the center of turnout, as shown in Fig. 6.26.

Track 3: the starting signal is set between track II and track 3, and the distance of the two tracks is 7.5 m. The two tracks are designed to be allowable to passing the out-of-gauge freights train, and the radius of connecting curve is 400 m. In calculation, we get $L_x=63.3$ m, $L_j=48.1$ m. According to the existed rail gaps, rail insulator can be set at the fourth gap, a distance of 57.49 m to the center of turnout, and a distance of 5.81 m outside of the starting signal, which is less than 6.5 m and meet the requirement for signal setting. The projected length on X-axis is 57.29 m. Then move the fouling post to the position of 53.49 m to the center of turnout, as shown in Fig. 6.27.

Track II: as track II has been limited by the fouling post of the fourth turnout, the fouling post at the second turnout must take the same coordinate with that of fourth turnout, that is 53.49 m from the center of turnout. In the case, the rail insulator should be set at the fourth rail gap, 57.49 m to the center of turnout, side by side with starting signal, as shown in Fig. 6.28.

Up direction: The calculation methods are the same as that of down direction. The design results are shown in Fig. 6.29.

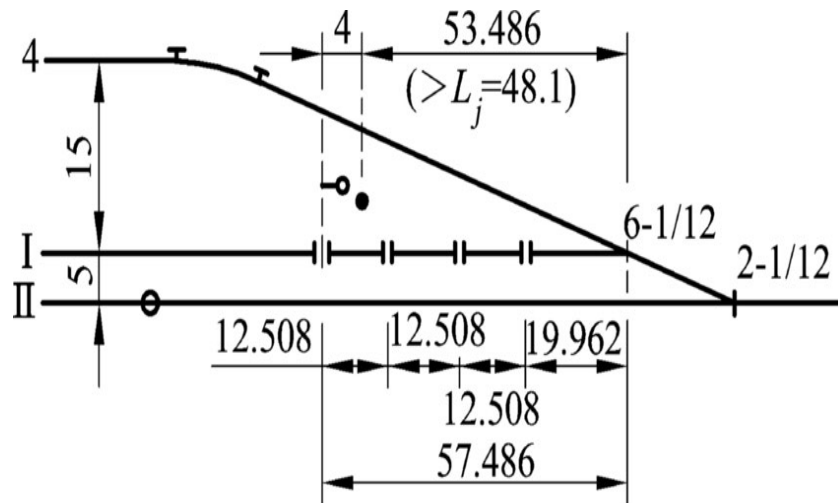


Fig. 6.26 Positions of signal and fouling posts.

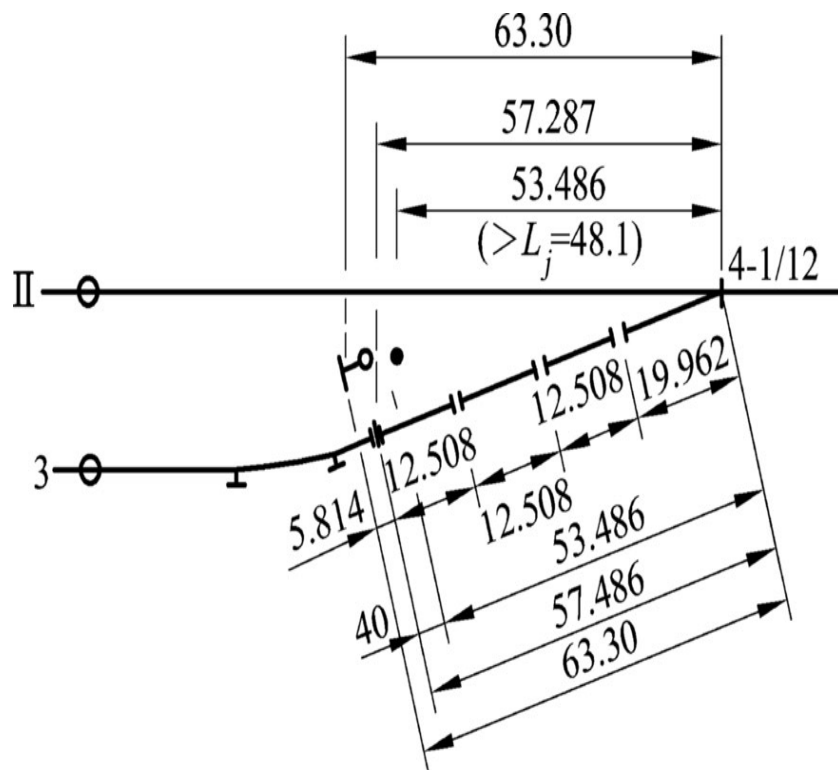


Fig. 6.27 Position of starting signal and fouling post of track 1.

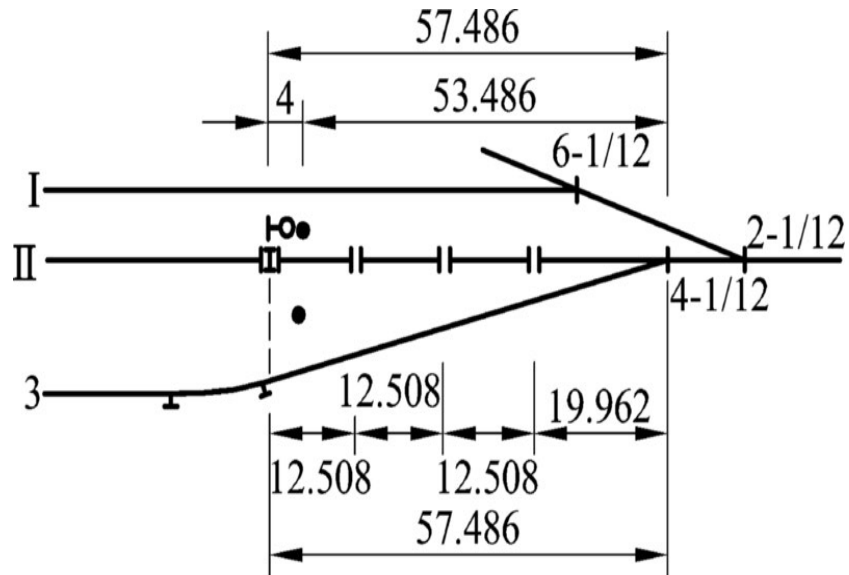


Fig. 6.28 Position of starting signal and fouling post of track II.

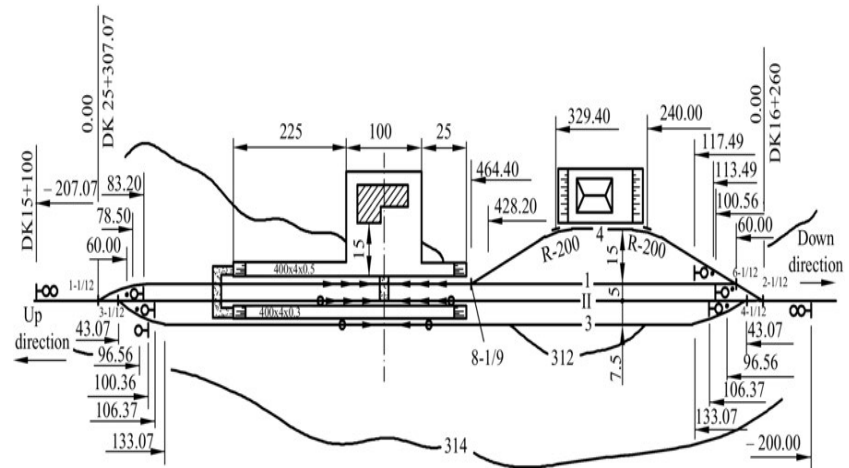


Fig. 6.29 Design plane of intermediate station.

(3) Coordinates

As stated above, demarcating by the center of station and taking the center of outmost turnout on main line as the starting point, calculate the coordinates from the end to the center of station.

For convenience, first, calculate the coordinates of the center of turnouts, then coordinate of starting signals, fouling posts, and the intersecting points of curves following turnouts. The calculation of coordinates for the arrival end of up direction shows in Table 6.10.

The design results should be noted on the station plane, as in the table above and Fig. 6.29.

Table 6.10

Coordinate for Arrival End of Up Direction (m)

Starting Point		Calculating Point	
Name	X	Name	
Center of 2#turnout	0	Center of 4# turnout	
Center of 2# turnout	0	Center of 6# turnout	
Center of 4# turnout	43.07	Fouling post of 4# turnout	
Center of 4# turnout	43.07	Starting signal of track 3	
Center of 4# turnout	43.07	Starting signal of track II	
Center of 4# turnout	43.07	Fouling post of 2# turnout	
Center of 4# turnout	43.07	Intersecting point of curve after 4# turnout	
Center of 6# turnout	60.00	Fouling post of 6# turnout	
Center of 6# turnout	60.00	1# starting signal	
Center of 6# turnout	60.00	Intersecting point of curve after 6# turnout	
Intersecting point of curve after 6# turnout	240.00	Intersecting point of curve after 8# turnout	
Intersecting point of curve after 8# turnout	329.40	Center of 8# turnout	
Center of 8# turnout	464.40	Fouling post of 8# turnout	

Note: The track length in above table is the projecting length of each effective track length. As the effective length of Track 1 and Track II are in a straight line, the length in table is actual effective length. But as there are curves on the two ends of Track 3, the length in above table is shorter than the actual one, it is only an approximate value.

(4) The effective length of tracks

The effective length can be calculated using Table 6.11.

The actual effective length of track can be calculated in different directions. Fill the coordinates of control points into column 3 and 4, and column 3 plus column 4 result in column 5. In column 5, the track with the maximum value is the track with the shortest effective length. Such as in following table, the effective length of up direction of track 4 is the shortest effective length. In column 6, give the differences between every track and the shortest one, there are differences between each number and the shortest one in column. Each value in column 6 adds the designed effective length get the value in column 7 (effective length of each track).

Table 6.11

Effective Length of Track Calculation

Track Number	Running Direction	Coordinates of Control Points of Effective Points		Sum of Coordin
Left End	Right End			
1	Up direction	83.20		113.49
Down direction	78.50	117.49		195.99
II	Up direction	106.37		96.56
Down direction	96.56	100.56		197.12
3	Up direction	100.36		96.56
Down direction	96.56	106.37		202.93

Note: The track length in the above table is the projecting length of each effective track length. As the effective length of track 1 and track II are in a straight line, the length in table is actual effective length. But as there are curves on the two ends of track 3, the length in above table is shorter than the actual one, it is only an approximate value.

(5) Determining the mileage of the center of the outmost turnout and the mileage of home signal

Take the center of the most outside turnout as the original coordinate point for calculating coordinates. The calculated results are only relative positions. In order to determinate the actual position of each major points, it is necessary to calculate the mileage of original points at the two ends of station.

The mileage of original coordinate point of station is calculated in accordance with the mileage of station center. First, determine the mileage of the center of the most outside turnout at one end of the main line in accordance with the mileage of station center, then determine that of the other end in accordance with the length of track.

For example, the mileage of station center is DK15+ 650, first determining the mileage of 2# turnout center on down direction:

DK15+650 (mileage of station center)

125 (the right part length of basic platform)

20.6 (distance from the end of basic platform to the center of turnout)

+ 464.4 (coordinate of 8# turnout center)

DK16+260 (mileage of 2# turnout center)

where $20.6 = a$ (front length of turnout) + the inserted straight + ϵ (the difference for integrating the mileage) = $13.839 + 6.25 + 0.511$.

where $\epsilon = (DK16+260) - (DK15+650 + 13.839 + 6.25 + 464.4)$.

From the above calculation, we obtain the mileage of the center of 2# turnout as DK16+260.

At the arriving end of the up direction, in order to meet the requirement of shunting, move the home signal 200 m outward from the center of the outmost turnout, and the position of home signal can be determined as follows:

Mileage of home signal = $DK16+260+200=DK16+460$

Therefore, at the arriving end for up direction, the distance from home signal to the actual point of switch rail of 2# turnout is:

$$200 - (16.85 - 2.65) = 185.8\text{m}$$

where 16.85 m is the front length of 12# turnout, and 2.65 m is the length from the gap of beginning of turnout to the actual point of switch rail.

At the other end of the station, the mileage of the center of 1# turnout can be calculated in accordance with the mileage of 2# turnout.

DK16+260.00 (mileage of 2# turnout center)

– 96.56

DK15+163.44 (mileage of fouling post of 2# turnout)

– 750.00

DK15+413.44 (mileage of starting signal of II track for up direction)

– 106.37

DK15+307.07 (mileage of 1# turnout center)

The home signal should be moved outward and set at the mileage of DK15+100. The distance from home signal to the actual point of switch rail of 2# turnout is:

$$15,307.07 - 15,100 - (16.86 - 2.65) = 192.87\text{m}$$

(6) Calculating the quantity of rail-laying and turnout-playing

As we know, the total length is the length from the stock rail joint of turnout in one end of the station to that of the other end.

The total length minus the length of all turnouts gets the length of rail-laying, as shown in Fig. 6.30.

Taking the 1-track as an example, the total length of track can be determined as follows:

The total length of 1-track=the distance from the stock rail joint of 1# turnout to the stock rail joint of 2# turnout.

The total length of 1-track=a+(the mileage of 2# turnout center- the mileage of 1# turnout center)+[(60/cos α-T+L)-(60+T)]+ (60/cos α-60)+a=16.85+(16,260.00-15,307.07)+(60.20-20.80+41.57)-(60+20.80)+(60.20-60)+ 16.85=987.00 m, where a is the deflection angle of curve connected to the rear part of turnout; T is the length of tangent; and L=the length of curve.

Length of rail=laying of track 1=987.00-(36.82+28.85+36.82+ 36.82)=847.69 m.

In the same method, the length of other tracks can be determined.

The total length of track and the length of rail-laying are given in Table 6.12, and the quantity of turnouts is shown in Table 6.13.

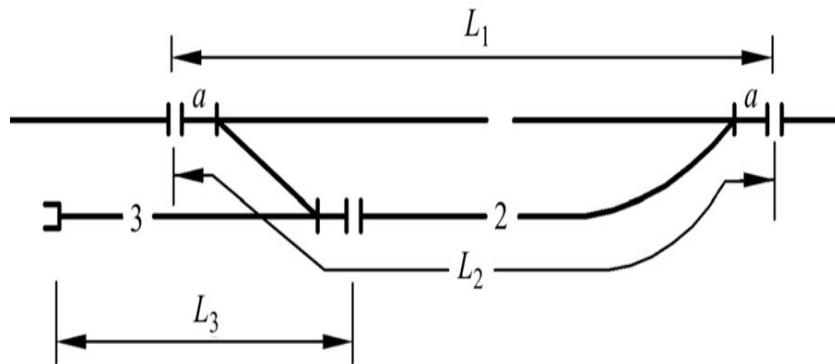


Fig. 6.30 The total length of track.

Table 6.12

Length of Tracks (m)

Numbering of Turnout			Total Length	Length of Rail-Laying	Note	
Starting	Through	Ending				
1	1#	8#,6#	2#	987.00	847.69	
3	3#	—	4#	901.08	827.44	
4	8#	—	6#	436.51	370.84	314
Sum					2045.97	

Table 6.13

Quantities of Turnout

Type and No. of Turnout	Numbering	Quantity	Note	
9	Left hand	8#	1 group	43 kg
Right hand	—			
12	Left hand	1#,4#,6#	3 group	6# is 43 kg, others are 50 kg
Right hand	2#,3#	2 group		
sum			6 group	

6.3 Essentials of District Station Design

District stations are train spacing points to divide tractive districts in railway network. Apart from handling with trains transferring and passenger-freights transportation, one of their major tasks is to provide locomotives for adjoining sections. Therefore, locomotive depots (basic depots or turnaround depots) are set in a district station, which is the obvious mark distinguishing between a district station and an intermediate station.

6.3.1 Operation and Type of District Station

In addition to all operations of intermediate station, the following operations should be handled in district station:

- (1) Technical operation of passenger trains, such as technical inspection of trains, locomotive replacement, detached repair and in-train repair of cars.
- (2) Technical operation of freight trains, such as inspection of trains and freights, replacement of locomotive and locomotive crew, reception and departure, break-up, and formation of district train, pick-up and drop train and less-than-carload train.
- (3) Locomotive servicing (including fuel, oil and sand supply, ash removal, and turn around), repair and inspection of locomotives.
- (4) Cars repair, including detached repair and in-train repair of freight trains and passenger trains.

Comparing with an intermediate station, facilities in the district station have several characteristics: there are locomotive depots and locomotive running tracks dedicated for locomotive replacement; there are special sidings for cars repair or rolling stock depots; there are specialized arrival-departure yards, and sorting tracks or marshaling yards for breaking-up and making-up of district trains and less-than-wagon-load trains; there are also passenger and freight facilities similar to intermediate station, but the scale is bigger.

The layout of facilities above should be determined by analysis of station traffic volume, transport requirements, terrain and geological conditions and city planning etc. district stations in single-track railway usually adopt transversal type district station as Fig. 6.31 shows; if there is little initial traffic on double track railway, it also uses transversal type as Fig. 6.32 shows; if there is large traffic and appropriate sites, longitudinal type district station in double track railway is more favorable, as Fig. 6.33 shows.

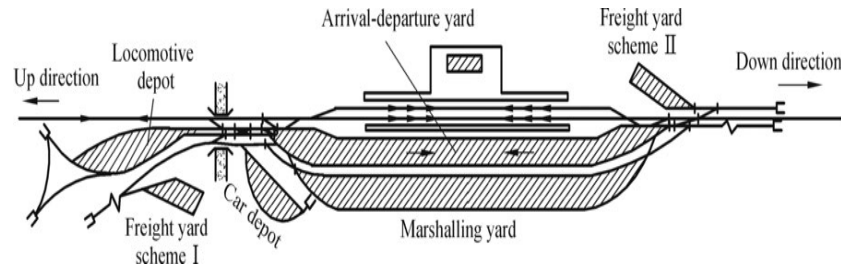


Fig. 6.31 Transversal type district station in single-track railway.

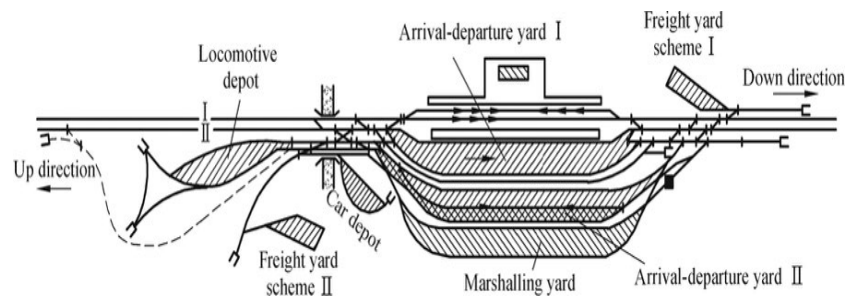


Fig. 6.32 Transversal type district station in double-track railway.

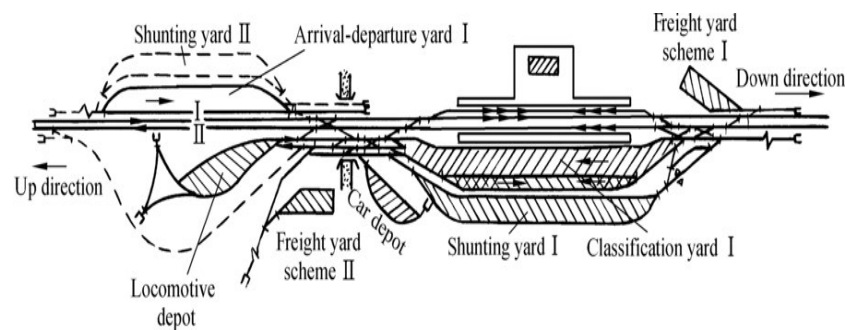


Fig. 6.33 Longitudinal type district station in double-track railway

6.3.2 Layout of Major Facilities in District Station

6.3.2.1 Facilities for Passenger Transportation

The basic requirements of passenger traffic facilities of district station are same as intermediate station. When there are not many passenger trains, there is no need to set a dedicated arrival-departure track for passenger trains. The arrival-departure track for receiving departing passenger trains can be also used as freight train receiving-departure track. For this reason, the arrival-departure tracks at the same side with passenger station building shall be connected with locomotive depot and lead track. In addition, because of the large passenger flow volume in a district station, the passenger passages shall use interchange to pass across tracks, such as the underpass tunnel or the overpass bridge.

6.3.2.2 Arrival-Departure Yard for Freight Train

The major task of district station is handling reception and departure operation of transit freight train without resorting. Thus the arrival-departure yards of freight train are set at the opposite side of the station building and nearby the main line. The transit freight train will be departed directly after replacing locomotive at arrival-departure yard. District trains and less-than-wagon-load and pick-up train are pulled on lead track by shunting locomotive and then are break up in shunting yard. The marshaled train is transferred to an arrival-departure yard through lead track, then attach the replaced locomotive and be set off from the arrival-departure yard. Therefore, there should be a direct and convenient passageway between the arrival-departure yard and shunting yard and locomotive depot.

The quantity of arrival-departure tracks should be determined according to traffic volume and transport properties, but not less than the value listed in Table 6.14.

Table 6.14

Quantity of District Station Freight Train Receiving-Departure Tracks

Converted freight train pairs	<12	13-18	19-24	25-36	37-48	49-72	73-96	>
Quantity of arrival-departure track	3	4	5	6	6-8	8-10	10-12	1:

6.3.2.3 Shunting Yard and Lead Track

A shunting yard is set for train breaking-up and make-up. Therefore, it is often laid out at the outside in paralleling with the arrival-departure yard so as to short the running time of train changing line and reduce interference with other operations.

The quantity and effective length of shunting tracks shall be determined according to direction number of connected tracks, number of cars with shunting operation, shunting operation methods and train marshaling plan, etc.

(1) At the district station with breaking-up and make-up, the quantity of shunting tracks is as follows:

At least one shunting track shall be set at each traffic direction, and more shunting tracks could be set deliberately at the direction at which there is large traffic flow volume, its effective length shall not be shorter than the effective length of the arrival-departure track.

It is necessary to set a storage track for local cars, S, a storage track for car to be repaired and other cars. If there are not much cars, the later can be shared with the former. If there is specialized connected track and large traffic volume, one more storage track can be added. When there are dangerous freight cars, one dedicated storage track should be set for dangerous freight car. The effective length of shunting tracks stated above shall be determined according to the maximum number of cars storage on this track.

(2) At the district station without breaking-up and make-up, two shunting tracks should be set for local cars storage and shunting operation.

The lead track is the major marshaling facilities of the district station. Lead tracks are set generally at the two ends of the marshaling yard. There is one lead track at each end and one is the main track. The effective length of main lead track shall not be shorter than the arrival-departure track. Under difficult conditions, it can be reduced when there are only adding or reducing loads operations. The minor lead track could be a little shorter, but not shorter than half the effective length of arrival-departure track. If the quantity of shunting operation is no more than seven trains in one day (day and night), the minor lead track could be set later.

The marshaling yard shall be connected with locomotive depot for shunting locomotive coming into and going out of locomotive depot. Sometimes the train formed in marshaling yard needs to be departed directly, so some shunting tracks shall be connected with main line.

6.3.2.4 Freights Yard

The basic requirements of freights yard of district station are same as intermediate station. There are much freight to be loaded and unloaded and many facilities at the district

station, so they should be arranged compactly, thus, stub-end freights yard should be used. It is good for urban transportation that freights yard is set at the same side and first quadrant of the station building. Because the delivery car between marshaling yard and freights yard pass across the main line and influence station operating when there are too much delivery car, the freights yard could be set at the third quadrant near the marshaling yard and be connected with the minor lead track of the marshaling yard. In this case, there should be convenient transportation between freights yard and urban areas, and overpass facilities can be constructed when possible.

6.3.2.5 Locomotive Depot and Locomotive Running Track

Locomotive depots can be divided into locomotive basic depots and locomotive turnaround depots. The locomotives belong to basic locomotive depots and haul trains between basic locomotive depots and locomotive turnaround depots. There are servicing facilities, examining and repairing facilities in basic depot, and only servicing facilities in turnaround depot. Servicing facilities include facilities for adding fuel, lubricate oil, replenish sand and water, etc. and equipment and lines for check locomotives. Examining facilities include examining shed and repair plant. The layout graph of electric locomotive depot is shown in Fig. 6.34.

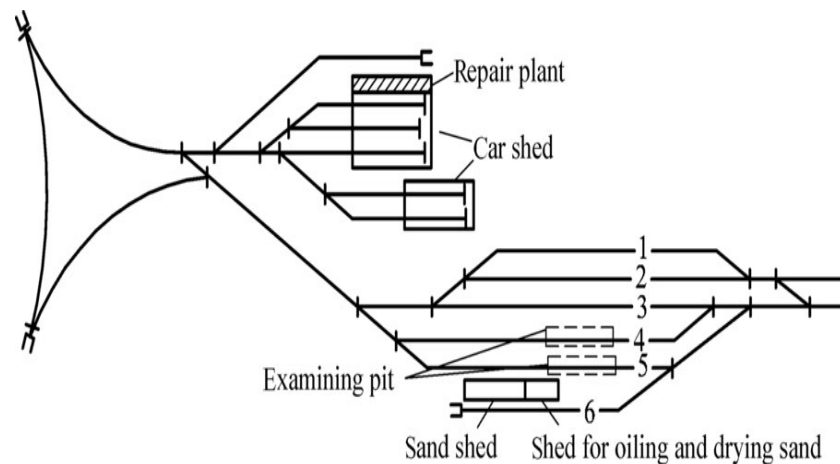


Fig. 6.34 Layout graph of electrical locomotive depot.

A locomotive depot is the main part of district station. Because of its busy locomotive operation, its noise seriously affects the environment. Choice of its location shall be determined according to the requirements of station operation and transportation as well as the requirements of terrain, geology, hydrology, wind direction and city planning. There shall be convenient access from locomotive depot to arrival-departure yard and marshaling yard for lead locomotive and shunting locomotive coming in and going out quickly. Therefore, the locomotive depot should be set at the third quadrant in transversal type district station. This location would be very convenient for locomotive coming in and going

out when the district station developing into a longitudinal type (as shown in Fig. 6.33). If there is no possibility that the district station would develop into a longitudinal type, the locomotive depot could be set at the fourth quadrant.

There should be one out-track and one in-track between the locomotive depot and the arrival-departure yard. When the number of the locomotives out and in the depot is not more than 60 per day (day and night), there could be only one track. There shall be a park position at the station parting of the out-in track. The gradient of the park position shall not be more than 2.5‰, and its length shall not be shorter than the safe distance equal to length of two locomotives plus 10 m.

When the number of the locomotives out and in the depot is more than 36 per day (day and night), there shall be a specialized locomotive running track to reduce the interference to other operations. The location of the locomotive running track shall be determined according to the station layout graph. To the single transversal type district station, the locomotive running track shall be located at the middle of the arrival-departure yard or between the arrival-departure yard and the marshaling yard. There shall be a waiting track at the throat section of the other end of the locomotive depot when there is a locomotive running track at the district station. The locomotive out from the locomotive depot shall be first stopped at the waiting track so that the locomotive could be replaced to ensure the train departs on time. The length of the waiting track is the length of the locomotive plus 10 m.

6.3.2.6 Car Maintenance Facility

When there is a car depot in the district station, the car depot should be set at the end of the second lead track near the marshaling yard for convenient delivery of repairing car in the marshaling yard. In some district stations, there is no car depot but a train inspection point. The repair track in the train inspection point should be set at the outside of the marshaling yard.

6.3.3 Layout of Throat Zone District Station

The throat zone refers to the zone from the stock rail joint of the outmost turnout at two ends of the station, to the innermost signal (or fouling post) as shown in Fig.6.28. The throat zones concentrate many turnouts with complicated structure and is the busiest part in the whole operation, thus it is also the weak part for station's carrying capacity. When designing the throat zone, the required carrying capacity and safe operation shall be guaranteed to create good operation condition, it also should be designed to reduce the expenses and be designed with the consideration of future development. Detailed requirements are as follows:

(1) Necessary parallel operation capacity shall be guaranteed. The parallel operation capacity means that two separate routes can operate simultaneously without disturbing each other. The district station throat of single-track railway shown in Fig. 6.28A can ensure the train starting (or arriving) and shunting simultaneously without obstructing each other.

The district station throat of double track railway shown in Fig. 6.28B has the ability of parallel operation of train arriving, starting and shunting, or train arriving, locomotive out (in) section, shunting.

(2) The maneuverability of operation shall be guaranteed. The marshaling yard shall have several tracks connecting to the main line to ensure the direct departure from the marshaling yard, if necessary. Each reception-departure yard shall be sure of train reception and departure at the opposite direction (e.g., the reception-departure yard in up direction can receive and depart the trains from down direction, or reception-departure yard can receive and depart trains from up direction).

(3) Crossing of routes shall be minimized, especially to avoid crossing with the arriving route. As the arriving train is fast, and the station cannot master the train's arriving time accurately, the route must be opened ahead of time to make the arriving route be occupied for a long time. (4) Turnouts shall be reduced as much as possible, especially the ones on the main line, so as to avoid laying extra turnouts.

(4) Try to shorten the length of throat zone to reduce the time of running in the station.

[Fig. 6.35 sets out the plane layout example of transverse district station throat zone for single-track railway and double-track railway based on the design principles and requirements above.](#)

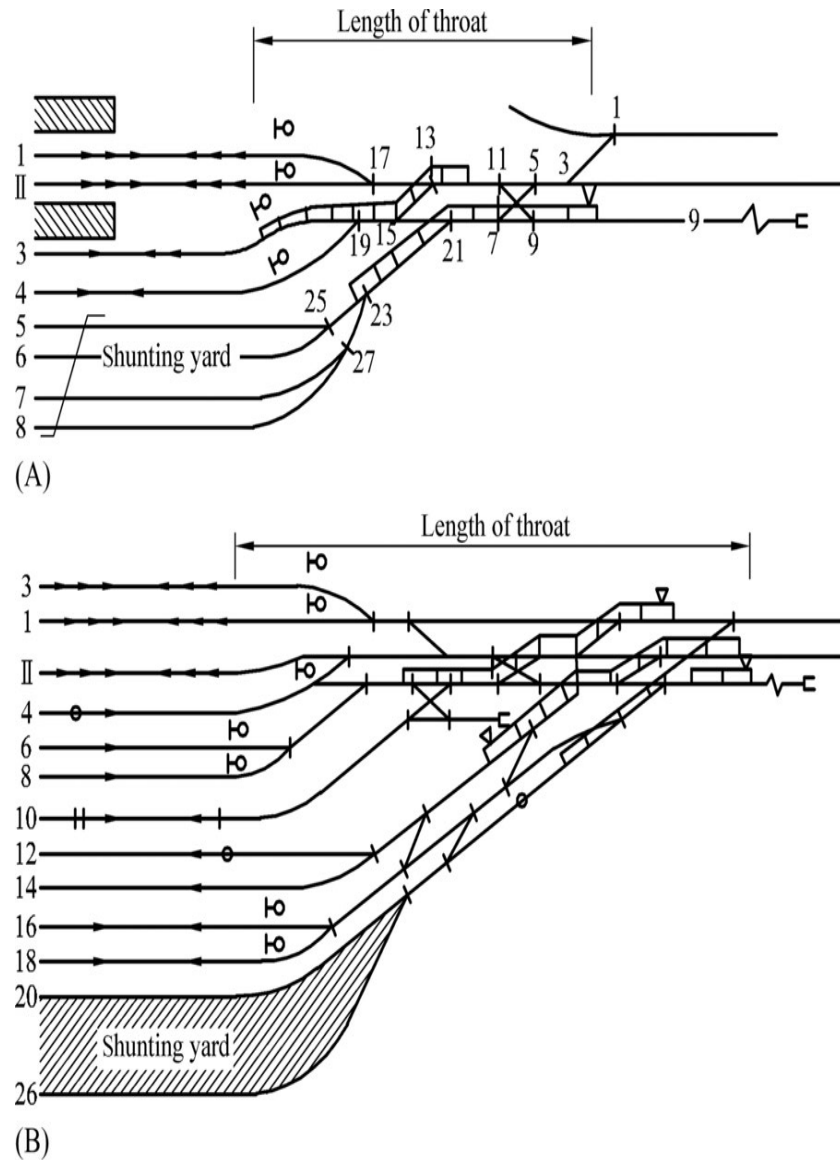


Fig. 6.35 District station throat zone layout and parallel operation. (A) Single-track district station. (B) Double-track district station.

[Fig. 6.36 is the detailed figure for Fig. 6.35A, i.e., the detailed figure of single-track railway transverse district station layout. It draws in detail each station track with their interconnection.](#)

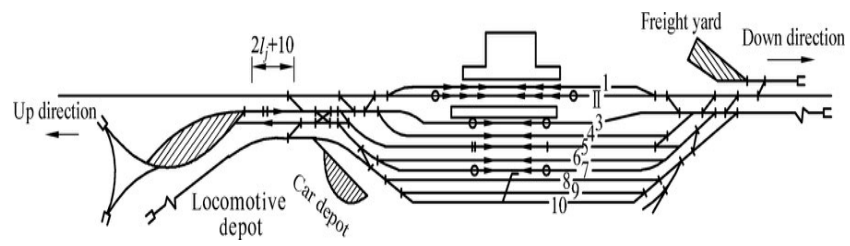


Fig. 6.36 Details of transverse district station layout of single-track railway.

6.4 Introduction of the Marshaling Station and Junction Terminal

6.4.1 Marshaling Station

In order to deal with the disintegration and marshaling operation of many freight trains, a station equipped with hump shunting equipment is called a marshaling station. Compared with district station, they have generally same passenger and freight transportation services and technical operation property, i.e., they all handle with the trains' arrival-departure and marshaling, the replace of locomotive and train crew as well as locomotive servicing, and train maintenance, etc. But they have obvious difference on the quantity of work.

The district station only handles with disintegration for district trains and less-than-wagon-load and pick-up trains with small working quantity; while marshaling yard handles with great numbers of the disintegration operation for freight trains including marshaling through train, district train, etc. Thus the shunting equipment (including marshaling yard), hump and lead track largely exceed district station with respect to quantity or technical equipment. The modern marshaling stations are equipped with mechanized or atomized hump shunting equipment.

The marshaling station pattern is divided into unidirectional and bidirectional types. Each type can then be classified into

transversal type, longitudinal type, and hybrid type based on yard arrangement. The unidirectional and bidirectional here refer to hump decomposition direction at the marshaling yard. Unidirectional marshaling yard has only one set of shunting system, all trains break up and make up at one hump shunting yard. A bidirectional marshaling yard uses two sets of shunting systems with two directions, and there are two hump shunting yard of different decomposition directions inside the station. Relatively more unidirectional marshaling yards are adopted on the railways in China, as shown in Fig. 6.37.

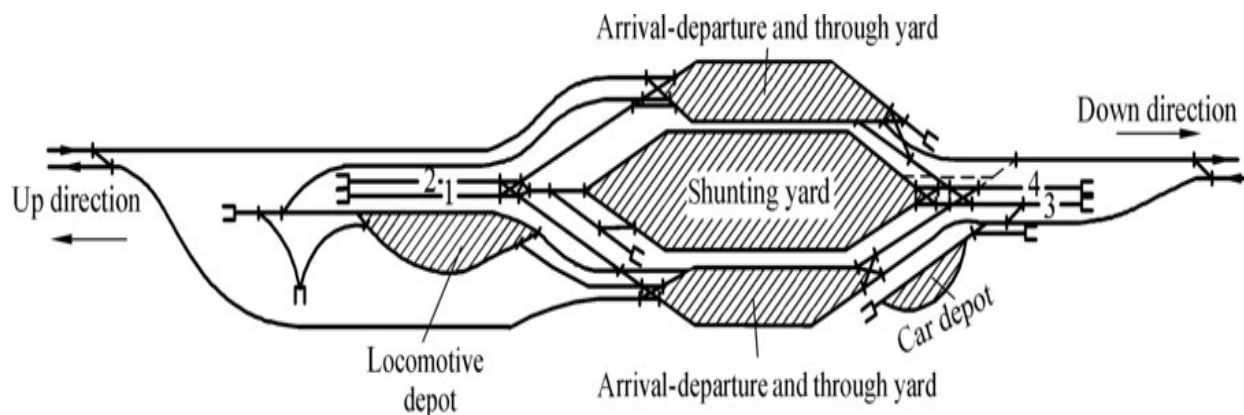


Fig. 6.37 Unidirectional transversal marshaling station.

The hump is the shunting devices in the marshaling yard. It makes use of the potential energy of height difference to help the train slip into the predetermined position of each shunting track by means of gravity; the plane surface is shown in Fig. 6.38. The hump decomposition process includes pushing, slipping, speed-down, and stopping.

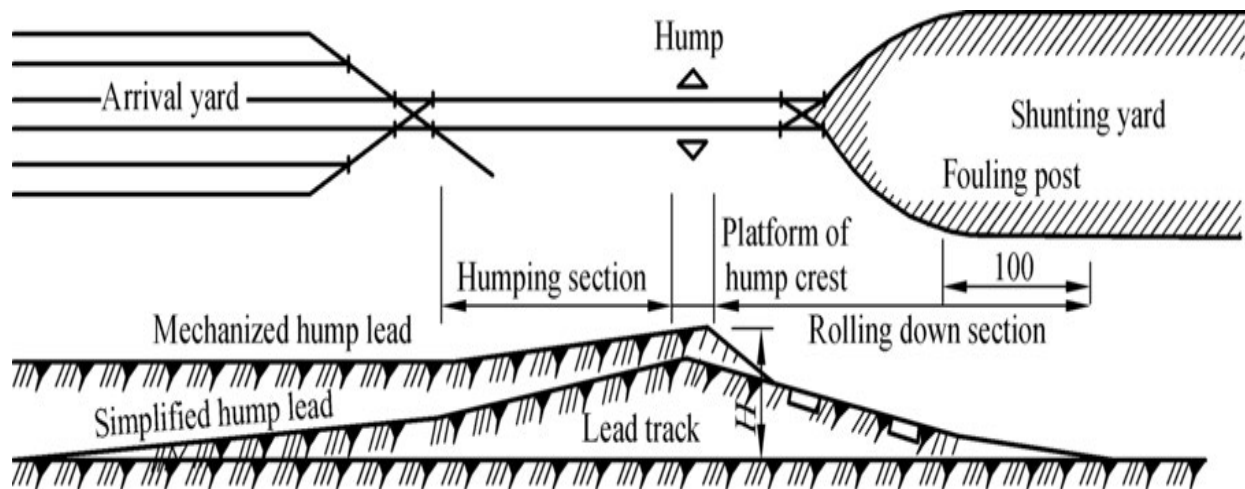


Fig. 6.38 Plane and profile alignment of the hump.

At present, the car retarders widely used in China's railway system are pressure clamp retarder and gravity retarder. There are also such devices for speed regulation and car pushing as dowty retarder, dowty accelerator, and wire rope pushing carriage. Many advanced hump yards at home and abroad are equipped with adjustable car accelerating and reducing devices through computer controlling automatically the train's slipping speed, which greatly improve the train's decomposition speed and enable the capacity of a hump yard to be fully used.

6.4.2 Junction Terminal

In the crossing point or terminal zones of railway network, the overall composed of different kinds of railway lines,

stations, and other equipment serving for transportation is called railway junction terminal.

A railway junction terminal is the central pivot connecting trunk railways and branch lines, and is an important part of railway serving for the cities, industrial, or port areas as well as connecting with various national economic departments; it is also the main part of traffic junction terminals. According to their status and role in the railway network, the railway junction terminals are classified into: network terminals, regional terminals, and local terminals. Local terminals mainly serve such local operations as industrial areas or ports, etc. and are usually located in industrial enterprises and water-land coordinate transport area such as Dalian, Qinhuangdao, etc. Regional terminals mainly serve certain regional scoped which are usually located in large and medium-scale cities where the trunk lines intercrosses or links up the branch lines. Regional terminals deal with through traffic flow and local traffic flow within the terminal scope with small scale of equipment, such as Changchun city, Yingtan city, Liuzhou city of China, etc. The tasks that a network junction terminal undertaken involve the whole railway network, which is located in big cities where several trunk railways link up. It deals with a great amount of cross-bureau through traffic and local traffic, and sets more professional stations with large scale and capacity of the devices such as junction terminals in Beijing, Zhengzhou, Shenyang, Ji'nan, etc.

[Fig. 6.39 shows the plan diagram of Ji'nan junction terminal located at the crossing point of three trunk railways as Beijing-Shanghai railway, Qingdao-Ji'nan railway, and Handan-Ji'nan railway.](#)

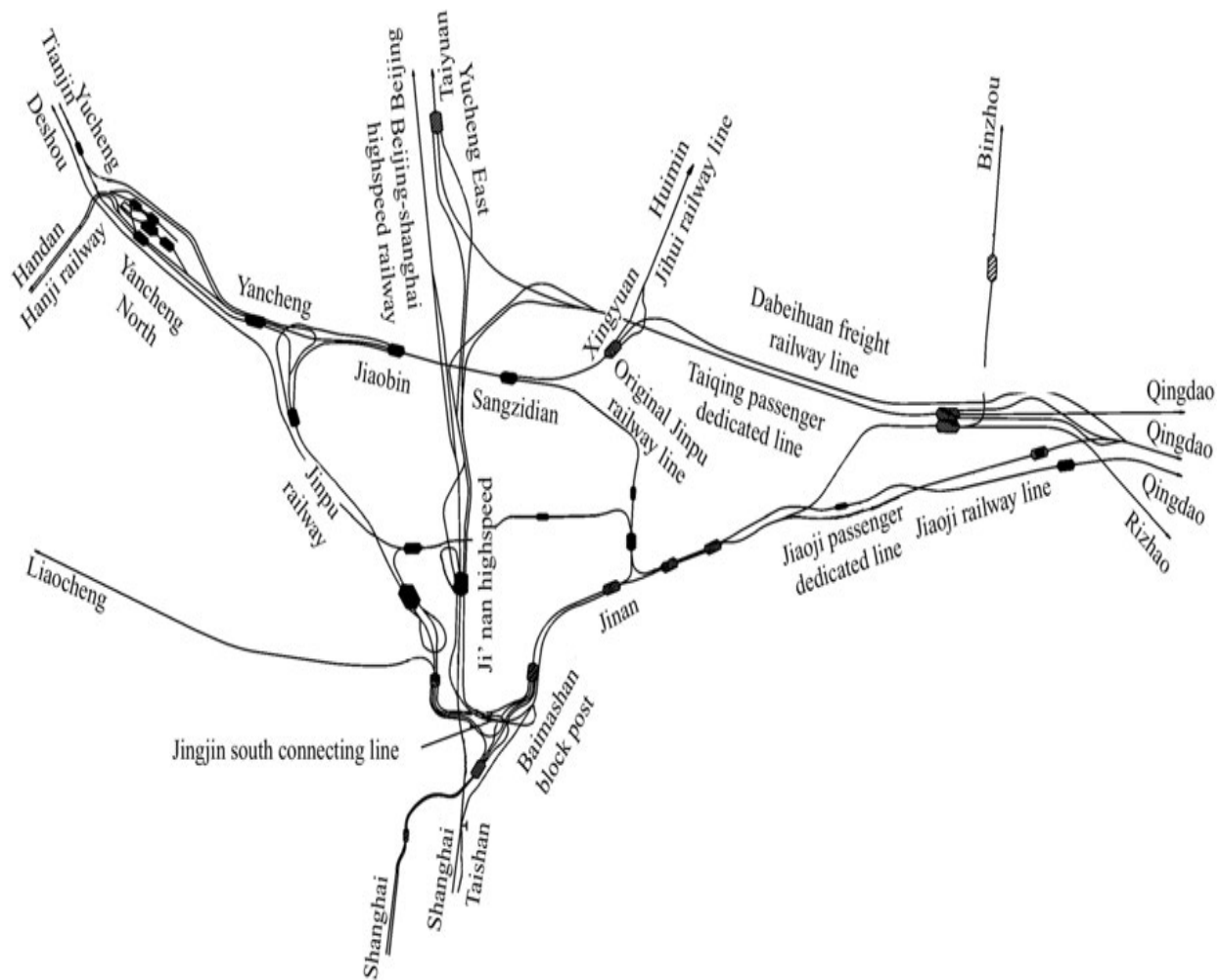


Fig. 6.39 Ji'nan junction terminal plan diagram.

The main equipment in the railway junction terminal include: railway line, station, untwining equipment and locomotive depot, car depot, and passenger car servicing depot, etc.

Various stations are the main component of junction terminal. The quantity of marshaling yards in the junction terminal shall be determined according to traffic volume of junction terminal, traffic characteristics and direction, lines leading in as well as marshaling yard division in the network coordinating to local condition. In the Ji'nan junction

terminal, Ji'nan West and Yancheng North marshaling yard is the core of train transportation, where many freight trains are broken up and made up.

The passenger stations inside the junction terminal shall be convenient for passengers boarding and alighting, coordinate with the urban planning, have convenient pathway in each introduction direction, and shall ensure convenient transport connection from the station to the main lines of the cities. The Ji'nan passenger station and Ji'nan East passenger station inside the Ji'nan junction terminal are collecting and distributing center for passenger flow. Such comprehensive stations as Shilibao, Dongshawangzhuang, etc. not only undertake the passenger and freight transportation business separately but also cooperate with each other, which forms the stations a whole.

The connecting lines inside the junction terminal connect railways, railway and station as well as station and station, to ensure the convenient pathway among railways and stations and try not to change the running direction, making the junction terminal has enough flexibility during operation. as shown in Fig. 6.39, the connection lines inside the Ji'nan junction terminal such as Beijing-Ji'nan South line, Beijing-Shanghai South line, North Ring to Ji'nan West up-direction yard line are set for linking up Ji'nan marshaling station with main railway lines and stations along lines such as Beijing-Shanghai railway, Qingdao-Ji'nan railway, Jinpu railway, Handan-Ji'nan railway, Beijing-Shanghai highway, and Taiyuan-Ji'nan bus line to form direct pathway and make the train disassembly more flexible. The great north ring connecting line of the freight train passes through the urban area, forming a circuitous line, so as to shunt the passing freight trains and to reduce the disturbance that the railway transportation has on cities.

6.5 Essentials of High-Speed Station

6.5.1 General Requirements

The high-speed station design shall comply with the requirement of system function, meet the traffic demand, be easy for the operation management, and be convenient for passengers. In addition, the conditions for further development shall be reserved.

The quantity of passenger stations at the terminals shall be determined according to the comprehensive factors, such as the passenger traffic volume at the terminals, the number of lead-in tracks, passenger train operation scheme, the existing equipment configuration, the passenger traffic layout of the terminal, as well as the overall urban planning, etc.

The location selection of the passenger stations shall be determined by considering the following factors, i.e., the alignment of lead-in lines, the location and conditions of the existing passenger stations, the overall urban planning, and the topographical and geological conditions, etc. The priority selection shall be the existing passenger stations or the locations in urban area. Given the circumstance of two or more selected passenger stations, there should be convenient links among the passenger stations.

If there are two or more passenger stations in the terminal, the work division of passenger stations shall follow the principles of smooth routing for passenger trains, well-coordinated transport capacity between stations and line, and convenient boarding and aligning of passengers and be carried out according to the direction of lead-in tracks, the types of passenger trains, and the passenger train operation scheme, etc.

The way of “separate track for passenger and freight traffic, passenger traffic inside the terminal while freight traffic outside the terminal” should be used for the passenger and freight traffic layout in the large railway terminal. The large passenger stations shall be integrated with the urban traffic system and constructed as a comprehensive traffic hub, creating a convenient interchange for passengers.

In the large passenger stations with multiple lead-in lines, the layout should be organized according to the different functions and types of the lead-in lines. Under difficult circumstances, separate lines and yards may be laid as the grade separation type, and the connecting line for the cross-line train shall be set up according to the traffic demand and the principle of the primary lines crossing tracks and the secondary lines applying interchange. As for the passenger station with lines only connected from the third direction, a combined yard may be laid out based on directions.

The stations may be classified into three types: the overtaking station, the intermediate station, and the originating train station, according to the character of technical operation. They may also be classified into four types: super-large station, large station, medium station, and small station, according to the passenger traffic volume.

The effective length of the arrival-departure track in station shall be 650 m and be designed as a two-way route.

The untwining lines and connecting lines shall be linked with the main lines or the arrival-departure tracks in the station. If they have to be linked with the main lines in the section, a block post shall be set up at the link area and the catch siding shall be built according to the needs of train operation.

The private siding and depot-managed siding shall be linked with the arrival-departure tracks in the station, and the catch siding shall also be built.

It is not necessary to set up catch siding if there are parallel route and separated turnout as well as the interlocking equipment in the station.

In an intermediate station, the catch sidings shall be set up at both ends of the arrival-departure tracks on which the trains would stay for a long time. It is not necessary to set up catch siding if there are other route and turnout separated with the main line as well as the interlocking equipment in the station.

At a station which has a down-grade of over 6‰ in the entrance direction outside the home signal and within the braking distance, the catch siding shall be set up at the end of the receiving direction of the main line or the arrival-departure track.

The catch siding shall conform to the following requirements:

- (1) The effective length of catch siding shall be no less than 50 m.
- (2) The longitudinal grade of the catch siding shall be designed as level grade or the up grade facing the bumper.
- (3) The buffer shall be applied to the end of the catch siding.
- (4) The guard rails shall be set out at both sides of the catch siding. If the catch siding is on the subgrade, there shall be wheel-stopping subgrade.
- (5) The distance between the end of the curve catch siding and the adjacent track shall guarantee that the adjacent tracks remain safety once there is a rollover accident of locomotive or car happening.
- (6) The catch siding should not be built on the bridge or in the tunnel.

At the straight line section in station, the distance from the main buildings and facilities to the railway axis shall conform to the rules set out in Table 6.15.

Table 6.15

Distance From the Main Buildings and Facilities to the Line Axis



Notes: 1. When the large-sized maintenance mechanic operation is applied to the ballastless track, the distance from the main buildings and facilities of Serial No. 1 to the track axis should be 3100 mm.

2. In difficult conditions, the distance between the catenary pole edge and the track center line shall be no less than 2500 mm on the side of the main track, and no less than 2150 mm on the side of the station track.

In the curve section of a station, the distance from all kinds of buildings and equipment to the center line of the track shall be widened according to method in 3.2.5.

At the straight section, the distance between the centers of two adjacent lines in station shall follow the following rules:

- (1) The distance between the centers of two main lines shall be the same as that of two main lines in section.
- (2) If there is no building or equipment between two lines, the distance between the center of the main line and its adjacent arrival-departure track, centers of the two arrival-departure tracks, or centers of the arrival-departure track and other tracks shall be no less than 5.0 m.
- (3) If there are buildings or equipment between two tracks, the distance between the centers of two tracks shall be calculated according to Table 6.15 which contains the standard distance between the buildings and equipment and the center line of the track as well as the structure width of buildings and equipment.

The MU depot and workshop (depot) should be set up near the station with room to be reserved for its further extension, and should be laid in a longitudinal type outside the throat zone with less arrival and departure trains.

Overhead lines shall be erected for the tracks in station and MU depot and workshop (depot). They may not be erected for the tracks in the comprehensive maintenance depot (work area).

As for the flyover bridge that crosses electrified railway inside the station or MU depot and workshop (depot), t. It may not be erected for the tracks in the comprehensive maintenance depot (work area).

As for the flyover bridge that crosses electrified railway inside the station or MU depot and workshop (depot), the height from its beam bottom to the rail top under the bridge in a straight line section shall meet the following requirements:

- (1) As for the flyover bridge that crosses the high speed main line, the height under the bridge shall not be lower than 7250 mm.
- (2) As for the flyover bridge that crosses the turnaround line and the tracks inside the MU depot and workshop (depot), the height under the bridge shall not be lower than 6550 mm,

and shall not be lower than 6200 mm in difficult conditions. For the existing flyover bridge, the height under the bridge shall not be lower than 5800 mm when there is enough reason.

If the beam bottom of the flyover bridge locates in the curve superelevation section, the headroom of the flyover bridge shall be heightened according to calculations.

In the stations of heavily snowy regions, the railway turnout on the main track and arrival-departure track shall be equipped with snow-melting devices.

In the section where the station road is parallel to the main track, the road shoulder shall not be 0.7 m lower than the railway shoulder. If it does not meet the requirement, safety provisions shall be set up between road and railway.

The landscaping of the station shall be designed with consideration of the surrounding environment, architectural style, and noise abatement as well.

The name of the station shall be given in accordance with the following requirements:

(1) The station name shall be in line with the name of the place where it is located, while being different from other names across the country.

(2) If a station is located inside an urban district or city suburban, it shall be named after the city. Meanwhile, if it lies in a county, town, or village, then it shall have the name of that county, town, or village.

(3) If more than one station are set up in an urban district or city suburban, the station with the most passenger services should have the name of the city, while the other stations may be named after the city added with the orientation words (i.e., east, west, south, and north), or named after the local place.

(4) As for a station located in secondary districts or exurban area, it shall not be named after the city or added with the orientation words.

6.5.2 High-Speed Station Operation

6.5.2.1 Overtaking Station

The main operations at overtaking station include:

(1) handling various trains passing through the main line;

(2) arrange trains which will be passed by other train in and out of arrival-departure track, and stopping to avoid the overtaking train; and

(3) the overtaking station of high-speed railway shall reserve the condition for passenger business development in the future.

6.5.2.2 Intermediate Station

The main operations in the intermediate station include:

- (1) dealing with various trains passing through main lines;
- (2) arrange stopping trains and overtaking trains in and out of arrival-departure track, and deal with service for passengers on and off;
- (3) intermediate stations with turnaround trains will deal with operations of train departing and train arriving at destination station;
- (4) managing the passenger servicing work of trains which will start from originating station or terminate at destination station (including cleaning and supplies, etc.) as well as passengers on and off;
- (5) for intermediate station with comprehensively maintaining base and private siding junction, on normal condition, handle with train inspection and maintenance at skylight time. At special cases, such as the main line for certain direction sealed up or ordered by control center, the maintenance train shall run into the main line;
- (6) controlling the departure and arrival operations of trains (including high and intermediate speed trains, inter-city motor trains units) from (to) existed railway to (from) high speed intermediate station, with an intermediate station interconnecting to the existed railway (station);
- (7) the water feeding operation for passenger trains shall be generally carried out at starting and terminal stations, in some cases, it is also possible of immediately retracing the train and carrying out water feeding at intermediate station; and
- (8) managing passenger transferring besides various operations mentioned above, with the high speed joint station connecting to other high-speed railways.

6.5.2.3 Starting and Terminal Station of High-Speed Railway Line

The starting and terminal station is only for trains running on the same high-speed line. For trains crossing the high-speed line, the starting and terminal station is still passing trains with only different form. The starting-terminal station has types of terminal (Shanghai) and passing (e.g., constructing two stations behind the diameter line from Beijing to Beijing West Station).

In addition to dealing with all intermediate station operations above, the starting and terminal station has other operation tasks as follows:

- (1) It has more arrival and departure operations of high speed train, in daytime the trains operate on arrival-departure tracks and retraces immediately, at night the trains arrive the station and stop operation, the high speed underbody (also unified called motor train unit)

attached to this station will be inspected (or maintained) and stored through running lines into motor train application and maintenance center.

(2) Train inspection, water feeding, and locomotive changing (according to locomotive routing) for intermediate trains might be executed.

6.5.3 Basic Pattern of a High-Speed Station

6.5.3.1 Rules for Station Layout

The plan layout of the station shall be determined by the quantity of the lead-in lines, carrying capacity, working amount of passenger trains and operation scheme, station functions and operational requirements as well.

The quantity of arrival-departure track for an overtaking station shall be two, and may be two to four for an intermediate station. As for starting train station and intermediate station with quick turnaround work, the quantity shall be determined by the pair number and function of the passenger train that the station actually assumes, the train operation scheme, the quantity of the lead-in lines, and the procedures of the technical work of the station as well, and shall meet the requirements of dense train arrival and departure in peak hours.

The layout in the throat area of the station shall meet the requirements of defined arrival and departure routes for trains and use for the arrival-departure tracks.

The layout in the throat area shall be tight and the quantity of turnouts in main track shall be reduced. Where there are the access of MU depot and workshop (depot) leading in, the layout in throat zone at the leading in end shall meet the quantity requirements of the parallel operation for the arrival and departure of train and MU going to and from the depot and workshop (depot).

A single crossover may be laid in the two ends of the station to form a splayed crossover, except the station with short distance from the adjoining one. A group of splayed crossovers shall be set up at two ends of the departure station and the end of the intermediate station with departing work.

If the main line is about 100 km long, a hold track inside the station should be set up for the construction train, and a parking base in every 200 km for the large-sized track maintenance machinery, ballast unloading car, and rail replacing train. The effective length of the hold track or the tracks inside the parking base shall be 650 m.

The turnouts in the main lines and the arrival-departure track in station should use movable-point frog, and have the same type of rail as the main line and the arrival-departure track.

The selection of turnout number shall meet the following requirements:

(1) The straight passing speed of turnout in main line shall not be lower than the design speed in the section.

(2) The lateral turnout connecting the main line and the connecting line for cross-line passenger train shall be determined by the design speed of the train. High speed turnout with the permissible lateral passing speed of 160 or 220 km/h should be selected. If the connecting track for the cross-line trains connects with the station where all the cross-line trains stop, the high speed turnout (1:18) with the permissible lateral passing speed of 80 km/h may be used.

(3) High-speed turnout with the permissible lateral passing speed of 80 km/h should be used in the crossover between two main lines in the station throat area, while the turnout (1:12) be used for the large stations for renovation and extension in difficult conditions.

(4) The high-speed turnout (1:18) with the permissible lateral passing speed of 80 km/h shall be used for the lateral turnout connecting the main line and the arrival-departure track.

(5) The lateral turnout (1:18) with the permissible lateral passing speed of 80 km/h shall be used when the arrival-departure track inter-connects with each other, while the turnout (1:12) shall be used for the station where all or most trains stop and the large stations for renovation and extension in difficult conditions.

(6) At least the turnout (1:12) shall be used when the running line of MU and maintenance cars is connected with the arrival-departure track. The turnout (1:9) may be used when the depot siding and maintenance line are connected with the arrival-departure track.

(7) The turnout (1:12) is suitable for the arrival (departure) end in the parking yard of the MU depot and workshop (depot), the turnout (1:9) may be used in difficult cases and for other turnouts.

The length of the rail inserted between adjoining turnouts shall meet the following requirements:

(1) If the turnouts in main lines are opposite arrangement, and two trains pass the two sidings at the same time, the rail with a length of at least 50 m shall be inserted, and the rail with a length of at least 33 m shall be inserted if limited by the length of station site. If no trains pass the two sidings at the same time, or the turnouts are set up in consequent positions, then rail with a length of at least 25 m may be inserted.

(2) If the trains pass the two sidings at the same time, the rail with a length of at least 50 m shall be inserted between the two turnouts in the arrival-departure track, and the rail with a length of at least 12.5 m shall be used in difficult cases. If no train passes at the same time, then the rail with a length of at least 12.5 m shall be inserted.

The layout and design scale of high speed station shall be determined according to train number in each station and train operation properties. The main factors affecting the station pattern design are: Collinear running mode of original line and cross line passenger trains, station nature, running requirements, motor train depot (station), configuration of passenger train servicing depot, and geographic conditions, etc. The station pattern shall be determined on the condition of meeting running requirements combing with specific situation. Generally, topography and engineering conditions have light impact on the pattern of intermediate station, but great affection to junction terminal station or final station, thus the pattern selection for stations in this type shall fully take project condition and the cost of construction into consideration.

6.5.3.2 Basic Pattern for Overtaking Station

The overtaking station is specially designed for overtaking and cross-line trains. Generally it makes the faster trains overtake the slower trains without taking charge of passenger on and off. Thus two starting and arrival lines to be avoided are necessary as shown in Fig. 6.2A.

6.5.3.3 Basic pattern for intermediate station

Based on the difference of transport organization and line connection condition, the intermediate station is divided into general intermediate station, station of immediately retracing, and station introduced from the third direction. According to the requirements of transport organization and operation, the configuration of intermediate station is slightly different.

(1) General intermediate station deals with passengers on and off besides trains passing and overtaking.

Determination of the number of arrival lines: on the analysis of its operation time, passenger on and off operation occupies 8 min, including 3 min for preparation of route and picking up, 2 min for passengers on and off, and 3 min for preparation of starting; assuming 0.5 as the calculation for utilization rate of arrival and departure line, i.e., 9 h are daily utilized, thus one arrival-departure track can deal with 67.5 trains; general intermediate station deals with a few passenger on and off operations, setting one line at up and down going system is acceptable. However, if the passenger number is great and a certain direction need cope with two trains for stopping to avoid overtaking train, an additional starting line can be added as shown in Fig. 6.40 with dotted line. What's more, in consideration of a bit more trains passing the station without stopping, and in order to ensure trains' high-speed passing in safety (the main line close to platform causing threat to the passengers, platform width and safety devices shall be added), two main lines shall adopt parallel design, no platform is set at two sides of the main line as shown in Fig. 6.40.

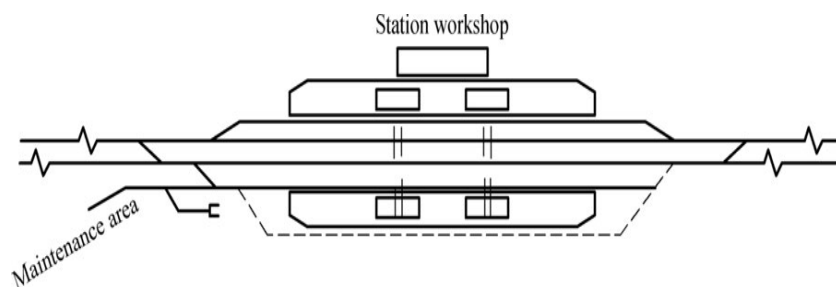


Fig. 6.40 The basic pattern for general intermediate station.

(2) The intermediate station immediately retracing back to operate

The intermediate station having train retracing back for operation shall open lines for the starting and arrival of retracing back train. Besides dealing with main line passing, stop for passing operation, it also deals with trains starting and final arriving operations. This kind of station belongs to intermediate station observing from the whole line with the nature of terminal station. The station of this type may become the capacity control spot for the whole line in the future. The departure and arrival line for retracing train shall prevent the trains from occupying the main line in principle. Through referring to general intermediate station, each direction of the stop sets a starting and arrival line. The number of arrival-departure tracks is calculated according to departure station and can be calculated according to each arrival-departure track dealing with 30 passenger trains. As the number of immediate retracing operation is low, setting one departure and arrival line at up and down going system respectively is acceptable. But in consideration of reserving development and flexible usage of the station, the layout in Fig. 6.41 can be adopted.

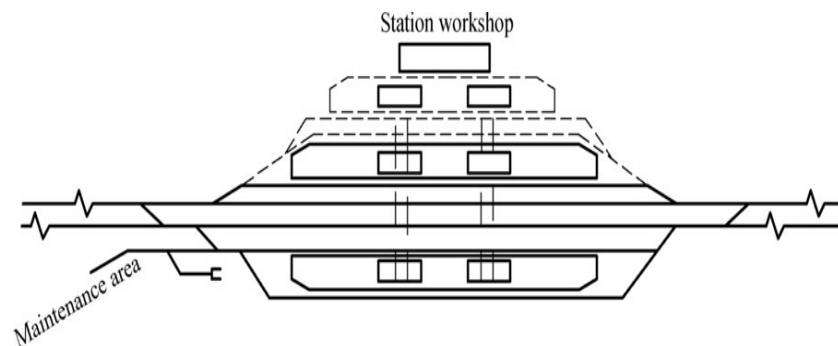


Fig. 6.41 Basic pattern of intermediate station with immediate turnaround operation.

(3) The intermediate station inductive from the third direction

If the main line and inductive line do not cope with stopping and passing operation, the layout in Fig. 6.42 shall be adopted, the third direction does not connect to the main line; if the third direction line and main line cope with great numbers of stopping and passing operation, the layout of third direction connecting the main line shall be adopted. The number of starting and arrival line in the station is dependent on the need of operation at this track.

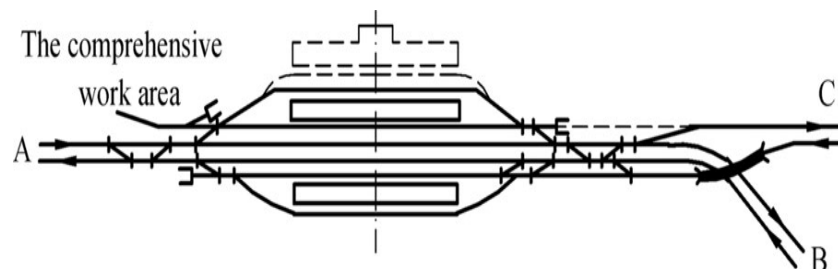


Fig. 6.42 Intermediate station from the third direction.

(4) The intermediate station where two specific passenger lines meet

The layout in Fig. 6.43 can be adopted, introducing to the station through parallel running on the main line respectively, as the main line condition is slightly limited, it is easy to meet the technical requirements of two trunk line and main line passing trains passing through the station at high speed.

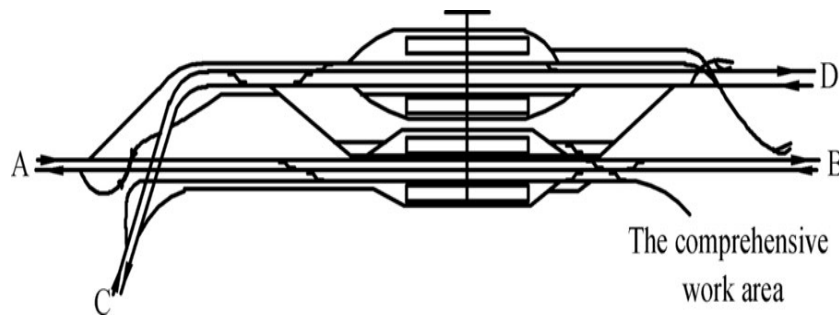


Fig. 6.43 Intermediate station where two specific passenger trains meet.

6.5.3.4 Departure Station

The departure station is mainly responsible for train starting, arriving, and passenger business; the train operates at arrival-departure tracks and retraces immediately. The motor train units come into motor train depot (station) for maintenance, reconditioning and storage. The number of arrival-departure track can be determined through calculations. The layout can take the following principles into consideration:

Introduce the pattern of existed stations, and determine according to existed conditions and specific situations.

The pattern selection for departure station to be newly constructed shall think about: (1) the planning of high speed railway network, and the possibility of introducing other high speed lines in the future; (2) the planning of urban station square and urban traffic situation; and (3) the position of motor train section and station, etc.

The departure station shall park, marshal, maintain, inspect, and serve the arrival motor train units, thus the motor train depot (station) shall be equipped in the departure station. In order to reduce the walking distance from motor train depot (station) to the departure station, the motor train depot (station) shall be close to the departure station to the greatest extent, the position shall be determined after considering elements of each aspect.

When there are frequent departing and arriving of trains, in order to avoid cross interference of line transfer of going and back trains and starting operation, the longitudinal layout form for motor train depot (station) and the departure station is suggested to be adopted. But if there are only a few arrival trains or restricted by geographical condition, the plane layout form can also be adopted.

On general conditions, through type pattern shall be the preferred solution, if there are a few trains stopping and passing through, station house and platform shall be arranged in the form of a through pattern, as shown in Fig. 6.44.

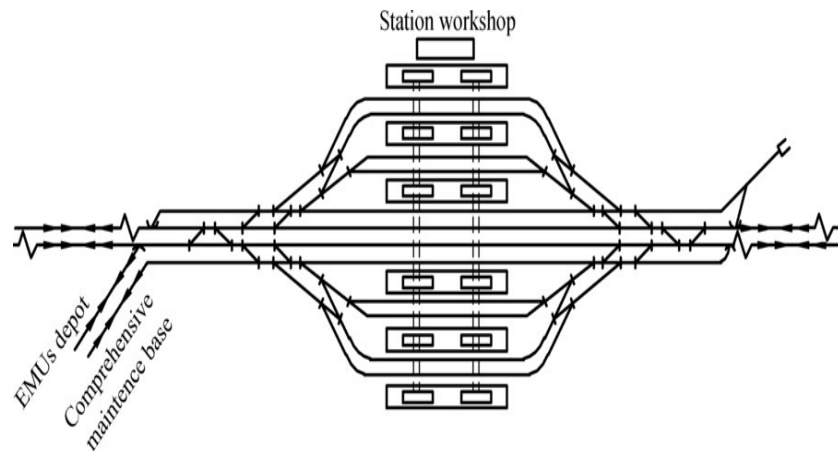


Fig. 6.44 Through type departure station pattern.

If the departure station does not have trains passing without stopping, the intermediate platform between main line and departing line can be set as shown in Fig. 6.45.

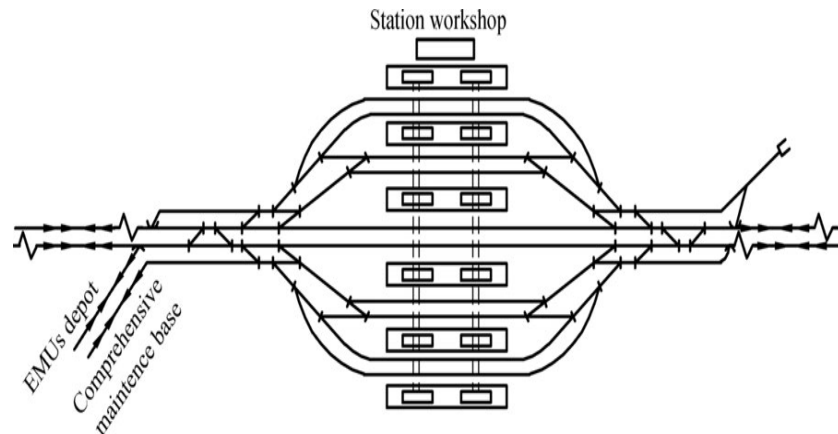


Fig. 6.45 Departure station pattern where intermediate station between main line and departing line is set.

The departure station introduced from the third direction is suitable of adopting the type of direction introduction to the station as shown in Fig. 6.46.

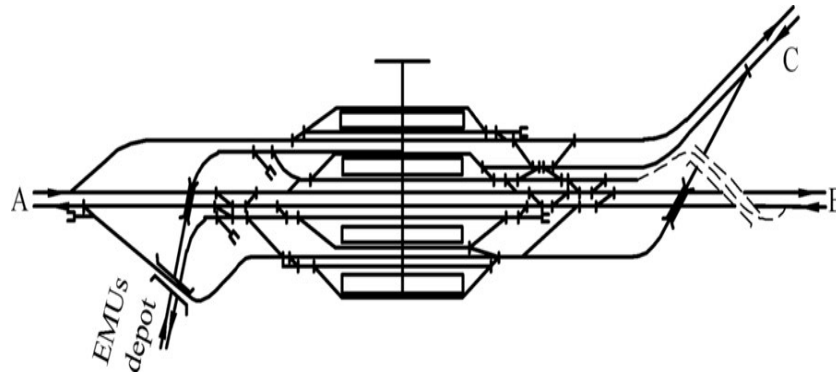


Fig. 6.46 The departure station pattern introduced from the third direction.

When two passenger lines intersect, the station type shown in Fig. 6.47 can be selected, adjusting for matching according to the train flow situation.

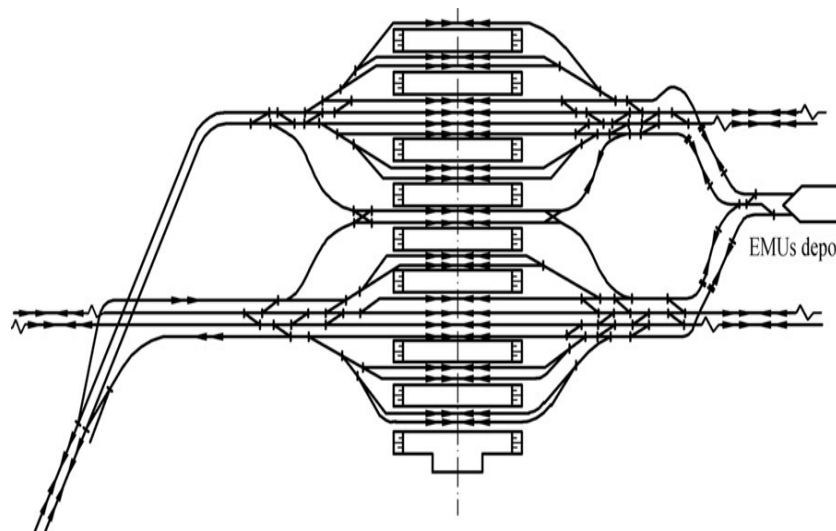


Fig. 6.47 The departure station pattern where two passenger lines intersect.

6.5.4 Plane and Profile of Station Tracks

If the turnout (1:18) is adopted in the station throat area, the curve radius in the arrival-departure route shall not be less than 800 m.

Meanwhile, if the turnout (1:12) applied, the relevant regulations in Chinese Standard GB50091 Code for Design of Railway Station and Terminal shall be followed.

The superelevation of outer rail shall be set for the curve in arrival-departure route. The curve superelevation value shall be determined by the plane curve radius and train passing speed, meeting the requirements of allowable deficient superelevation, allowable surplus superelevation, and the allowable value of their sum should not be less than 20 mm.

The transition curve in the arrival-departure route shall be designed and its length shall be determined by the train passing speed, the curve designed time-varying rate of superelevation, (deficient) superelevation, and the superelevation slope ratio, will not be less than 20 m. If the curve radius is more than 1200 m, the transition curve may not be set up.

When the transition curve is designed in the arrival-departure route, the length of the intermediate straight line between the circular curves and between the two curves shall not be less than 25 m. On the contrary, if the transition curve is not set up, the length of straight line without superelevation between two curves shall not be less than 20 m.

The length of straight line from the turnout in arrival-departure route to the end of curve superelevation slope shall not be less than 20 m, while the straight line section after turnout shall be in accordance with the length of L' from the end of the turnout to the last turnout tie. As for the distance between other turnouts and curves, Chinese Standard GB50091 for Design of Railway Station and Terminal shall be followed.

A single grade section inside the effective range of the arrival-departure track should be designed, while the length of the grade section within the platform range shall not be less than 450 m in difficult cases.

If the gradient difference between the adjoining grade sections in the arrival-departure track is above 3‰, the vertical curve shall be used, and its radius may be 10,000 m. Meanwhile, the vertical curve shall not overlap the transition curve.

The turnout in the station shall not overlap the vertical curve and the grade change point. The distance between the turnout in main track and the starting point, ending point of the vertical curve, or grade change point should not be less than 20 m.

The rail top of the main line and the arrival-departure track as well as the rail top of the arrival-departure track and the arrival-departure track should be designed to be of the equal height. If the height difference exists in the rail top of the throat area, its smooth connection shall be designed while taking into account the transverse grade of the subgrade surface and the depth of track bed, and the range of smooth connection grade shall be from the common sleeper adjoining the end of the turnout to the starting point of the train stop post, with the gradient being no more than 6‰, with the differences between the adjoining grade sections no higher than 3‰, and with the grade length being at least 50 m.

The smooth connection grade in other lines shall follow the requirements in Chinese Standard GB 50091 for Design of Railway Station and Terminal.

As for the stations with considerable quick turnaround work, the turnaround line should be set up at the end of the train receiving direction. If a lot of trains running on the main line,

the grade separation turnaround lines shall be set up. The turnaround line shall meet the following requirements:

- (1) The effective length of the turnaround line shall not be less than 480 m.
- (2) The turnaround line should be set in a straight line, or in curves with at least a 600 m radius in difficult cases.
- (3) The turnaround line should be set in a flat grade, or in grade with the gradient not exceeding 6‰ in difficult cases.
- (4) The plane curve radius in the running part of the turnaround line should not be less than 400 m, with the gradient not exceeding 30‰.

The plane layout of the MU depot and workshop (depot) shall meet the following requirements:

- (1) The train yard shall be set in a straight line.
- (2) The connecting curve radius after the turnout shall at least equal the lead curve radius of the adjoining turnout, while not be less than 250 m.
- (3) The length of the straight line section between the turnout and the curve shall not be less than 6.0 m before the turnout, and the distance behind the turnout shall not be less than the sum of the distance from the end of the turnout to the last turnout tie with the minimum straight line length required for the gauge widening on curve and the curve superelevation.
- (4) The decline rate of gauge widening shall not exceed 2‰, and 3‰ in difficult cases, while the rate of curve superelevation slope ratio below 2‰.
- (5) Curve section may not have transition curve.

The plan layout in comprehensive working area (maintenance location) shall follow the requirement in Chinese Standard GB50091 for Design of Railway Station and Terminal.

The lines inside the MU depot and workshop (depot), comprehensive working area (maintenance location), and large-sized track maintenance section should be set up in flat grade, or in a grade not exceeding 1‰ in difficult cases. The throat area may be located in a grade not more than 2.5‰, or not more than 6‰ in difficult cases.

The gradient of the running line for the maintenance train shall not exceed 30‰ in difficult cases, while not exceeding 6‰ for the draw-out track.

6.5.5 Equipment for Passenger Transportation

The design of the passenger platform shall meet the following requirements:

- (1) The platform shall be 450 m long, and be 230 m for the railway station with only 8-cars MU, while being at least 220 m in difficult cases.
- (2) The platform shall be 1.25 m higher than the top of rail.

(3) The width of the platform shall be determined by the station function, platform type, density of passenger flow, safety draw-back distance, and the width of platform entrance and exit as well. Table 6.16 may be referred to.

Table 6.16

Width of the Passenger Platform

Name	Super-L
Distance between the margins of projecting part of the station building (operation room) and the platform	15.0-20
Island intermediate platform	11.5-12
Side intermediate platform	8.5-9.0

Note: As for the width of passenger main platform, if the access entrance and exit are set up outside the station building, it shall not be less than the width of side intermediate platform.

- (4) The platform shall not be laid on both sides of the main line which passenger train goes through. If the platform is set on one side of the arrival-departure track, its security guard line shall be 1.0 m from its margin. The security guard line should be colored in yellow and laid with the warning blind sidewalks, not exceeding 250 mm and at least 17 mm wide.
- (5) The platform should be set up in a straight line. If it is laid in curve, the curve radius should not be less than 800 m. If the turnout (1:12) is adopted, the curve radius shall not be less than 600 m in difficult cases.
- (6) The width of the end of platform should not be less than 5.0 m.
- (7) Steps, slopes or protecting stockade shall be laid on both sides of the platform, and the stockade gate shall not be less than 1.0 m wide, marked with “No Entry.”
- (8) The train stop signs shall be set on the platform in accordance with the requirements of the railway administration.

The setting of the passenger entrance and exit access shall take into account the flow line of passenger underpass comprehensively, while it should meet the following requirements:

- (1) The entrance and exit of the passenger platform shall be bidirectional, with the width following the requirements in Table 6.17. If escalators or elevators are laid in the access entrance and exit, the width shall be widened according to the quantity and requirements of the lifting equipment.

Table 6.17

Width of the Entrance and Exit for the Passenger Platform

Name	Super-Large and Large Station (m)	Medium Station (m)	Small Station (m)
Basic platform, island intermediate platform	5.0-5.5	4.0-5.0	
Side intermediate platform	5.0	4.0	

Note: The width of the passenger entrance and exit access in super-large and large station includes the width of an escalator.

(2) Where the high-speed railway is led to the existing passenger station, the entrance and exit access of existing passenger may be used on condition that it meets the requirements of function and safety.

The distance between the margin of the passenger station platform beside the track and the platform entrance and exit or the building margin, shall not be less than 3.0 m, while 2.5 m for medium or small station in difficult cases, and shall not be less than 2.0 m on one side where the existing station is reconstructed.

If luggage and mail operation is to be done in the station, access for transporting luggage and postbag shall be set up while meeting the requirements as follows:

- (1) Quantity of access: 2 for large station, and at least 1 for medium and small stations.
- (2) Width of the access: the width of access shall not be less than 5.2 m.
- (3) The clear height of the access should not be less than 3.0 m.
- (4) The entrance and exit to the passenger platform is better to be designed as a single way, with the width of 4.5 m at least.
- (5) The access shall be laid at the end of the platform.

S grade crossing shall not be set in the station where high speed train goes through.

The protecting stockade shall be laid on both sides of the station while connecting with the section protecting stockade. The protecting stockade shall be laid at 0.5 m in right of railway.

The track numbering for super-large and large passenger station shall meet the requirements as follows:

- (1) The numbering of the main line in passenger train yard and the arrival-departure track shall start from the side of the station building, ranging from 1, 2, 3, etc. in sequences, which is the same for the branch yards in transversal type layout.
- (2) If the station buildings are laid on both sides of passenger train yard, the track numbering shall start from the track on the main station building side to the secondary station building in sequences.
- (3) As for other tracks in the passenger train yard, the track numbering shall start from the side of the station building to the opposite side in sequences of up track and down track after the main line and the arrival-departure track have been numbered.
- (4) As for other yards or depot and workshop (depot) linking with the passenger train yard, they shall be numbered separately and added with the yard name or number.

(5) The arrival-departure track and the station track shall be numbered in Arabic numbers, and main line in capital Roman numbers.

As for the super-large and large passenger station platform, they shall be numbered according to platform surface with the track number. If the track is not close to the platform, the platform may not be numbered in sequences.

Chapter 7

Strengthening of the Railway Transport Capacity

Abstract

This chapter introduces the methods for increasing railway transport capacity from the aspects of enhancement of transport capacity of the existing line, passenger transport speed up, construction of high-speed railways, development of heavy haul traffic, etc. The schemes and time for the strengthening railway capacity primarily depend on the required capacity and the level of existing capacity. The railway transport capacity is determined by the carrying capacity and the tonnage. The required carrying capacity is calculated in accordance with the number of passenger and freight trains in the future and in consideration of certain reserve capacity. High-speed railway technology, which reflects the advancement of science and technology in traction power, rolling stocks, route, track structure, communication signal, traffic organization and operation mode, etc., is the most efficient method for substantially improving the capacity and service level of passenger transportation. Railway heavy haul traffic refers to freight trains with large total weight and axle load or railway transportation with heavy traffic and big transportation volume. Heavy haul freight transportation is one of the important directions of the railway development in the world. Since the 1960s, railway heavy haul transportation has gained broad interest in many countries.

Keywords

Carrying capacity; Upgrading; Railway passenger transport; Construction; High-speed railway; Heavy haul traffic

When the railway network was established, the major tasks for railway industry turn to rationalize the network, that is, enhancement, with an emphasis on system mergers, rehabilitating system segments that have experienced deferred maintenance, or upgrading for higher speeds, axle loads, or traffic densities. Access to energy sources, especially coal, is causing a flurry of construction activity, as is the need to meet the passenger demands of certain highly populated and congested corridors.

With the continuous development of national economy and ever increasing of people's living standards, the demand on railway transport will necessarily increase. Consequently, the technical equipment and transport capacity of the existing railways, more often than not, cannot meet the requirements of railway modernization and traffic volume growth, and these railways need technical reform and enhancement of transport capacity. Meanwhile, the passengers have higher requirements for the running speed to save travel time. Moreover, the railways which are facing a severe competition against other transport mode require higher running speed objectively so as to achieve their own development. This chapter introduces the methods for increasing railway transport capacity from the aspects of enhancement of transport capacity of the existing line, passenger transport speed up, construction of high-speed railways, development of heavy haul traffic, etc.

7.1 Principal Measures in Strengthening the Carrying Capacity of the Railway Line

The schemes and time for the strengthening railway capacity primarily depend on the required capacity and the level of existing capacity. The railway transport capacity is determined by the carrying capacity and the tonnage. The required carrying capacity is calculated in accordance with the number of passenger and freight trains in the future and in consideration of certain reserve capacity, i.e.

$$N_{\text{need}} = \frac{N_{\text{GFT}} + \varepsilon_p N_p + (\varepsilon_{\text{EFT}} - \mu_{\text{EFT}}) N_{\text{EFT}} + (\varepsilon_{\text{LTL}} - \mu_{\text{LTL}}) N_{\text{LTL}} + (\varepsilon_{\text{PU}} - \mu_{\text{PU}}) N_{\text{PU}}}{(1 + \alpha)}$$

(7.1)

$$N_{\text{GFT}} = \frac{10^6 \beta C}{365 \varphi G} \quad (\text{pairs/d})$$

where α is the reserve coefficient of carrying capacity (for single track and for double track. The meanings of other symbols have been mentioned in Chapter 1). The required number of passenger trains can be calculated according to the following equation:

(7.2)

where β_P is the monthly passenger flow fluctuation coefficient; A is the annual passenger flow volume per direction (up or down), in persons; and γ_p is the average seating capacity of train, in persons.

The enhancement of transport capacity of an existing line shall focus on the increasing in the carrying capacity, N , and in the tonnage, G . The measures for enhancement of transport capacity of existing railway lines can be summarized as transport organization, the reformation of traction power and signaling, interlocking, and block equipment and the reconstructions. However, as marking techniques for railway modernization, passenger transport speed up, development of railway heavy haul traffic and construction of high-speed railways are the most effective means of enhancing the railway transport capacity and improving service level.

7.1.1 Measure of Transport Organization

The measure of organization of train operation basically adopts special modes of train operation to tap the potential of existing railway so as to increase the carrying capacity, without adding equipment nor reconstructing works. It is usually used as a transition measure for adaptation to the

traffic volume growth requirements before reconstruction of existing railways.

7.1.1.1 Shortening the Period of Time in Train Working Diagram of Controlling Section

In a scheduling train working diagram, make the train in ascending grade direction in the controlling section not stop so as to increase its running speed, shorten the running time and increase carrying capacity.

When the electric staff system is used for existing line, the electric staff instruments for the stations at both ends of the controlling section can be moved into the switchman's cabin to save the walking time for the station operator to deliver train staff and reduce the time interval for two meeting trains at the station. Alternatively, the train staff of controlling section can be allowed for immediate use for train reversal to save the time for fetching train staff and reduce the time interval for two meeting trains at the station.

When adjacent sections of a technical operation station are controlling section, if the period in the train working diagram is increased due to a long time for such technical operations as water supply as well as detaching and attaching of locomotive, the period in the train working diagram of controlling section can be reduced by moving the train paths, as the case may be.

7.1.1.2 Adopting Special-Type Train Working Diagram in Single-Track Districts

Adoption Train Working Diagram Not in Pairs

When the up and down traffic volumes are unbalanced, a train working diagram not in pairs can be scheduled to run extra trains in the direction of heavy traffic. The redundant locomotives in the direction of light wagons can be attached to the return trains for reversal. The carrying capacity of the train working diagram not in pairs can be calculated on the basis of the directions of heavy traffic and light traffic, respectively.

[Fig. 7.1A is the train working diagram not in pairs of nonautomatic block district and its carrying capacity is:](#)

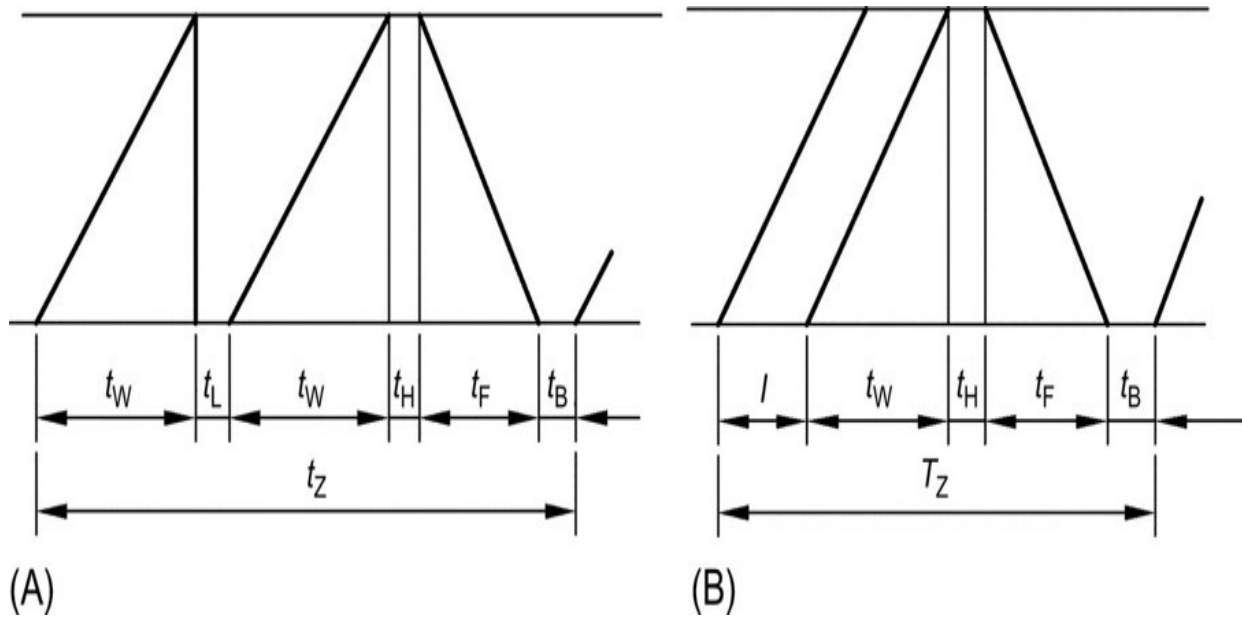


Fig. 7.1 Train working diagram not in pairs. (A) Nonautomatic block. (B) Automatic block.

Heavy traffic direction

$$N_{HF} = \frac{(1440 - T_{CMW})\beta}{(t_F + t_B + t_A + t_C) + (\beta - 1)(t_F + t_S)} \quad (\text{trains/d})$$

(7.3)

Light traffic direction

(7.4)

where: N_{HF} , N_{LF} is the carrying capacities in the directions of heavy traffic and light traffic direction, respectively (trains/d); t_F , t_B is the forward and backward running time of train in the section (min); t_A , t_C is the time intervals for two trains meeting at the station and arriving time difference of two opposing trains (min); t_S is the time interval for two trains dispatching in successive in the same direction (min); β is the not-in-pairs coefficient, i.e., ratio of the train quantity in the direction of loaded vehicles to that in the direction of light wagon, $\beta = N_{HF}/N_{LF}$. In Fig. 7.1A, .

[Fig. 7.1B is the train working diagram not in pair in automatic block district, with trains able to be spaced by automatic block signals in heavy traffic direction, and its carrying capacity is:](#)

Heavy traffic direction

$$N_{HF} = \frac{(1440 - T_{CMW})\beta}{(t_F + t_B + t_A + t_C) + (\beta - 1)I} \quad (\text{trains/d})$$

(7.5)

Light traffic direction

(7.6)

where I is the time interval between trains spaced by automatic block signals, $I=10$ min or $I=8$ min in general.

Train Working Diagram of Trains Spaced or Partly Spaced by Automatic Block Signals

In the single-track automatic block district, when the intermediate station has sufficient arrival-departure tracks to be able to organize the meeting and overtaking of bidirectional following trains at the station, it may use the working diagram of train spaced for automatic block signals or partially spaced train diagram for automatic block signals for continuous departure of two (or several) trains, as shown in Fig. 7.2. Although the working diagram of trains spaced can increase the carrying capacity, the extended time of train meeting and passing reduces the district speed and requires further station tracks. In order to mitigate the above disadvantages, as a matter of fact, the train working diagram of partially spaced for automatic block signals is often applied.

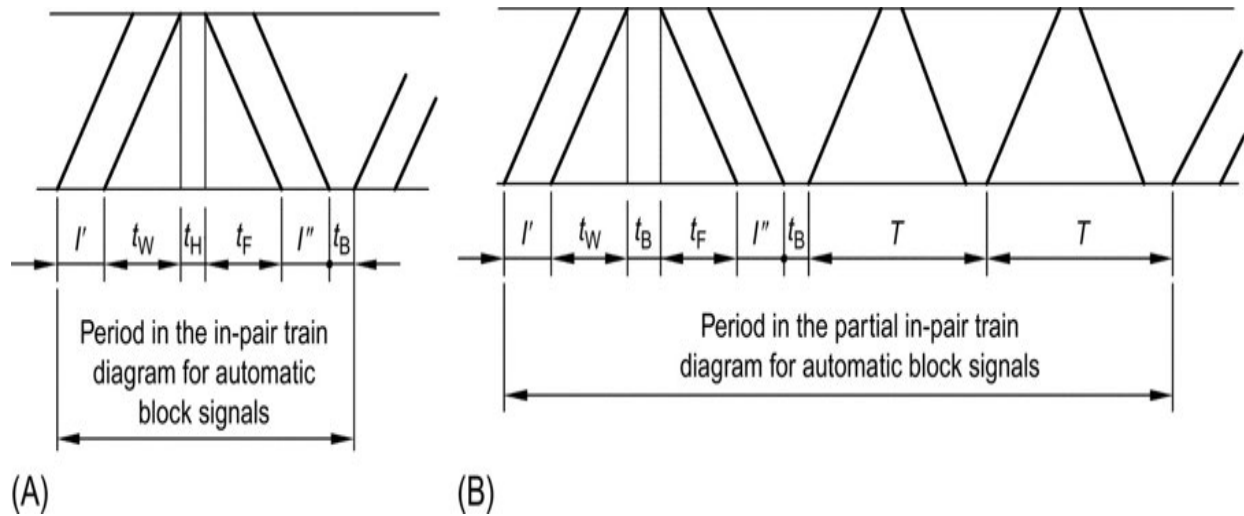


Fig. 7.2 Train working diagram of trains spaced or partly spaced for automatic block signals. (A) Trains spaced. (B) Trains partly spaced.

Fig. 7.2A is a train working diagram of two trains spaced and its carrying capacity is:

$$N_{HF} = \frac{(1440 - T_{CMW}) \times 2}{(t_F + t_B + t_A + t_C) + (l' + l'')} \quad (\text{pairs/d})$$

(7.7)

where l', l'' is the time interval between following trains spaced by automatic block signals in the up and down directions, respectively (min).

Fig. 7.2B shows a train working diagram of trains partly spaced for automatic block signals and its carrying capacity is:

$$N_{HF} = \frac{(1440 - T_{CMW}) \times 4}{3 \times (t_F + t_B + t_A + t_C) + (I' + I'')} \quad (\text{pairs/d})$$

(7.8)

Temporary Measures in Strengthening the Carrying Capacity

1. Despatch trains in succession at specified time-interval

In the nonautomatic block district, the departure of a train in the same direction to the section at a certain time interval before the arrival of the preceding train in the front and neighboring stations is called “despatch trains in succession.” To guarantee the safety, the mode of trains departing in succession is generally specified to be run only under clear weather conditions at daytime; moreover, the time interval between departures of two successive trains shall not be less than 10 min and the running speed of the following train shall not exceed that of the preceding train.

2. Running trains in reverse direction on double-track lines

The organization of reverse departure in double-track line is usually used for adjustment of train operation. However, part of the trains in the direction with a larger traffic volume can also operate on the opposite track in its original direction in the short term when the up and down traffic volumes are unbalanced and the carrying capacity in the larger-traffic-

volume direction is insufficient while that in the reverse direction is redundant, as shown in Figs. 7.3 and 7.4.

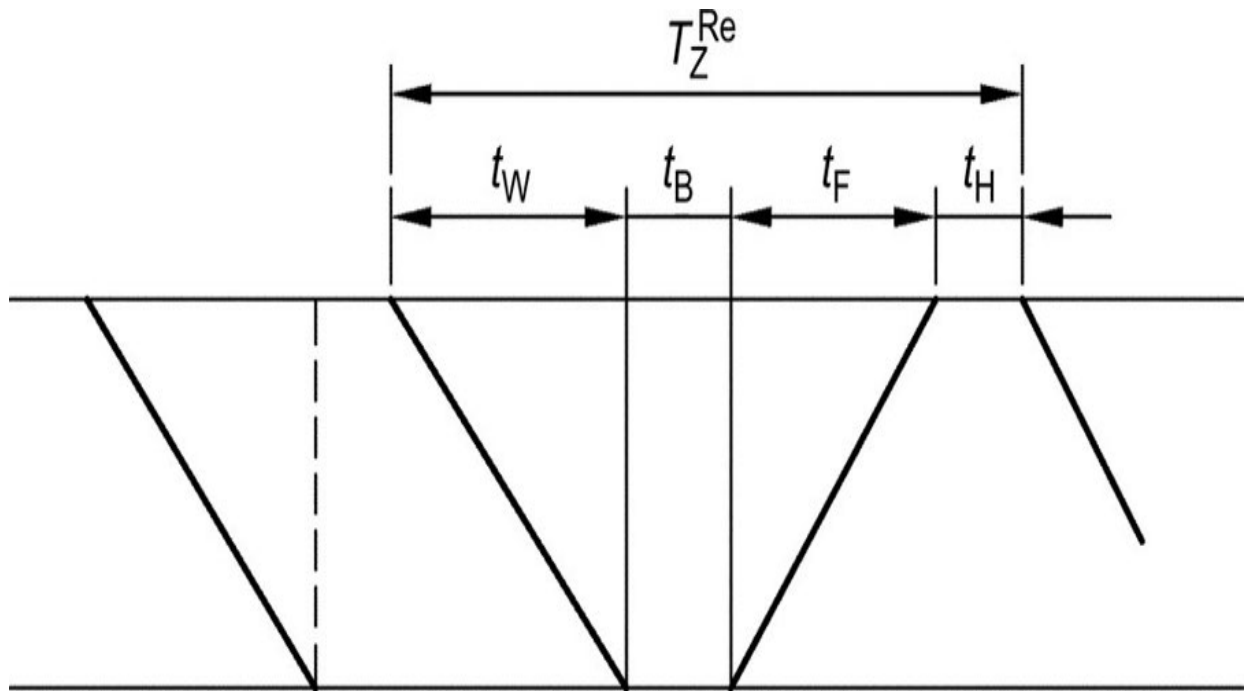


Fig. 7.3 Running trains in reverse direction on double-track lines: semiautomatic block.

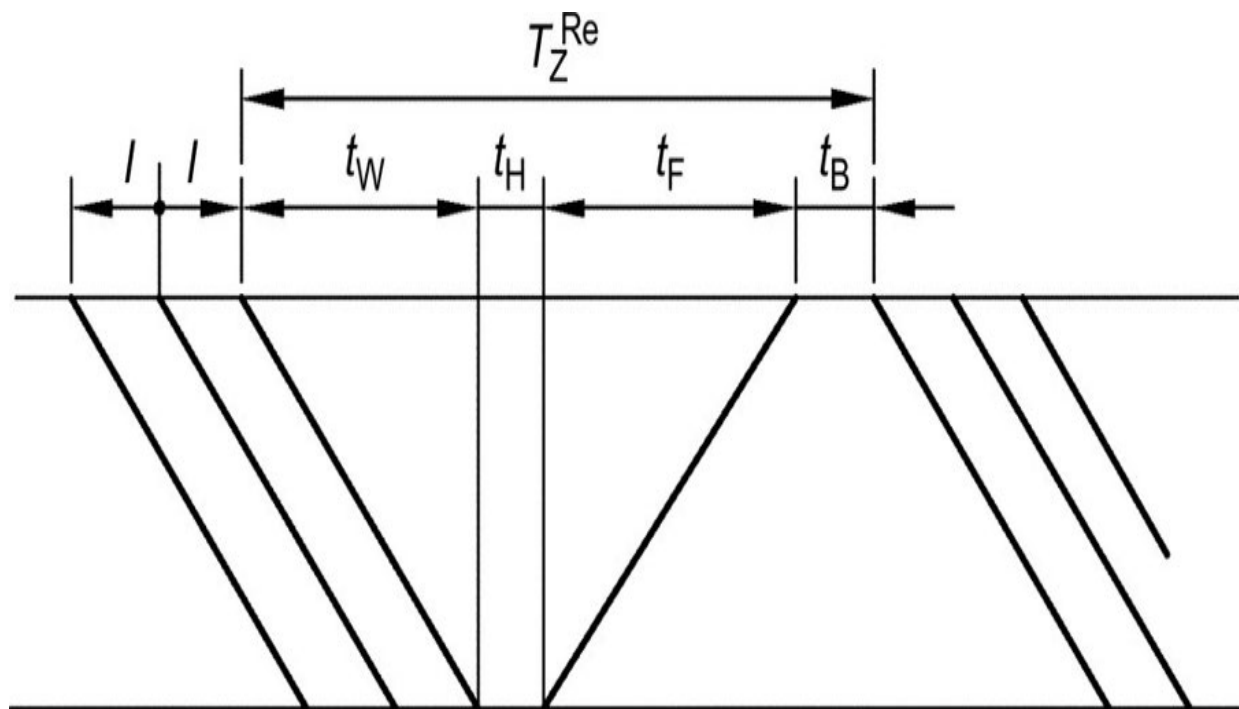


Fig. 7.4 Running trains in reverse direction on double-track lines: automatic block.

7.1.1.3 Reducing the Removal Coefficient for Scheduling One Passenger Train

In scheduling of the train working diagram, if the paths of ordinary passenger trains which have to stop at most stations can be scheduled based on the freight train path, the removal coefficient of these passenger trains can be reduced so that the carrying capacity of line can be increased to some degree. Centralized departure of fast passenger trains, can also reduce the removal coefficient of these fast passenger trains to increase the carrying capacity.

7.1.1.4 Increasing Running Speed of Train

An increase of a train's running speed can reduce the time that the train occupies the railway facilities so as to enhance the carrying capacity of the railway. An increase of train running speed, which involves numerous technical and economic factors, is a complicated technical and economic problem, with related knowledge detailed in Sections 7.2 and 7.3 of this chapter.

7.1.1.5 Utilize the Train Momentum or Pusher Operation to Overcome the Gradient

1. Utilize the train momentum to overcome the gradient

When the tonnage of the whole district is restricted by some steep and short grade section, some appropriate measures can be taken, such as not stopping train at the station ahead of the steep grade, with the driver's advanced operating skills to increase the train speed ahead of the steep grade and locomotive tractive force to ascending steep grade section, to make locomotives can haul the heavier train to overcome the steep grade by momentum so as to increase the tonnage of the whole district.

When momentum is utilized to overcome the gradient, the train speed at the grade top should not be lower than the calculated locomotive speed and the tonnage for gradient overcome by momentum shall be determined on this basis. The tonnage can be determined by the graphical method. This method is to assume 2-3 tonnage values first, plot the speed-distance curve according to the plane and profile to obtain 2-3 corresponding speeds at top of grade section and the relation curve between the traction tonnage and speed at top of grade can then be drawn, as shown in Fig. 7.5. The corresponding tonnage can be found on the curve according to the speed, i.e., the tonnage for overcoming the gradient at the calculated locomotive speed can be found on the curve. If necessary, it is allowable to reduce the speed at top of grade appropriately which should generally not be lower than 15-20 km/h.

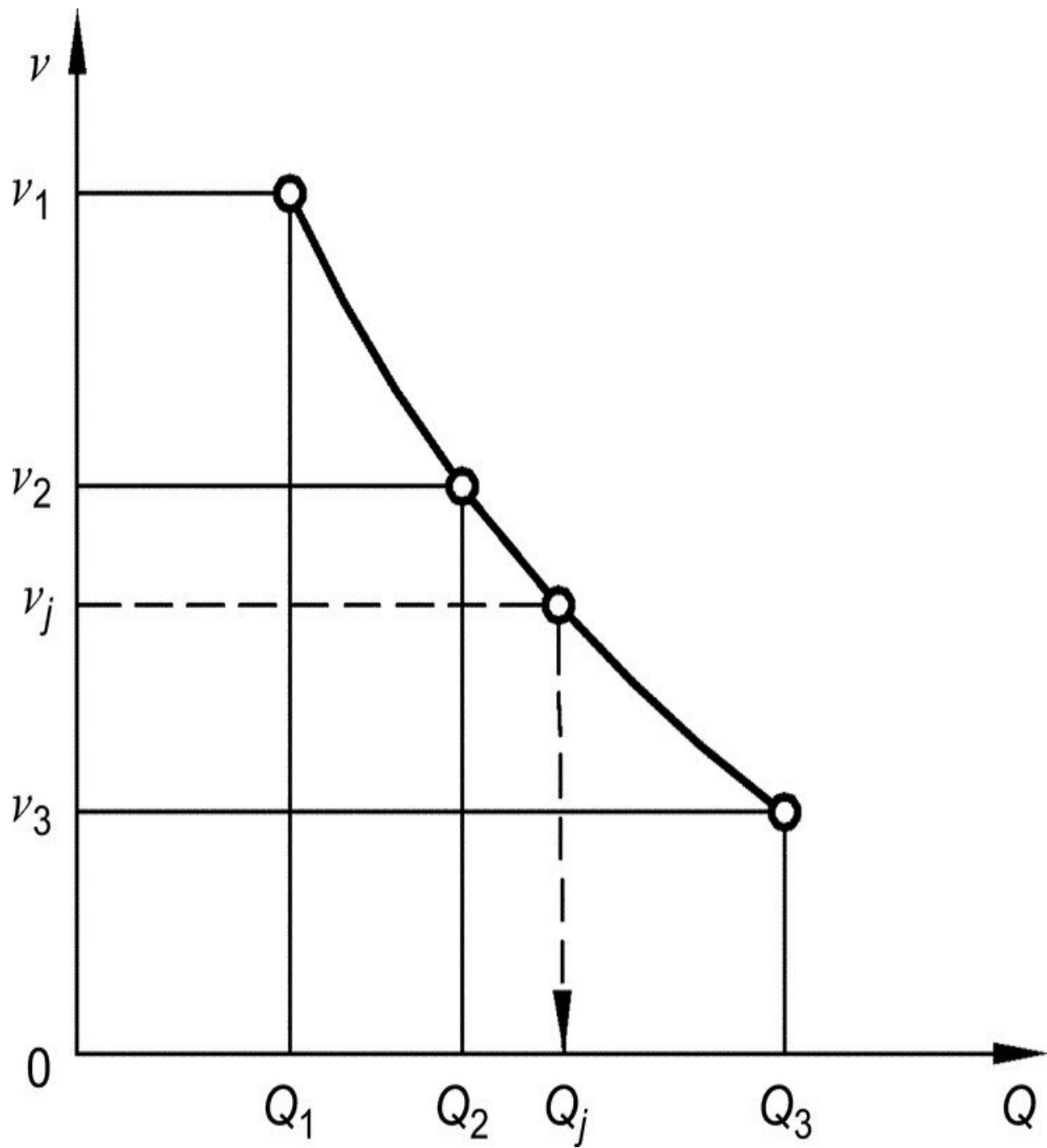


Fig. 7.5 Relating curve between Tonnage and speed at top of grade.

2. Adopting assisting locomotives

When the tonnage is restricted by a steep grade near the station in the district and the train cannot ascend to the summit of the steep grade section by utilizing the train momentum, the assisting (banking) locomotives can be adopted to increase the tonnage and running speed. The banking locomotive is attached to the train rear to the next station and then is attached to the opposite train to return to the banking locomotive station; the assisting locomotive can also be used to push the train to the summit of steep grade and is then uncoupled for retracing in the section.

A pusher operation with banking locomotive can be employed in the single-track line and double-track nonautomatic block district. The carrying capacity shall be calculated in accordance with the organization of train operation and the operation mode of banking locomotive.

Fig. 7.6 shows a train working diagram of pusher operation with banking locomotive on single-track section. In this figure, (A) shows pusher operation of banking locomotive in the whole section while (B) and (C) indicates retracing with uncoupling of banking locomotive in the section. The sum of the time of pusher operation and retracing ($t_{BF}+t_{BB}$), is not more than the running time of the ascending train in section, t_F , in (B), while $t_{BF}+t_{BB}>t_F$ in (C). The calculation equation of the carrying capacity of section in Fig. 7.6A-C are Eqs. (7.9)-(7.11), respectively.

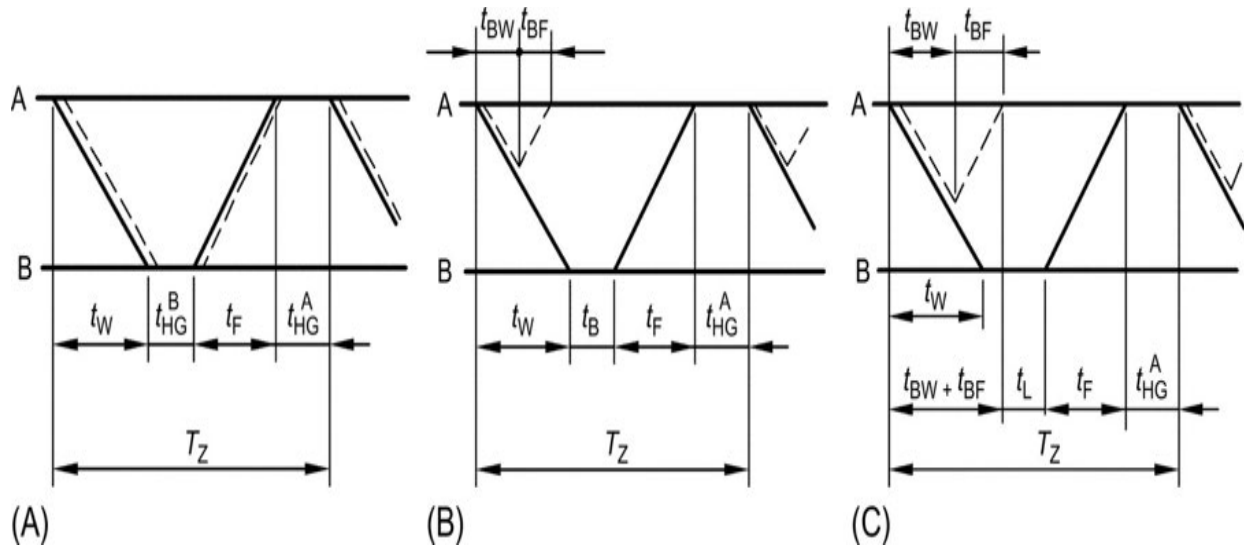


Fig. 7.6 Train working diagram with pusher operation of banking locomotive in single-track line.

$$N = \frac{1440 - T_{CMW}}{T_P} = \frac{1440 - T_{CMW}}{t_F + t_B + t_{CA}^A + t_{CA}^B} \quad (\text{pairs/d})$$

(7.9)

$$N = \frac{1440 - T_{CMW}}{T_P} = \frac{1440 - T_{CMW}}{t_F + t_B + t_{OB} + t_{CA}^A} \quad (\text{pairs/d})$$

(7.10)

$$N = \frac{1440 - T_{CMW}}{T_P} = \frac{1440 - T_{CMW}}{(t_{BF} + t_{BB}) + t_B + t_S + t_{CA}^A} \quad (\text{pairs/d})$$

(7.11)

where (t_{CAA} , t_{CAB}) is the operating time for change and attachment of assisting locomotive at Stations A and B (min); t_{OB} is the time interval for operations at Station B (min); and t_S is the time interval for two trains dispatching in successive in the same direction (min).

7.1.1.6 Operation of Helper Grades

The simplest helper grade operation is that of an engine spotted in a pocket track at the foot of the helper grade. When a tonnage train arrives, the helper couples on behind. After pushing the train over the crest of the grade, the helper cuts off, and drops back to the foot of the grade to await another train. If traffic is heavy or the grade is long, more than one helper may be necessary. Passing sidings or even an entire second main may be necessary to aid the helper in returning or to avoid delay of passenger and dispatch trains. The operation is further complicated and delay introduced when the helper engines are placed in front to double-head or are cut in between the train and the caboose (as required by law and the safety rules of the railroad). A relatively long delay may be occasioned both at the base and at the summit of the grade. Excessive delays occur when helpers must also be cut into the middle of the train.

7.1.1.7 Running of Combined Train and Development of Heavy Haul

Traffic

This measure combined two freight trains into one to operate. The combined train occupies only one train path on the train working diagram while the tonnage is doubled, so aim of increasing the transport capacity can be achieved.

The running of combined trains is a measure of small investment, rapid effectiveness, and good benefits to enhance the transport capacity. But it shall be employed in accordance with the different technical conditions and traffic flow conditions of various districts as well as the influence of this measure on the carrying capacity.

For the running of combined trains, the effective length of one arrival-departure track at the origin and terminal stations (district station or marshaling station) shall be doubled for coupling of combined train before departure and for uncoupling after arrived; it is unnecessary to extend the station track for general stations where ordinary trains will wait on the siding to enable the combined train to pass on the main line. One arrival-departure track of a small quantity of stations in the district can be extended for dwell of combined train at the time when a fast passenger train meets and overtakes the combined train;

For the single-track line, the extended station track can also be used for meeting of combined trains in both directions.

7.1.2 Measures for Advancing Traction Power, Signaling, Interlocking, and

Block Equipment

7.1.2.1 Increasing Traction Power

An increase of the traction power can raise not only the tonnage but also the running speed, thus increases the carrying capacity correspondingly. After the tonnage is raised, the effective length of the arrival-departure track of the station shall also be extended correspondingly.

1. Adoption of multiple locomotive traction

In a district, when the tonnage is restricted by the continuous steep grades in several consecutive sections, multilocomotive traction may be applied in the whole district. In this way, the tonnage of the whole district can be determined according to the tonnage of the section of easy grade in other single-locomotive traction sections so that the tonnage of the whole district can be raised.

The locomotive tractive effort is often redundant in the multilocomotive traction section, which can be used to increase the running speed. If the sections which restricted the carrying capacity are located in the pusher grade section, the carrying capacity of the whole district can also be increased correspondingly. At the origin and terminal stations for multilocomotive traction, the time interval for station operation shall be increased due to detaching and attaching of banking locomotive, so this will probably reduce the carrying capacity of the start section and end section for multilocomotive traction, to which attention shall be paid, and corresponding measures shall be taken according to the

specific conditions. Servicing equipment for banking locomotive shall be provided for the origin or terminal station of multilocomotive traction district; it is likely to use stations with locomotive facilities as origin and terminal stations for multilocomotive traction. The effective length of the arrival-departure track of the station in the section for multilocomotive traction shall be extended by the length of a locomotive compared with the specified effective length.

2. Adoption of more powerful locomotives of the existing type of traction

Using a higher power locomotive in the whole line or in individual district can increase not only the tonnage but also the train running speed and reduce the period in the train working diagram of limiting section, thus increasing the carrying capacity of railway line. Compared with the effect of use of multilocomotive traction, use of high-power locomotive can not only achieve the same purpose but also save required locomotives and the locomotive crews.

3. Adoption of electric or diesel traction

With great tractive effort, high speed as well as good starting and braking performances, the electric and diesel locomotives can considerably increase the tonnage, running speed, and transport capacity.

After serviced once, the electric and diesel locomotives can run a very long distance without the necessity of water supply or coal feed midway. Thus, using electric and diesel locomotives may greatly extend the routing distance, increase the locomotive operation efficiency along with the district speed and reduce the number of locomotive depots; moreover, the crew has good working conditions. As a result, super-long routing of locomotive crew looping system is

often employed in use of electric or diesel traction and the routing distance can be extended to more than 300 km.

To increase the tonnage by using electric or diesel traction requires to extending the effective length of arrival-departure track, reconstructing the existing locomotive facilities, dismantling unnecessary water supply and turning equipment. Electric traction also necessitates the construction of power supply equipment and the existing communication line also needs reconstruction due to interference of alternating current of power supply system. For the increasing of the height of construction clearance, it is likely to lead to reconstruction of tunnel, bridge and over-bridge.

Since maximum horsepower is available at low and high speeds, the electric locomotive accelerates rapidly. This is of great importance in increasing track capacity and maintaining faster schedules, especially in suburban and rapid transit service, where many stops are required but where a fast overall schedule is also desired.

Electrics may be designed for higher adhesion coefficients (0.20–0.25) through the rotation delivery of torque to the driving wheels and better weight transfer due to tractive effort with modern truck design. Although a single electric unit can contain more horsepower than an equivalent unit of any other type, still greater power is available through the multiple operation of several units that can be controlled from one cab without additional crews. Electric locomotives offer the advantage of regenerative braking. On descending grades, the motors may be operated in reverse to generate current and feed it back to the line. The motors, when regenerating, exert a "drag" on the locomotive that, if skillfully utilized, permits control of the train with little or no application of the air brakes. There is a saving in power

consumption, and it can lead to greater speed ascending grades, can reduce costs of brake shoes and equipment, and a reduction in thermally cracked wheels and train delays due to overheated wheels or sticking brakes. Additional advantageous features of electric operation include greater availability and the elimination of smoke, soot, and cinders and of fuel and ash facilities. The use of a central station power supply permits flexibility in the type of fuel used for the prime mover.

7.1.2.2 Reconstruct the Signaling, Interlocking, and Block Equipment

Improvement of the signaling, interlocking, and block facilities is an important measure to ensure the traffic safety, to increase the carrying capacity and to ameliorate the transportation indices. Use of improved signaling, interlocking, and block devices can reduce the operation time of train meeting and overtaking at the station so as to increase the carrying capacity. After the time interval between two adjacent trains at the station is reduced, the district speed can also be increased correspondingly, the turnover speed can then be upgraded and the transport cost is reduced.

Using the electric staff system, the through train shall complete the staff handover at the station and pass through the station with a speed less than 40 km/h, which can be increased to 60 km/h if a staff exchanger is provided. As the station operator has to finish the train reception and departure, handle the block formalities and deliver the staff to the driver, the electric staff system the train dwell time at

station may be longer. For the electric staff system, the operating time for arrival and departure of a pair of trains at both ends of the section is usually 8–10 min and the carrying capacity is relatively reduced. In reconstruction of an existing railway, the staff block system is generally changed into semiautomatic block, automatic block or centralized traffic control (CTC) instead.

Changing from the electric staff system to the semiautomatic block for a single-track railway can generally increase the carrying capacity by around 10% and use of CTC semiautomatic block can raise the carrying capacity by around 15%. Pure use of automatic block for a single-track railway can increase the carrying capacity by around 25% and further installation of CTC and organization of following train operation can increase the carrying capacity by 35%–40%. However, the quantity of arrival-departure tracks of the station shall be increased correspondingly and the train district speed reduced.

With use of automatic block for a double-track railway and the time interval between trains spaced by automatic block signals to be 8–10 min, the carrying capacity of parallel train working diagram can reach 140–180 pairs/d and the carrying capacity in use of semiautomatic block can only reach 70–90 pairs/d. As a result, automatic block shall be employed for double-track railways as far as possible while semiautomatic block can be adopted only when the traffic volume grows slowly or automatic block is unsuitable due to restraints of line conditions.

7.1.3 Measures for Reconstruction of Engineering Facilities

From the present conditions of China's railway, the commonly-used measures for reconstruction engineering facilities include extension of station tracks, stations and block posts, reduction of over-ruling grade or mitigation of ruling grade, addition of the second line or multiple lines, etc. These measures are used to increase the railway transport capacity from the aspects of heightening the train quality, increasing the train operation density and upgrading the running speed. Certain measure or combination of several measures can be taken in accordance with the specific conditions.

7.1.3.1 Build Out or Shut Down Crossing Stations or Block Posts

1. Construct new crossing stations or block posts

Under the circumstance of unbalanced carrying capacities of various sections of an existing single-track railway, it can be taken into consideration to build out crossing stations in these control sections to reduce the running time and increase the carrying capacity, if only the distances of a few control sections are long enough, terrain is more gentle in the middle of sections, to build out crossing station would not lead to huge works. This measure generally need a small investment cost but produces conspicuous effects.

It should be note that the distance between stations could not be too short after adding stations. The minimum distance between stations shall be calculated and determined

according to the operating time required for handling train block at two stations, as shown in Fig. 7.7.

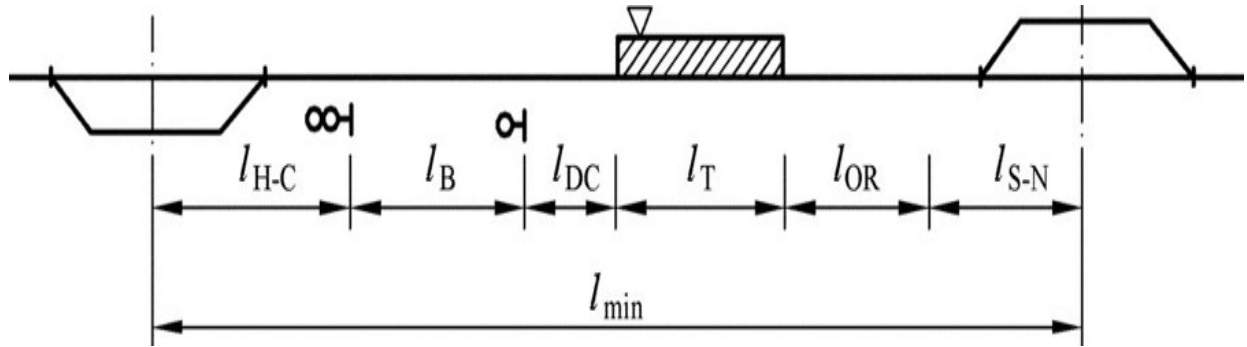


Fig. 7.7 Minimum distance between stations.

$$l_{\min} = \frac{1000}{600} \times [V_{S-N}t_{S-N} + V_A(t_{OR} + t_{DC})] + l_T + l_B + l_{H-C}$$

(7.12)

where t_{S-N} = time required for supervising the train departure and notifying the adjacent station of train departure (min); V_{S-N} is the average train running speed within t_{S-N} (km/h); V_A is the average train running speed within the section (km/h); t_{OR} is the operating time for handling the receiving route and signal at the station (min); t_{DC} is the time for the driver to confirm the signal indication (min); l_T is the train length (m); l_B is the braking distance (m); and l_{H-C} is the distance from the home signal to the central line of station (m).

According to conditions such as running speed, train length, braking distance, and block mode in China, the minimum distance between stations should not be less than 6 km in general.

In the district where automatic block is not installed, if it is difficult to construct a station in the control section, block post can be added between two stations to organize trains dispatching in successive in the same direction so as to increase the carrying capacity. In the single-track railway with pusher operation, a block post as an auxiliary for pusher operation can usually also be added to reduce or to eliminate the impact of retracing of banking locomotive on the carrying capacity.

The provision of a block post in the single-track railway will extend the meeting time of two opposing trains, consequently reducing the traveling speed; moreover, the carrying capacity will often be limited by other sections after the block post is open. As a result, this measure could be taken only when it is inconvenient to add a passing station due to topographical conditions and in the single-track district with obviously unbalanced traffic volumes in the up and down directions.

2. Shut down stations

It is preferable to shut down stations with a small handling volume under the circumstance of permission of carrying capacity for reconstruction of an existing line or addition of a second line.

On a speed-up line, increase in the train speed reduces the running time between two stations. When the time of train running between two stations cannot meet the requirements of Eq. (7.12), it is necessary to close some passing and

overtaking stations which deal with train meeting and overtaking operations only.

7.1.3.2 Lengthening the Effective Length of Arrival-Departure Track

The purposes of increasing the traction power and reducing the maximum gradient are both to raise the tonnage and extend the train length. When the arrival-departure track of the existing station is insufficient to stop the lengthened trains, it shall be extended as required. The required effective length of the arrival-departure track, L_{ad} , shall be calculated according to the following equation depending on whether the caboose is canceled.

With caboose (guard's van)

$$L_{ad} = \frac{G - w_{cab}}{w_{ag}} + n \times l_{LCO} + l_{cab} + 30 \text{ (m)}$$

(7.13)

Without caboose (guard's van)

(7.14)

where G is the tonnage of freight train (t); w_{cab} , l_{cab} is the mass (t) and length (m) of caboose, $w_{cab}=16$ t and $l_{cab}=8.8$ m for four-axle caboose; q is the mass of freight train per linear meter (t/m); n is the number of traction locomotives of freight train; $ILCO$ is the locomotive length (m); and 30 is the safety distance for train stopping (m).

To implement the extension of the effective length of arrival-departure track, it is necessary to move the positions of signals, relaying out interlocking equipment and turnouts at throat correspondingly. The corresponding extension of station site will also cause reconstruction of subgrade, retaining walls, bridges and culverts in the extension part. If the grade section leading to station is steeper, as the gradient of station site is small, it will probably cause route developing with huge engineering works. Under special difficult conditions and with a full basis, the throat of reconstructed station can be located on a slope with a gradient less than the ruling grade or dual locomotive traction grade, but the maximum gradient should be less than 4‰ for district stations and less than 15‰ for passing, overtaking and intermediate stations.

After the tonnage of freight train is increased, it is necessary to extend not only the effective length of arrival-departure tracks of intermediate and district stations along the line but also the effective length of tracks of receiving yards, classification yards and departure yards of marshalling stations. Extension of the effective length of marshalling station track often involves very large quantities of arduous demolition and relocation works. Therefore, efforts shall be made to aggressively develop large-sized freight cars and shortened freight cars and increase the mass of freight car per linear meter so as to relieve the pressure of extension of the effective length of station track. If the effective length of design-selected station track restricts the tonnage, the train

shall be subject to under-loaded operation and the surplus tractive power can be used to increase the running speed.

When it is necessary to reconstruct the existing station due to extension of the effective length of arrival-departure track or for other reasons, the curve radius and grade of the main line of station site can be lower than those of the new line to keep the present conditions.

7.1.3.3 Rebuild Grade Sections With Over-Of-Ruling Grade and Reducing the Ruling Grade

In order to increase the tonnage or unify the tonnage rating of the whole line, the maximum grade may be reduced when reconstruct the existing line. However, reduction of grade means relocation of the line, which often causes large quantities of abandoned works, huge investments, operation interference and occupation of farmlands. So the reconstruction design of the existing line shall increase the tonnage with traction power, shall avoid reduction of grade for relocation of the line as possible in order to save the reconstruction investment, to accelerate the reconstruction progress and to reduce the operation interference.

The ruling grade of the existing line shall generally not be changed and it is unnecessary to unify the ruling grade of long trunk line. For the unification of the tonnage rating should be realized by locomotives with different powers. The dual locomotive grade of the existing line shall generally be retained and the grade reduction scheme should not be

employed randomly; after the change of type of traction, the specified tonnage can be realized by dual locomotive traction or by higher-power single or dual locomotive traction, as the case may be.

After addition of the second line, the carrying capacity can be increased considerably and can be 3-4 times that of the existing line even with the same locomotive. The existing line retained steep grade can be used as train path of double track in the descending grade direction and would not restrict the tonnage; if necessary, the kind of traction can also be changed to increase the transport capacity further. As a result, it is generally unnecessary to reduce the maximum grade of the existing line. If only a few short steep grade sections have gradients exceeding ruling grade and restrict the increase of tonnage, and to reconstruct them by reducing the over-ruling grade would not cause huge engineering works, this measure may be used to increase the tonnage. Some corresponding measures can be taken to reduce the over-ruling grade in accordance with the specific conditions of reconstruction sections, such as constructing another segment of new line to reduce the over-ruling grade by route developing; build tunnel to replace subgrade with deep cutting at the summit of convex profile to low the grade climbing height; or the descent height can be decreased by replacement of fill with viaduct at the toe of slope of concave profile. The first reconstruction mode causes a little interference to the operation of existing line but necessitates increase of the line length; the latter two reconstruction modes cause great interferences to the operation of existing line but they can reduce the operating cost to some degree for their ability to reduce the overcome height but not to increase the line length.

Since the past reduction data and methods of maximum grade are different from the current Code for Design of

Railway Line, the resultant exceeding value of over-ruling grade is not great in general. It is allowable to keep the original design standards and not to reconstruct the existing line if reduction of the grade according to the current provisions will lead to huge works. In variation of the ruling grade of existing line or change to dual locomotive traction grade, the algebraic difference of the grade of adjacent grade sections should not be more than the allowable value of reconstructed grade difference; however, with sufficient basis, it is also allowable to keep the original algebraic difference of grade and not to reconstruct the existing line.

7.1.3.4 Constructing the Second Line and Relevant Transitional Measures

Construction of the second line is the most effective yet high-cost measure for railway capacity improvement. For the existing line with slow volume growth, staged improvement measures such as extending the station track towards the control section or building out the second line in the control section shall be adapted, so as to improve the carrying capacity of the whole district before building double track on the whole line. In this way, not only the recent volume growth can be handled and the initial investment can be saved, but also the initial built-out project can be fully used instead of being abandoned when building the second line.

1. Extending station tracks towards the limiting section

When a limiting section is appeared due to the unbalanced operating time of various sections in an existing line and build out station in limiting section is not allowable, the

station sidings can be extended towards the limiting section, so as to improve the carrying capacity by shortening the period of train working diagram of the control section.

Fig. 7.8 shows a schematic diagram of extending station sidings which shortens the limiting section's period of train working diagram by an asynchronous time t_A . The dotted line marked as (1001) is the train path of the 1001st train after station track extension. According to the moved paths of the 1001st and the 1002nd trains, the length of the station track extension IEX can be preliminarily determined.



2. Constructing a partial second track connected with one or both ends of the station for facilitating nonstop meets of trains

If two adjacent sections of an existing station are limiting sections with limited carrying capacity, the station tracks of the station can be extended towards the two ends of the section, so as to facilitate the nonstop meets of trains. See Fig. 7.9 for the details.

The possibility of delay shall be considered when building partial second track and organizing nonstop meeting of trains. A schematic diagram for length calculation of the left station track while taking the possibility of delay of the down train into consideration is shown in Fig. 7.10. An up train and a down train will meet each other at the theoretical meeting central line when operating on schedule. Assuming the down train delays t_{delay} (min), it will reach point P' when the up train reaches the theoretical meeting central line N' , and the distance between the theoretical meeting central line and point P' will be L_{down} . When the tail of the down train enters the double track section and the center of the train reaches point P , the up train will reach point N . At this time, the distance between the head of the up train and the starting signal shall be the sum of the following values: the operating distance of the up train in the access time t_{Pre} which is calculated by the length of the double track section shown in Fig. 7.10, the operating distance of the up train in the signal time t_{DC} which is confirmed by the driver, and a braking distance of S_{bs} (m). Accordingly, the distance between the theoretical central line of meeting and the starting signal, L_{down} (m), can be calculated by the following equation:

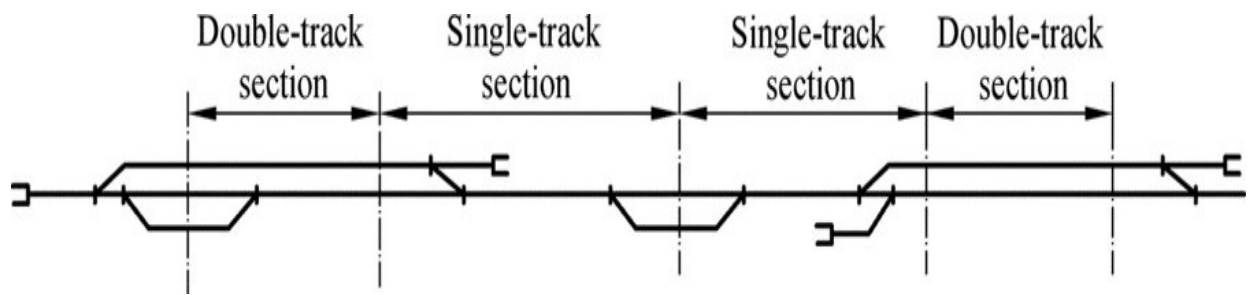


Fig. 7.9 Schematic diagram of partial second track.

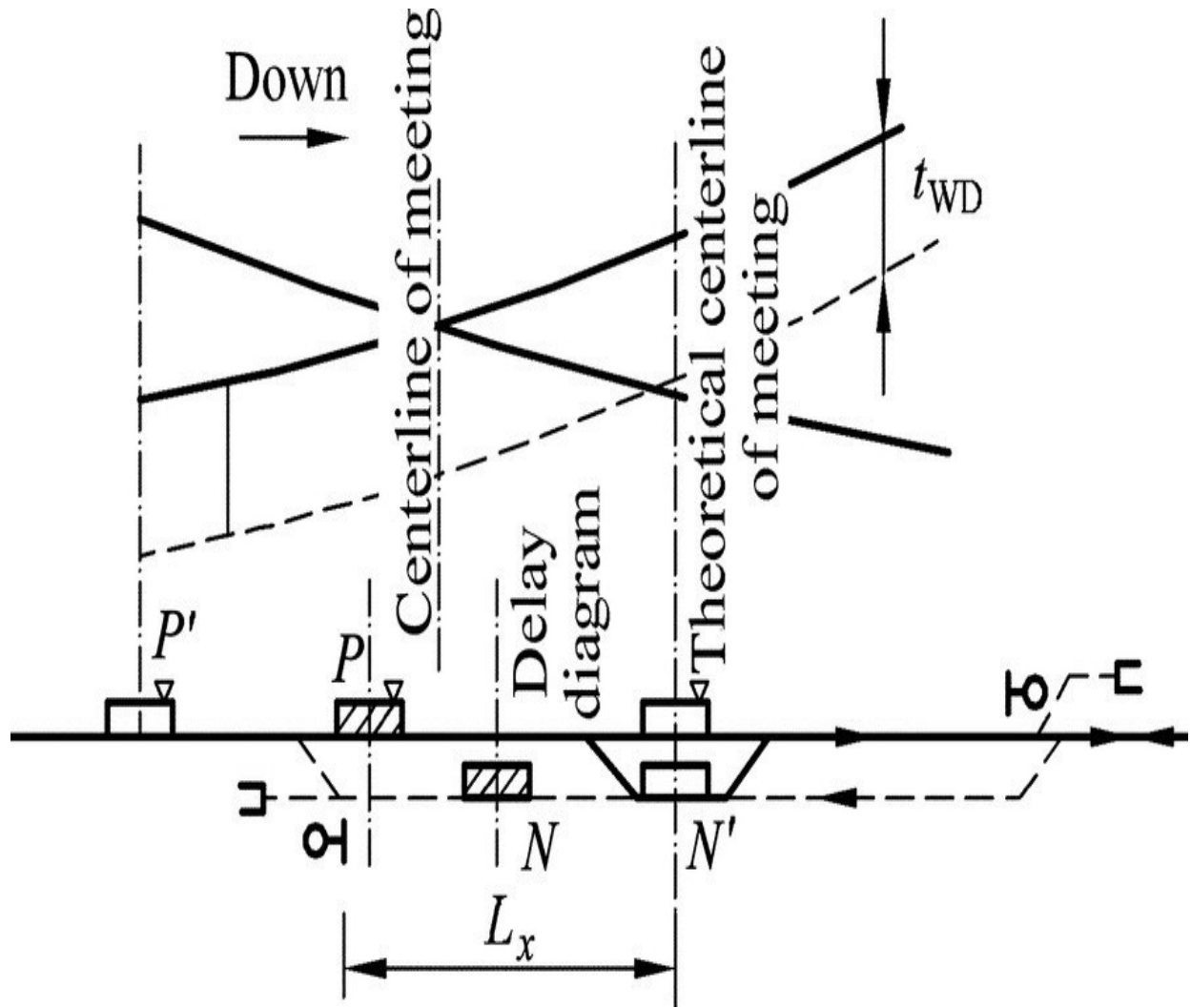


Fig. 7.10 Schematic diagram of length calculation of partial second track.

$$L_{\text{DOWN}} = NN' + \frac{L_T}{2} + 16.7(t_{\text{Pre}} + t_{\text{DC}}) \times V_{\text{up}} + S_{\text{bs}} NN' = 16.7V_{\text{up}} \times t_{NN'}^{\text{up}}, (t_{NN'}^{\text{up}} = t_{PP'}^{\text{down}})$$

$$t_{PP'}^{\text{down}} = t_{\text{delay}} - \frac{L_{\text{signal}} - \frac{L_T}{2}}{16.7V_{\text{down}}}$$

where are the operating time of the up and down trains at section N'N and section P'P, respectively, the values of which are equal.

As shown in Eq. (7.15), the value of Ldown (m) can be obtained by solving the above simultaneous equations. As shown in Eq. (7.16), when up train delays, the length of the right side station track Lup (m) can be calculated through the same method mentioned above. The total length of the double track interpolation L is the sum of Ldown and Lup (m).

$$L_{DOWN} = \frac{16.7(t_{\text{delay}} + t_{\text{Pre}} + t_{\text{DC}}) \times V_{\text{up}} \times V_{\text{down}}}{V_{\text{down}} + V_{\text{up}}} + \frac{S_{\text{b-up}} \times V_{\text{down}}}{V_{\text{down}} + V_{\text{up}}} + \frac{L_T}{2} \text{ (m)}$$

(7.15)

$$L_{UP} = \frac{16.7(t_{\text{delay}} + t_{\text{Pre}} + t_{\text{DC}}) \times V_{\text{up}} \times V_{\text{down}}}{V_{\text{down}} + V_{\text{up}}} + \frac{S_{\text{b-down}} \times V_{\text{up}}}{V_{\text{down}} + V_{\text{up}}} + \frac{L_T}{2} \text{ (m)}$$

(7.16)

(7.17)

where Vup, Vdown is the average speed of the up and down trains at the calculating section (km/h) (This can be determined through calculation. The speed of the train passing through the main line is unlimited, and the speed of the train passing through the side track is limited by the

turnout through speed); t_{delay} is the delay time of the train, which is taken as 1.5 min for plain areas and 2.0 min for hilly areas; t_{Pre} is the access preparation time for turnout shifting and signal clearing, which is taken as 0–0.1 min for CTC and 0.1 min for automatic block and electric interlocking; t_{DC} is the signal time confirmed by driver, which can be taken as 0.2 min; $S_{\text{b-up}}$, $S_{\text{b-down}}$ is the braking distance of the up and down trains, which is generally taken as 800 m when the speed is not more than 120 km/h; and LT is the length of the freight train (m).

Attention shall be paid to the following issues when designing double track interpolation:

(1) To ensure the stopped train can start smoothly before the starting signal and starting signal has good observation conditions.

(2) The turnouts connecting the main line shall be set on straight tracks. No. 18 turnouts are preferred, so as to avoid serious limitation on the running speed of train when entering and exiting side tracks.

(3) Catch siding shall be set at the connecting point between the extended station track and the main line, so as to separate the entering route and exiting route and to ensure the operation safety.

(4) If the operation time of the sections adjacent station differs a lot, the theoretical centerline of meeting can be moved towards the limiting section. The length and location of the partial second track segment can be determined according to the new meeting central line.

3. Constructing a second track in the limiting sections of the district

After constructing the second line in the limiting section, the carrying capacity can be improved by organizing nonstop meeting at this partial second track section. Meanwhile, it can also be used as a transition measure before realizing double track of the whole line.

This measure is generally appropriate for the following conditions:

- ① The limiting section has sustained steep slopes where building out new stations or extending station tracks is hard to be realized.
- ② The length of single track is less than 3 km after extending the station track towards the section;
- ③ The grade of the limiting section is steep and long, which not only limit the carrying capacity, but also restrict the tractive tonnage. (The existing line can be used as the downwards operating line and the second line with mild gradient can be used as the upwards operating line. Therefore, both the carrying capacity and the tonnage can be increased.)

4. Constructing the second line

For an existing line with rapid volume growth, the construction period of the second line could only be delayed slightly if adopting interim measures to strengthen railway capacity. Therefore, in order to reduce the interference on normal operation by constructing frequently, it is reasonable to build the second line covering the whole line at a time.

In comparison with the single track, in double track with automatic block, the carrying capacity may increase 3-4 times, district speed increases 30%, and operating costs may reduce 20%.

7.1.3.5 Improvement and Strengthen of Railway Crossing

With the development of highway transportation, the increase of agricultural machinery and the increase of railway traffic volume, it may be required to reconstruct the existing crossings of the existing line. The crossing should be reconstructed and crossing facilities should be improved together with the reconstruction of the horizontal and vertical alignments of the line based on relevant regulations on road intersection, such as to build flyover, improve alarming device and automatic operated barrier, so as to ensure the safety.

For lines with a design speed of 160 km/h or over, the whole line shall be reconstructed into a fully enclosed and flyover line. Level crossings at district with a design speed less than 160 km/h and higher than 120 km/h shall be reconstructed into a flyover. If it is difficult to build out an automatic crossing without watchman into a flyover, it should be changed as crossing with watchman. For crossing with watchman which hasn't been reconstructed into a flyover yet, the alarming distance of its crossing signals and automatic control equipment shall be extended, and obstruction signal, wireless alarming and antibreak equipment shall be installed.

Flyovers changed from level crossing and new bridges and culverts should be built in segments with high embankment or deep cutting.

7.1.3.6 Strengthen Track Structure

Due to the volume growth of existing lines and the weaker structures of existing tracks, the maintenance workload is increased, and the overhauling cycle is shortened so as to disturb normal operation. When strengthening an existing line, relevant track (see Table 7.1) shall be selected according to the annual total carrying mass and maximum running speed of the line while in combination with the condition of line reconstruction.

Table 7.1

Type of Track for Main Line



Continuously welded rail shall be laid out for class I railway. For 200 km/h speed-up line, 60 kg/m quenched rail or micro alloy rail shall be used and over-section continuously welded rail shall be paved.

7.1.4 Construction of the Third, the Fourth and the Diverting Lines

For double-track railway for both passenger and freight transportation, the absolute traffic volume can reach around 120 pairs. However, with the growth of passenger and freight volume, the unit operation expense will increase dramatically as well. When the traffic volume of passenger train reaches 30-50 pairs and the most favorable traffic volume of the double track exceeds 95-110 pairs, construction of a diverting line or building up the third and fourth lines shall be considered.

7.1.5 Overall Design for Strengthening the Existing Line

The overall planning for existing line enhancement shall be carried out according to the characteristics of the passenger and freight volume growth and the condition of the

engineering, equipment, and topography along the existing line. Staged enhancement schemes shall be determined by making the best use of the existing facilities according to the local conditions and adopting comprehensive measures, so as to achieve aims of small investment, large carrying capacity and high economic benefit.

7.1.5.1 Work Contents of Overall Design

The major work of overall design includes coordinating the comprehensive transport capacities of existing lines and the plan staging enhancement measures.

The comprehensive transport capacities of existing lines means the coordination between station capacity and section capacity. In order to increase the transport capacities of existing lines, it is necessary not only to improve line technical conditions so as to increase the tonnages and carrying capacities, but also to strengthen other facilities to coordinate the capacities enhancement. Facilities should be strengthen include the quantity of tracks and effective length of sidings at intermediate stations, the power supply facilities of electric traction, the checking and repairing capacity of related locomotive depot, the uncoupling capacity of related marshaling station, the construction of connecting line at the junction between the existing line and other railways, and the extension of terminals. Sometimes the capacity of adjacent railway could become a new limiting factor after strengthening existing lines.

Step-up enhancement measures shall be planned under the guidance of the overall planning. On one hand, the transport capacity shall be increased step by step so as to match the growth of volume. The existing line should not be strengthened to much to cause in excessive carrying capacity, idle facilities and investment cost waste. On the other hand, the enhancement measures of each stage shall coordinate with each other, so that the existing engineering equipment can be used completely without causing new abandoned construction work.

7.1.5.2 Rules of Overall Design

The overall design should manage to use the existing project and buildings as much as possible, Increase the transport capacity by using new mode of transportation and advanced technical equipment. Try to avoid reconstruction of civil work, avoid large-scaled demolishing, reconstructing and abandoning of existing project. Attention shall be paid to the following matters:

1. Rules for selecting strengthen measure

Firstly, innovative and potential-digging methods for transportation organization shall be adopted. These include running combined freight trains, expanding passenger train formation, adopting pusher locomotive traction, special operation mode and so on. During the transition period of reconstruction engineering, potential transportation organization shall be carried out instead of being restrained by traditional mode of transportation, so that the transportation task can be fulfilled. Secondly, to enhance the

transportation equipment which includes the upgrading of signals, interlocks and block system, adopting modern traction power, building out new station and block post and so on. Priority shall be given to such strengthening methods due to its cost effective, quick effect and less interference.

Due to great investment cost and serious interference in operation, reconstruction of civil work, including grade reduction and rerouting, building out the second line and so on, shall be adopted only when necessary.

2. Rules for planning strengthen scale

For existing line enhancement, priority shall be given to those weak parts which restrict the capacity. Electrification renovation shall only be applied to the updating or reconstruction of projects which are in relation with capacity improvement. The construction of the second line shall be carried out step by step, so that the improvement of capacity can match the increase of traffic volume. For lines with rapid traffic volume growth, double-track railway should be constructed at a time.

3. Minimizing mutual interference between construction and operation

As the reconstruction of the existing line and the addition of the second line are all carried out during normal operation, the effect on operation by construction is inevitable. For example, blocking sections would cause operations to be interrupted, and speed to reduce; and the carrying capacity will be influenced by engineering transportation. On the other hand, in order to ensure normal transportation and safety operation, normal construction will be influenced inevitably during the reconstruction of existing line. Therefore, the mutual interference between construction and operation shall be fully considered when selecting

enhancement scheme. In the aspect of planning, relevant measures shall be planned and reasonable period of construction shall be determined. In the aspect of construction organization, construction sequence shall be arranged according to the transportation needs, so as to provide favorable conditions for operation as early as possible.

During the reconstructing process of existing line, subgrade cutting (gradient reduction or subgrade defect renovation), bridge and culvert reconstruction, and tunnels and structures construction, temporary line construction and other construction measures maintaining traffic capacity are often adopted to maintain the transportation and operation. Such measures, however, will more or less influence the running speed and transportation capacity, and lead to certain abandoned projects.

7.1.5.3 Diagram of Equipment-To-Traffic-Capacity

In addition to the required traffic volume during its adoption period, certain extra capacity shall also be provided by every selected enhancement measure. The extra capacity shall not be too high, so that early stage investment can be saved. Meanwhile, the enhancement measures of each stage shall be capable of fitting the volume growth for around 5 years, to avoid railway under frequent reconstruction and influencing normal operation.

During the selection of an enhancement measure, a diagram of strengthen measures with traffic capacity shall be drawn,

so that the most appropriate measure can be selected after determining the applicable period of each enhancement measure, studying the feasibility and rationality of their staged application and analyzing their economic effects. A diagram of equipment-to-traffic capacity (see Fig. 7.11) consists of two groups of curves. The first group consists of only one curve which represents the traffic capacity growth of each existing line in each design year. The curve is drawn on the basis of annual freight traffic volume that is obtained from volume prediction, and it rises with the annual increase of freight traffic volume. The second group consists of several curves which represent the expected transport capacity of the line after each enhancement measure is implemented. With the annual growth of passengers train, less-than-carload freight train and pick-up and drop freight train on existing lines, the through transport capacity decreases correspondingly. Therefore, for a same enhancement measure, a downward trend is seen on the transport capacity after its implementation. The intersection points of these two groups of curves represent the years that an enhancement measure is capable of fitting the required volume. The shaded areas represent the capacity of the line in extra traffic volume; such capacity is also called the reserved capacity.

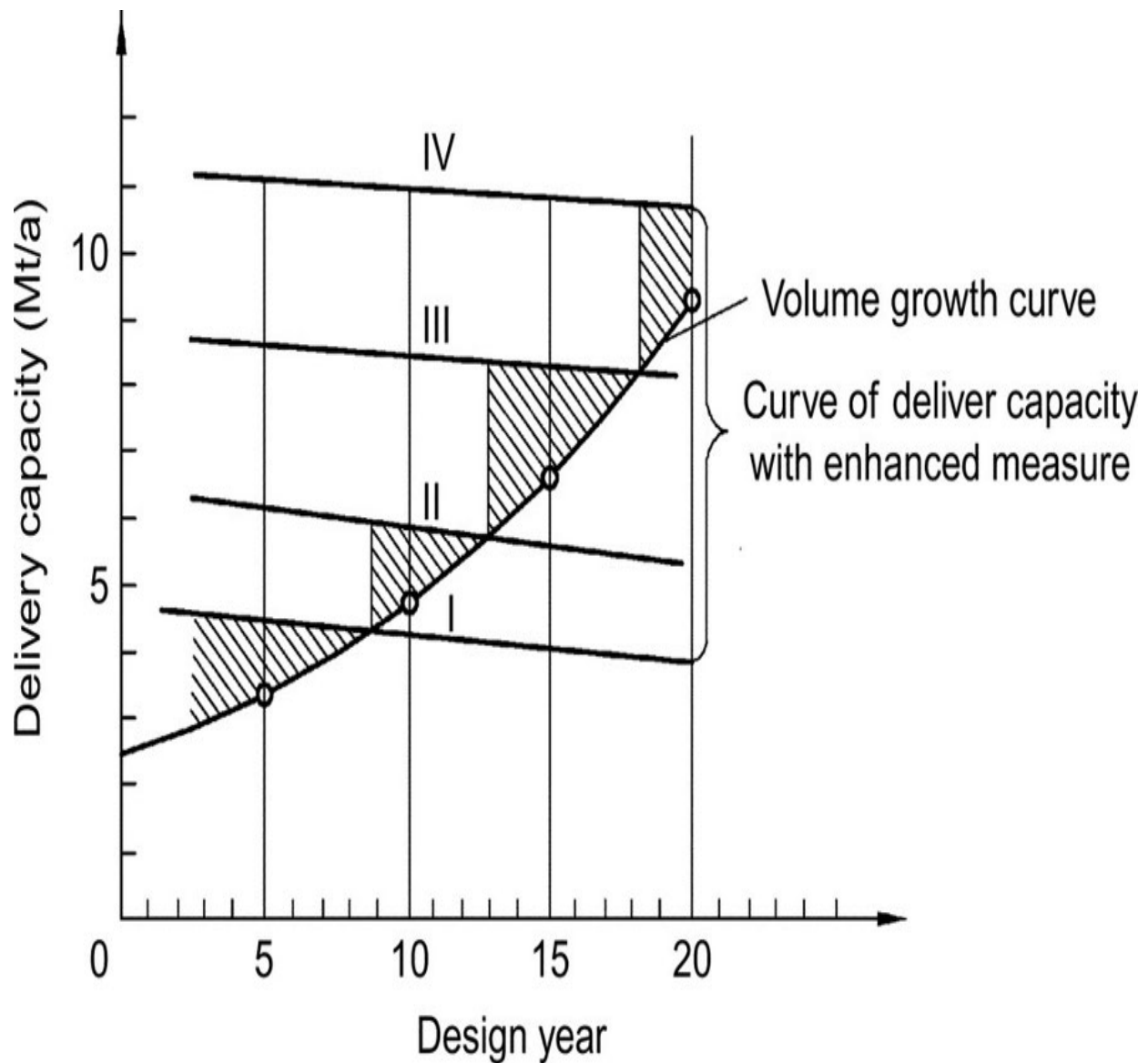


Fig. 7.11 Diagram of equipment-to-traffic capacity.

The reconstruction time in each staged enhancement measure shall be scheduled prior to the saturation year of the railway carrying capacity, so as to mitigate the mutual interference of construction and operation and reduce the cost of construction interference. The time of reconstruction shall be determined according to the difficulty level of the reconstruction project and the speed of traffic volume

growth, so as to ensure the delivery of construction project before capacity saturation. It is generally recommended to carry out construction when the capacity utilization ratio of the line reaches 75%–85%, the capacity utilization ratio between the station and the arrival-departure track reaches around 80% and the resorting capacity utilization ratio of marshaling station reaches 85%–90%.

7.1.5.4 Carrying Capacity Diagram

If the tonnage in each enhancement measure remains the same, a diagram of district carrying capacity can be drawn to indicate the adaptability between the expected carrying capacity of each enhancement measure and the required carrying capacity. The chart of staged and transitional carrying capacity during the construction of the second line is shown in Fig. 7.12. The transitional measures include the construction of new stations, the construction of double track in limiting section, the construction of partial double track with installation of automatic block CTC, and the construction of the second line covering the whole line.

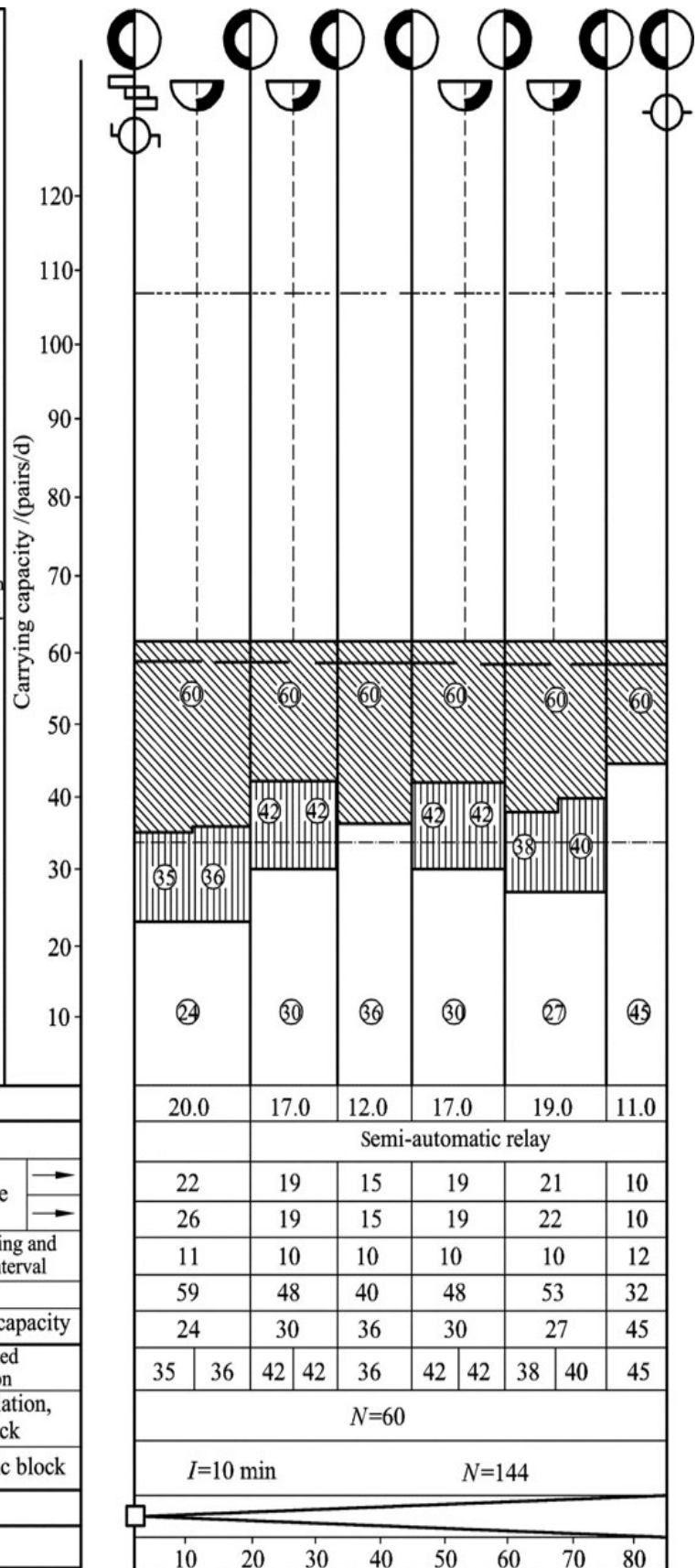
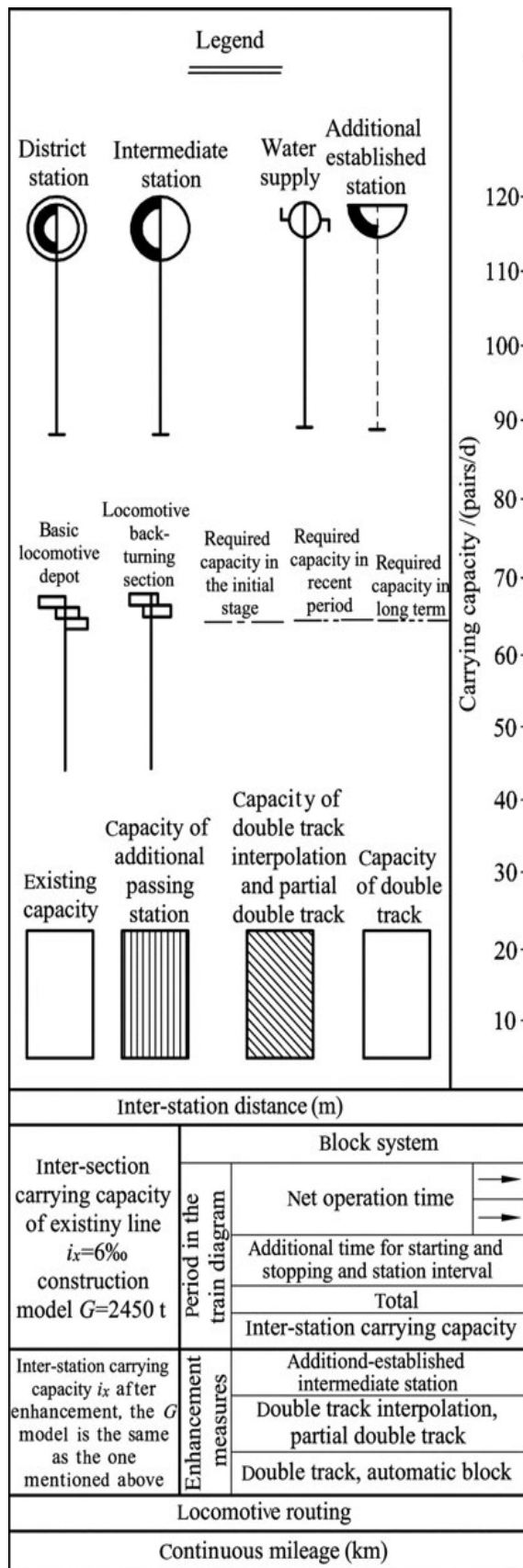


Fig. 7.12 Diagram of carrying capacity.

The required carrying capacity can be calculated by Eq. (7.1).

7.2 Upgrading of Railway Passenger Transport

7.2.1 Overview

Since the railway came into being, the speed of train has been gradually increased in pace with the development of the society and economy and the modernization of technical equipment. Especially after the Second World War, the economy of the developed countries was recovered, and this raised new and higher requirements for the transportation. Since 1950, the development of highway transport and air transport has broken the monopoly position of railway transport; thereby the transport industry was brought into an era of competition. Faced with the competitive transport market, the train speed has to be increased. Since the first high-speed railway in the world—Tokaido Shinkansen in Japan was put into operation in 1964, high-speed railway has shown a tendency of vigorous development with various advantages like fast speed, large transport capacity, safety and comfort, sound comprehensive economic benefits and high scientific and technological content. By Dec. 2008, the total operating mileage of the high-speed railway in the world was up to 7785 km, and the high-speed railway planned to be constructed (excluding Mainland China) was up to 19,500 km.

While building new high-speed railway lines, in order to maximize the advantages of high-speed railway, the developed counties also increased the operating speed of the existing railway lines that were bordered on or extended to the new lines on a large scale, so that high-speed trains can also run on the existing railway and the domestic and international express (including high-speed) or high-speed (including express) passenger train systems can be established and enlarged accordingly.

Not only can the speed-up of passenger trains shorten the travel time, but also increase the throughput, and speed up the rolling stock turnover and reduce the number of trainmen. For freight transport, the speedup can greatly accelerate the goods delivery; for passengers transport, it can shorten the spatial distance between city and county, and save the travel time. On the other hand, the railway upgrade can ease the transport capacity tension over a long time, and accelerate the development of national economy and promote the rational distribution of productivity. This is helpful for the adjustment of industrial structure. In addition, the increased railway speed can also bring vitality to the tourism and meet the increasing demands of the people's living.

The railway is the main force for transportation industry in China and the trunk line of national economy. The shortage of transport capacity has brought the railway in a state of tension for a long time. There has never been waste in the railway transport market; therefore, there was not any reform motivation in the operating mechanism, and the operating speed of the trains has not been increased for a long time. In 1995, the average travel speed of passenger trains and freight trains were 49.0 and 30.2 km/h, respectively. The maximum speed of the passenger train was less than 120 km/h, lagging far behind the international level. From the middle of 1990, with the construction of high-class highway and the development of air transport, significant changes have taken place in the transport market in China. The proportion of passenger and freight transport volume by railway was reduced year by year, resulting in that in some areas and railway lines, an oversupply

situation emerged in the railway transport, i.e., a buyer's market emerged, and the railway transport lost some market shares in competition. There are many reasons contributed to this situation; however, the transport speed is the basic factor.

Since the end of the 20th century, in China, great efforts have been exerted to increase the passenger transport speed to cope with the transport market competition and mainly to meet the demands for railway transportation in the national economy development. After large-scale speed upgrading for six times, Chinese railway has mastered the comprehensive technologies in transportation equipment, tracks, communication, signal and operation management for the speed levels of 160 and 200 km/h, and the speed upgrading railway lines have covered more than 16,000 km. Our existing railway speedup technology has reached the world advanced level.

7.2.2 Targeted Speed of Passenger Trains and Implementation Scheme for Speeding Up

7.2.2.1 Targeted Speed Speeding Up of Passenger Trains

Train speed is an important indicator for evaluating the railway level, and it is usually represented by the maximum speed and travel speed.

The maximum speed is an indicator for the development of passenger trains; it is decided by the level of locomotive power, design speed of rolling stock, brake performance, structure in railway line, turnout and signal device, etc. Not only is it the basis for upgrading the existing railway lines and equipment and for establishing the technical standards for new railway lines construction, but also a general indicator for the consistence between the equipment and transportation organizations.

The travel speed of railway passenger/freight trains (including the station dwelling time and additional time for starting and stopping the train in each intermediate station) is the indicator for assessing the performance of railway organizations at all levels on the operation of passenger trains between the departure and arrival stations and that of freight trains between all sections and of all kinds of stops, i.e., assessing the comprehensive level of locomotive maintenance quality, driver manipulation technology, maintenance quality of the track sections, and the work of train dispatching command department, especially the maintenance department and transport organization. The railway travel speed relates directly to the rolling stock turnover and travel time which in turn will influence the passenger travel speed and freight delivery speed. Therefore, the train travel speed is one of the important indicators for railway operation. To greatly increase the passenger/freight train travel speed is of great practical significance.

It is widely believed that the purpose of increasing the train speed is to improve the competitiveness against other means of transportation and increase the railway revenue by shortening the travel time. From the view of Dr. Brighton from Switzerland, for a short distance (within 300 km), under the condition that the average speed of a plane is 600 km/h (the time for waiting, flight transfer and check-in will be totally 90 min) and the average speed of an automobile is 80 km/h, and that the waiting and transfer time of the

train is 30 min, if the average speed of the train is less than 100 km/h, it is unable for the train to compete with the automobile. For a medium distance (500,600 km), if the average speed of the train is under 250 km/h, it is unable for it to compete with the plane.

In May 1985, the Economic Commission for Europe (ECE) defined the international railway travel speed, indicating that the maximum operation speed for high-speed dedicated line for passenger transport shall be 300 km/h, and that for mixed passenger and freight high-speed railway shall be 250 and 160–200 km/h of the existing railway after upgrade.

The practical speedup experience of the existing busy railway lines in the USA, UK, and USSR (respectively the northeast corridor from Washington to Boston, the east coastal main line from London to Edinburgh, and the line from Moscow to Leningrad, now renamed as St. Petersburg, hereinafter the same) proves that the targeted speedup value of busy railway lines of medium-long distance should be 140–160 km/h (excluding titling trains). It needs considerable investment to increase the targeted speed to 200 km/h. According to German's experience, for the existing railway, the maximum speed of 160 km/h is a turning point for the expenses for construction, and upgrade and maintenance expense, and the expenses differ greatly. For example, the expense for a crossing at the speed more than 160 km/h will increase by more than 20% than that at 100–160 km/h. According to the new Regulations on Railway Technical Management issued in 1994, for the railways on which the train speed exceeds 160 km/h, there shall be no level crossing and continuous speed control device shall be introduced in the signal system, but accordingly, the expense will be increased greatly; the cost for overhead line will increase by 1%–2%. For the railways on which the train speed is 140–160 km/h, the sleeper space, sleeper length and rail weight will be 60, 250, and 54 kg/m, respectively, but at least 57 cm, 260 cm, and 60 kg/m for the speed exceeding 160 km/h, and accordingly, the expenses will differ greatly. In addition, for the speed exceeding 160 km/h, the engineering expenses on curve radius, railway ballast, and distance between the centers of railway lines will increase greatly. The speed of the tilting car body trains can reach 160–200 km/h or much faster without railway modification or slight modification of the railway. Thus tilting car body trains have been adopted as a new means to increase the speed on the existing railway in recent 30 years and it has been adopted by Italy, Spain, Sweden and Switzerland, etc. The maximum speed of passenger trains on the existing busy trunk railways is required to be increased to 200 km/h. Generally, these railways are used for continuous running of high-speed trains from the high-speed lines or used as interconnection railways, and they are spread widely in Germany, France, Japan and Italy, etc.

In some countries, the main purpose of upgrade of existing railway is to gain competitive advantages against the road and air transport for a certain travel distance, and the ratio of modification expenses to the gained benefit is apparently reasonable. Therefore, the increased and targeted speed value of railway is mostly be set to 200 km/h as the maximum speed for the passenger trains. As for the freight trains, the maximum speed is within 80–140 km/h due to the actual situations of different countries.

7.2.2.2 Step-By-Step Implementation Scheme for Speedup of Existing Railway

In order to achieve the above goals, most countries adopt a two-step solution. During the initial period, the maximum speed of passenger trains is to be increased to 140–160 km/h, and then to 200 km/h. The reason is that when the speed is increased to 200 km/h, it is

necessary to meet higher technical requirements and more equipment modification expenses will occur, but there is no obvious benefit resulting from the speedup.

According to the experience of some countries in railway construction, the requirements for express passenger trains running on the existing mixed passenger and freight railways include:

1. Speed upgrading the existing trunk railways with speed of 140 km/h

As for the maximum speed at 140 km/h, the existing rolling stock, railway lines, communication and signal device could meet the operation requirements. The aim of speed upgrading could be realized with little reconstruction and investment, and immediate effect.

2. Speed upgrading of the existing trunk railways with the maximum speed of 160 km/h

As for the maximum speed at 160 km/h, the speed-up could be realized based on the existing technical equipment, and it is only necessary to slightly modify the vertical profile and horizontal plane of railway, to upgrade the running part of rolling stock, improve the traction and braking force, and to adopt automatic block, etc. In Germany, the crossings adopt flashing signal light with half barrier.

3. Speed upgrading of the existing trunk railways to maximum speed of 200 km/h

As for the maximum speed increased to 200 km/h, it is necessary to improve the profile, plane and cross sections for the mixed passenger and freight railways, and to use multidisplay (e.g., four-display) locomotive signal or to increase the signal display. Like Japan and France, for the speed exceeding 160 km/h, train speed control device is used to supplement the ground signal system; in German, continuous train speed control device is used for not only reducing the burden for the driver to watch the signal from a distance but also providing conditions for the train operation through the program control. Thus, it can increase the throughput of the mixed transport railways at all speeds. However, the level crossing shall be changed into overpass in order to better improve the braking force, e.g., when the electric pneumatic braking and electromagnetic rail braking are used.

In the event that the maximum speed of passenger trains on the existing busy trunk railways is required to be increased to 200 km/h, generally, these railways are used for continuous running of high-speed trains from the high-speed lines or used as interconnection railways.

4. Newly-built high-speed passenger dedicated line

Due to different regional and natural conditions and unbalanced economic development, passenger and freight transport volume through railways grow prominently in the densely populated, industry concentrated, and economically developed urbanization areas with convenient transportation and on the busy trunk railways that connect with important national economic regions. This indicates a trend of transport volume concentration. For the technical modification on the busy passenger/freight transport trunk railways, with the technical load reaching a certain level, high-speed passenger dedicated line shall be built to separate from freight transport and achieve rapid passenger transport, so as to improve the railway transport capacity.

According to the research from International Railway Congress Association (IRCA) and International Railway Union (UIC), as for Europe, under the conditions that the passenger/freight transport capacity is saturated on the existing railways and the two-way

annual passenger capacity exceeds 10 million, it will be preferable to build high-speed passenger dedicated railways; whereas, for Germany, France and Belgium, under the conditions that the transport capacity is saturated on the existing railways and two-way annual passenger capacity exceeds 5 million, it will be preferable to build mixed passenger and freight high-speed railways.

7.2.3 Technical Conditions for Speedup Passenger Trains

The train system refers to the rolling stock combination of locomotive traction type and the combination of motor car and trailer of motor unit train. The related technical conditions include traction performance, braking performance (e.g., dynamic braking), dynamics performance and thermodynamic performance (e.g., energy consumption and air conditioning), etc. The train system is an important part in train operation, and it has direct impact on the safety, convenience, comfort and economical operation of the trains.

7.2.3.1 Requirements for Traction Performance of Trains

For speed-up trains to run on the existing railways, the locomotive is required to provide enough traction to overcome the increase of various resistances rising from speedup. Under the same conditions of other factors, the increase of traction power shall be in direct proportion to the speed and the train resistances. The train resistance is a variable changing with speed, and as a major factor, the air resistance is also in direct proportion to the square of speed.

1. Maximum speed of train and construction speed of rolling stock

The practices at home and abroad show that the construction speed of the rolling stock (or motor train unit) shall be 10% higher or more than the maximum speed in order to realize the operation in the maximum speed.

The ratio of maximum speed to design speed is about 0.9. If the maximum speed in the medium to long term remains stable, the ratio shall be larger to avoid any waste of the design ability; however, if the maximum speed is predicted to be increased, the ratio shall be smaller in order to meet the development requirements in the medium to long term. In addition, the high efficiency speed zone and constant power speed range of the traction power are usually lower than the design speed too, and this is also one of the reasons why the maximum speed is lower than the design speed.

According to the ratio $T \approx 0.90$, when the speed of a passenger train is increased to 140–160 km/h, the design speed of the train system shall reach 154–176 km/h; when the speed of the passenger train is increased to 200 km/h, the design speed of the train system shall reach 220 km/h; when the speed of a freight train is increased to 85–90 km/h, the design speed of the train system shall reach 95–100 km/h or even higher.

Studying the railway rolling stocks manufactured in China, we can find: if the speed of passenger trains is increased to 160 km/h, DF11, DF10F, and SS8 locomotives and 25Z

quasi high-speed passenger trains or double-deck passenger trains can meet the basic requirements of speedup. If the speed of freight trains is increased to 85–90 km/h, the original locomotive can meet the requirements. Freight trains with 8A bogie need corresponding modification to meet the requirements for the speed of 85–90 km/h. The speed of 25G and 25B passenger trains with 209 and 206 bogies can reach 140 km/h; and that of 25Z quasi high-speed passenger trains with CRC CW-2 bogie, Sifang 206KP bogie and 25Z quasi high-speed double-deck passenger train with Puzhen 209HS bogie can reach 160 km/h.

If the speed of passenger trains is increased to 200–250 km/h, high-speed EMU shall be adopted. Based on the introduced foreign advanced technology, CRH series EMU manufactured in China can meet the speed requirements of 200–250 km/h.

2. Parameters of traction and acceleration allowance

In order to realize the maximum speed, apart from overcoming the corresponding operation resistance, a train is required to keep a certain amount of extra acceleration allowance when it reaches the maximum speed. Accordingly, the required traction performance can be determined in consideration of the following: first, there is a certain acceleration allowance at the maximum speed on the straight path; secondly, the maximum speed is reached on an ascending grade (or there is a certain unit acceleration allowance at the maximum speed on the straight path); thirdly, the maximum speed should be increased by a certain percentage. The first and second ways are substantially the same, i.e., the acceleration allowance a (m/s^2) is equivalent to the surmountable path gradient i (‰) or unit acceleration f (N/kN). The relation is

$$I=f=10^3a/g(\text{‰})$$

where $g\approx9.81\text{ m/s}^2$, is the gravity acceleration.

Hereby, the corresponding relation between the required acceleration allowance and gradient can be acquired, as shown in Table 7.2.

Table 7.2

Relation Between Acceleration Allowance and Corresponding Profile Gradient

Acceleration Allowance a (m/s^2)	0.1	0.05	0.03	0.02	0.01
Corresponding profile gradient I (‰) or unit accelerating force f (N/kN)	10.2	5.1	3.1	2	1

The acceleration allowance is related to the train types. The acceleration allowance of passenger trains should be higher than that of freight trains; the acceleration allowance of express trains should be slightly higher than that of normal passenger trains, and the high-speed trains should be much higher. Referring to the operation practice international, Table 7.3 is recommended for reference in choosing acceleration allowance.

Table 7.3

Recommended Acceleration Allowance

Train Type	High-Speed Train	Express Train	Normal Train
Maximum speed range (km/h)	>200	120-200	80-120
Acceleration allowance a (m/s ²)	0.05-0.1	0.03-0.05	0.01-0.09

3. Traction performance of passenger locomotive and EMU

For passenger trains with a speed up to 160 km/h, it is advisable train formation of no more than 12 double-deck coaches or 14 coaches using an SS8 locomotive on electrified railway; and train formation of no more than 9 double-deck coaches, or 11 coaches using a DF11 locomotive on nonelectrified railway. For the passenger trains speed up to 140 km/h, it is advisable train formation of 15 double-deck coaches or 18 coaches using an SS8 locomotive, train formation of 13 double-deck coaches or 15 coaches using a DF10F locomotive, and train formation of 12 double-deck coaches or 14 coaches using a DF11 locomotive. For the passenger trains speed up to 120 km/h, it is advisable for an train formation of 20 double-deck coaches or 24 coaches using SS8 locomotive, train formation of 17 double-deck coaches or 21 coaches using a DF10F locomotive, train formation of 15 double-deck coaches or 18 coaches hauling by a DF11, and 12 double-deck coaches or 14 coaches hauling by a DF10D locomotive.

Reducing the requirements of acceleration allowance can increase the tractive tonnage and the number of coaches. Take the DF4D locomotive, for example. The unit resistance of locomotive with the speed of 120 km/h is 4.97 N/kN and the passenger train is 4.79 N/kN. According to the constant power calculation, the traction of the locomotive is around 72.7 kN, thus, when the acceleration allowance a is 0.02 m/s^2 , a DF4D locomotive can haul about 18 coaches, and when a is 0.01 m/s^2 , it can haul 22 coaches.

4. Traction performance of freight locomotive

If the speed of passenger trains is increased but the speed of freight trains remains unchanged, the transport capacity will be influenced and this means that the speedup will reduce the efficiency on the contrary. Therefore, the speed of the freight train shall also be increased while the speed of the passenger train is increased.

International studies and researches show that the speedup of passenger trains on the existing railways causes the deduction coefficient to rise sharply. Because of the different speeds of trains, the express trains will take up a large proportion of capacity. The most effective method to reduce the deduction is to increase the speed of freight trains and schedule the train working diagram more reasonably. After upgrade of the existing trunk railways in some countries, the maximum speed of passenger trains can reach 160–200 km/h and the speed of freight trains can reach 80–140 km/h, even the speed of freight express trains is above 90 km/h.

For the freight trains speed in China increased to 85 km/h, a double DF4 locomotive can draw 5000–5500 t, a DF10D locomotive can draw 4500–5000 t, a DF8 can draw 3500–4000 t, and a DF5 can draw 3000–3400 t. The power of electric locomotives is relatively higher, so a freight train with larger mass can be drawn.

5. Starting-up performance of traction power

In order to ensure the starting-up acceleration, the trains shall have enough starting-up acceleration. As rolling bearings are commonly used, the starting resistance is usually moderate, about 1.5–3.5 N/kN. For easy verification, the starting resistance of trains is ignored but considered in combination with the required starting acceleration, thus, the relation between the starting traction power F_{start} (kN) and starting acceleration a_{start} (m/s^2) is: $F_{\text{start}} \approx (1 + \gamma) \cdot M \cdot a_{\text{start}}$, wherein, M is the mass of trains (t), γ is the gyrating mass coefficient, generally, .

Generally, the required starting-up acceleration speed of high-speed trains is relatively high, about 0.4–0.6 m/s².

With the application and development of three-phase AC asynchronous drive, independent driving radial bogie and antislip and antisliding technology, the effective adhesion coefficient of motor vehicle (or locomotive) can be increased by 10%–20% and the starting adhesion coefficient can be increased by 0.4–0.45 or much higher, and this is quite advantageous for the starting-up and continuous traction condition of trains.

7.2.3.2 Requirements for Braking Performance of Trains

The braking performance of trains is the general performance of the braking system of locomotives (or motor cars) and cars (or trailer), and is a guarantee for the safety and improvement of braking deceleration. Therefore, it is the basis for improving the average speed of trains.

With the increase of maximum speed, the braking distance needs to be prolonged. The prolonged distance is gained under the condition of adopting electric pneumatic and composite braking and antislip system. For example, the motor car usually adopts disk braking and dynamic braking, and sometimes uses rotating vortex braking; the trailer usually uses disk braking plus electromagnetic rail braking or linear vortex braking. Generally, the restriction of emergency braking distance is prolonged with the square of primary braking speed increase. The emergency braking distances of high-speed trains in several speeds are shown in Table 7.4.

Table 7.4

Emergency Braking Distance of High-Speed Trains

V (km/h)	300	250	220	160	140
Sz (m)	3500	2700	1700	1400	1100

When a train is under normal operation, the braking deceleration is only 50%–80% of the emergency braking; therefore, the normal braking distance is twice of the emergency braking distance.

The combination of various braking modes and reinforcement of braking system have caused the increase of both emergency braking deceleration speed and that of normal braking deceleration speed accordingly. The emergency braking deceleration of some trains reaches 1.4 m/s^2 , and the normal braking deceleration is 1.1 m/s^2 . This is good for not only the safety and speedup but also the arrangement of signal machines.

To increase the braking speed limit on descending grade (sometimes even on level grade or slight ascending grade) is also a requirement for the braking performance. A practical and effective method is to reasonably increase the train brake conversion rate to 100 θ h (i.e., the pressure on brake shoe kN for every one hundred kN of train mass) and to prolong the emergency braking distance.

In order to ensure the safety, the emergency braking distance in an automatic block section shall be definitely less than the length of the block section under the influence from self-stopping device, operation monitoring device or over-speed protection system, etc., and this means that the passing speed of a train shall be strictly confined when the yellow light is on, ensuring that the train can stop at the red signal after emergency braking. It should be better to add a function on the monitoring device to control the passing speed of the train when the yellow light is on. In order to avoid use of emergency braking and to ensure easy speed control of the driver, it is advisable to adopt the uniform speed limit (i.e., the passing speed of the train when the yellow light is on) in the whole section. For example, the speed of freight trains may be controlled within 40–50 km/h and passenger trains 60–70 km/h.

7.2.3.3 Selection of Traction Power Types for Speedup Trains

1. Selection of speedup locomotives for passenger transportation on busy trunk railways

(1) Diesel locomotive types for passenger transportation: For diesel locomotives on the existing busy trunk railway with the speed up to 160 km/h, there are two types currently in China, DF11 and DF10F. The former can haul a train with 13 coaches and 11 coaches, with the maximum speed of 160 and 170 km/h, respectively, and it takes 11.5 and 8.5 min to increase the speed from 0 to 160 km/h, respectively. The latter can draw a train with 20 coaches and 16 coaches marshaling, with the maximum speed up to 140 and 160 km/h, respectively; when it draws a train with 20 coaches, the speed can be increased from 0 to 140 km/h in 11 min.

(2) Electric locomotive types for passenger transportation: SS8, SS9, and SS7D can meet the transportation requirements with speed up to 140–160 km/h. An SS8, SS9, or SS7D can respectively draw a train with 20 coaches with the speed of 160 km/h on straight railways. Even on a grade with 6‰ gradient, the speed can also reach 100 km/h. The speed can reach 170 km/h when one of the types of locomotive draws a train with 14 coaches.

(3) EMU. Passenger EMU has various advantages, including good safety, high speed, large capacity, high riding comfort, low energy consumption, low operation cost and less pollution emission. Compared with the passenger trains drawn by locomotive, passenger EMU is flexible in operation (two-way shuttle operation) and marshaling, with fast starting acceleration and short braking distance, and are reliable in operation.

In China, electric multiple unit (EMU) or diesel multiple unit (DMU) trains are available for the sections where speedup is feasible. 2M4T and 2M6T units can be formatted flexibly as needed and a long formation of two 2M4Ts can also be adopted for the long term. DDJ1 EMU “Great White Shark,” and DMU “New Dawn” and double-decker “Shenzhou” can all meet the requirements for speedup to 140–160 km/h. CRH series EMU can meet the requirements for speedup to 200–250 km/h.

2. Selection of speedup locomotives for freight transport on busy trunk railways

Employing heavy-load trains or multiple unit trains is a practical and effective solution for improving the freight transport capacity. According to the provisions in Main Railway Technological Policy, on the busy trunk railways, the total mass of a heavy-load train is 5000 t or above, and the speed of freight train shall reach 90 km/h. The effective ways to improve the transport capacity include improving the loading capacity of the trains, employing heavy-load trains and increasing the running speed. The two ways to resolve the conflict between the transport capacity and volume include employing a large amount of heavy-load trains (5000 t) and increasing the train speed of freight trains (up to 90 km/h) on the existing railways.

Electric locomotive SS4 and diesel locomotives DF6 and DF8 may be used as double-locomotive traction for drawing the trains with a total mass of 5000 t to realize speed more than 90 km/h, so as to meet the requirements of freight transportation.

7.2.4 Technical Conditions of Railway Lines for Passenger Transport Speedup

7.2.4.1 Plane and Profile

1. Plane

(1) Limiting speed on curve

The calculation equation for the limiting speed on curve lines for normal trains is:

$$(7.18)$$

The calculation equation for the speed limit for tilting car body trains is:

(7.19)

where h is the actual superelevation (mm); h_{da} is the allowable deficient superelevation (mm): 90 mm for general conditions, 110 mm for difficult conditions; and Δh is the additional superelevation generated by tilting car body train: .

The actual superelevation shall ensure that when the freight train operates under a relatively lower speed, there shall be no serious abrasion on the inside rail. Generally, the following two methods are adopted to calculate the actual superelevation:

In the first method, the mean square root speed of passenger trains is usually adopted. See Chapter 3 for the equation.

In the second method, the actual superelevation is calculated by a certain allowable surplus superelevation h_{sa} when the freight train is passing by. The equation is:

(7.20)

where V_F is the the passing speed (km/h) of the freight train, for which the average value of speeds of up and down freight trains may be used; and h_{sa} is the allowable surplus superelevation: 30 mm for general, 50 mm for serious.

The actual superelevation calculated by the second method depends on the average passing speed of up and down freight trains, for which, the average speed of an up-direction train may be calculated by the locomotive type, the tonnage of traction and railway gradient, or be calculated roughly by the balancing speeds on various slopes; while the average speed of a down-direction train may be calculated by the braking speed limit.

(2) Length of transition curve

After the speedup of passenger trains, both the actual superelevation and the curve speed limit values may increase. If the original length of transition curve is not enough, the operation safety and passengers' comfort may be influenced. For normal trains, the length of transition curve shall be calculated according to three conditions: the outside rail superelevation slope will not cause any derailment, and neither the variability of superelevation nor that of deficient superelevation will affect passengers' comfort. The largest one will be adopted.

For tilting car body trains employed for speedup, the transition curve needs to be prolonged to ensure the essential comfort of the passengers.

(3) Length of circular curve and immediate straight line

The same standard is adopted for the length of a circular curve and an immediate straight line in the Code for Design of Railway line and Interim Provisions. They are calculated by overlaying the different vibrations generated from the train passing the ends of transition curve of the circular curve and immediate straight line. For the speedup railway, new railway standards shall be adopted as much as possible to ensure smooth operation. For

large-scale reconstruction project, the standard for existing railway shall be reserved to ensure smooth operation.

(4) Distance between centers of lines in double-track railway

For a double-track railway, the minimum distance between the centers of lines shall be 4.0 m. The operation practice shows that when the maximum speed is less than 140 km/h, the distance between the centers of tracks is applicable; when the maximum speed is equal to or greater than 160 km/h and two opposing trains are running in parallel, great pressure wave may be generated in the middle part and this may cause the window glasses of the enclosed passenger train falling down and break. Therefore, it will be a huge task to widen the space between railways, and for passenger trains with the maximum speed of 160–200 km/h, it is preferable to take corresponding safety measures like train streamlining.

2. Profile

In the continuously steep grade sections on a railway line, because of the locomotive power restriction in ascending grade section and braking control in descending grade section, the speed of trains will be reduced significantly. The actual superelevation of the curve will be reduced as the speed of the passenger train decreases; after the speed of the passenger train decreases, the required curve radius will also be reduced accordingly. In preparation for the strengthening scheme for the speedup railways, the speed of the passenger train in each section and the curve radius standard shall be determined according to the profile.

7.2.4.2 Track Structure and the Infrastructure

1. Track structure

When the speed of the passenger train reaches 140–200 km/h, continuously welded rail tracks of 60 kg/m shall be paved. In sections with a small radius of curve and long steep grade, as rails may experience serious abrasion, the track shall be gradually replaced with quenched steel track of full length, and Type III ties and matched elastic fastenings should be adopted. The thickness and width of the ballast bed shall be enlarged appropriately. The maintenance standard shall be higher than that for a normal railway.

2. Turnout

The main turnouts of the mixed passenger and freight railway in China are usually No. 12 common ones, with the straight passing speed of 115 km/h; a few No. 9 turnouts are also used, with straight passing speed of 85 km/h only. For the speedup, turnouts shall also be upgraded accordingly to avoid any acceleration or deceleration when trains are passing the station.

3. Level crossing

There are many level crossings on the existing railways in our country. Currently, there is one crossing every 3.0 km on double-track railways (about 1.5 km on single-track railways). With speedup of passenger trains, if protective measures at the crossings are not proper nor completed, operation accident of trains will take place frequently.

In railway sections where the speed of passenger trains is 140–200 km/h, highway and railway level crossings shall be changed into overpass; flashing lights and alarm devices shall be installed at sidewalk crossings. In population-dense sections, enclosed fences shall be installed on both sides of railways.

In railway sections where the speed of passenger trains is lower than 120 km/h, busy crossings shall also adopt overpass. For level crossings that need large-scale reconstruction shall be perfected with protective measures and be attended.

4. Subgrade works

For the subgrade in a speedup section, general investigation shall be carried out. The subgrade defects that may limit the speed, such as subgrade bed sink and mud-pumping, shall be renovated completely. In the sections with elastic subgrade mutation, such as transition from abutment to subgrade, at the front and the back of level crossings and steel culverts, the track stiffness will change easily, and this will cause unevenness and increase abrasion of the track. Therefore, the length of transition sections shall be increased to ensure uniform changes of the stiffness and smooth running of the trains.

5. Bridge testing and reinforcement

In China, bridges on the existing trunk railways have been used for a long time and the foundation, pier and beams have been aged in various degrees, so necessary check and reinforcement shall be conducted to meet the requirements for speedup of passenger trains.

According to the inspection of relevant departments, as for passenger trains speed reaching 140–200 km/h, transverse connection devices shall be added to the T-reinforced concrete beams laterally connected by double beams in order to avoid any inconformity of the transverse amplitude and vibration phase position of the two beams; As for the 32 m rivet connection plate girder steel bridge, when the speed reaches 160–200 km/h, vertical resonances may be generated. In such cases, laminated rubber bearing should not be used for steel bridge, and transverse limit devices shall be added to the concrete beams.

7.2.5 Signal Devices

Currently, in China, three-aspect automatic block devices are adopted, of which the green light indicates running, the yellow light indicates warning (predicting that the following light is red), and the red light indicates stop. According to Regulations on Railway Technical Management, the display distance shall be no less than 1000 m under normal condition, and the block section length between the signal machines shall generally be no less than 1200 m. The automatic block device can meet the requirements for operation of passenger trains under the maximum speed of 120 km/h.

For the speed of passenger trains reaching 140–200 km/h, it's generally believed that the position of signal machine may be unchanged while the current three-aspect mode is changed into four-aspect mode in order to exert the functions of current signal devices and reduce modification investments. i.e., an olive light (or green flash) signal is added in the four-aspect device. The green light still indicates running, the olive light (or green flash) indicates warning, the yellow light indicates slowdown, and the red light indicates stop. The

speed control of passenger and freight trains can be divided into several sections, e.g., 200-160(140)-110(100)-0, and 120-90-80(75)-0, respectively.

Where the display distance of ground signal is influenced by heavy fog, rain or snow weather, locomotive signal subjectification is necessary; on the other hand, the control system for overspeed protection also needs information from the reliable locomotive signal. In order to meet the requirements of the locomotive signal subjectification of the speedup trains, it is still necessary to improve the existing locomotive signal in our country in terms of reliability and safety.

7.2.6 Speedup of Passenger Transportation Influence on Freight Transport

When the speed of a passenger train is increased, great importance shall be attached to its influence on freight transport throughput. Great efforts shall be exerted to ensure the coordination of passenger/freight trains speed with the traffic density and mass of the trains, and ensure that the freight transport will not be influenced greatly.

In automatic block sections of double-track railways, with the current speed of passenger/freight trains, the deduction coefficient ϵ_P of passenger trains is related to the number of passenger trains N_P (row/d) and the tracking interval time I . When the number of passenger trains increases, ϵ_P decreases; when the tracking interval time shortens, ϵ_P increases. After the speed of passenger trains is increased, if the speed of freight trains does not increase, the speed difference between passenger trains and freight trains will increase and ϵ_P increases accordingly, and this will reduce the throughput of freight trains. If the speed of freight trains is increased accordingly and it matches the speed of passenger trains, it will decrease, which is good for increasing the throughput of freight transport.

In the nonautomatic block sections of single-track railways, with the current speed of the passenger/freight trains, the deduction coefficient of passenger trains is 1.1-1.3. After the speed of passenger trains is increased, the speed of freight train remains, the deduction coefficient of passenger trains does not increase in general, which will not have adverse impacts on the through capacity of freight trains; when the speed of freight trains is increased accordingly, the deduction coefficient of passenger trains decreases, which is good for increasing the through capacity of freight transportation.

In conclusion, the speed of freight trains shall be increased while the speed of passenger trains is increased. It is generally believed that the reasonable ratio of speed of freight trains to the speed of passenger trains is 0.6. For busy trunk railways with double automatic block, when the maximum speed of passenger trains is 160 km/h, the maximum speed of freight trains properly should be 90-160 km/h, and this is the targeted speed of busy trunk railway lines with express trains.

7.3 Construction of High-Speed Railway

High-speed railway technology, which reflects the advancement of science and technology in traction power, rolling stocks, route, track structure, communication signal, traffic organization and operation mode, etc., is the most efficient method for substantially improving the capacity and service level of passenger transportation.

7.3.1 Targeted Speed and Mode of High-Speed Trains

7.3.1.1 Targeted Speed

1. “Economic speed” of high-speed railway

The so-called economic speed means the speed at which the high-speed railway earns the most profit. In the beginning when western countries were planning to build high-speed railways, they had studied on the economic speed, and the result of the studies showed that improvement of speed saves the travel time, but the faster the speed is, the additional time required for accelerating

and decelerating when stop at stations, thus the travel time saved is comparatively reduced; and if the maximum speed increases, as the standards for the construction and technical facilities also increase, this will inevitably increase the construction investment, increase cost for maintenance of routes and rolling stocks; in addition, a lot of energy is consumed due to the resistance of air, resulting in more operation cost and transportation expenses.

During the 1970s, Western countries worked out their economic speeds based on their own situations, where Britain had 230 km/h, France had 280–300 km/h, Germany had 270 km/h, and the study by International Union of Railways shows 300–350 km/h. The economic speed has a decisive function on the determination of the maximum speed of high-speed railways for each country, and normally, the maximum speed is slightly higher than the economic speed.

2. Basis for selection of a target speed

Target speed is the major indicator for weighing the level of the high-speed railway technologies, and it is also a decisive parameter for the general design of high-speed railways. The target speed will decide the investment on the construction of railways, the application of new technologies, the operation expenses and economic efficiency, etc. The target speed should be determined on the following factors comprehensively:

(1) Ability to attract passenger traffic

The target speed should meet the requirements of passengers for fast and safe transportation, stable and comfortable journey, moderate price, accurate schedule and convenient travel so that significant passenger flow is

attracted and that more competitive position can be obtained in the competition for middle and long distance passenger transportation.

(2) The advancement and feasibility on technology

The target speed should be advanced and technically feasible. It is possible to identify the optimal coordination between the routes and the locomotives with the method of systematic engineering in order to reduce the engineering cost and operational expense.

(3) Economic rationality

The construction of a high-speed railway requires significant investment, thus it requires stable and preferable direct economic benefit, time efficiency by saving the travel time, and significant indirect economic and social efficiency by promoting related industries and the economic development of areas along the line.

(4) Adaptability with national and regional economic development

The target speed of high-speed railway should be adaptable with the current situation and planning for national and regional economic development as well as the general strategy for traffic development. The over-pursuit of high speed is not encouraged.

Experience shows that with comprehensive consideration of all factors and different construction modes and operation modes, there are basically three major options for the speed target of high-speed railways:

(1) For newly built high-speed railway line for passengers only, maximum speed preferred are 300–350 km/h.

(2) For newly built high speed line for passengers and freights with time-share operation, maximum speed preferred are 250–280 km/h.

(3) For newly built high speed line for both passengers and freights, maximum speed preferred are 200–250 km/h.

The preferred maximum speed for tilting car body trains on existing lines for both passengers and freights is 200–240 km/h.

7.3.1.2 Power Mode of High-Speed Trains

High-speed trains are key technologies for high-speed railways. Due to different national conditions and basic situations, different modes are employed for high-speed trains on passenger-only lines in different countries, mainly including power-dispersed multiple units, power-concentrated multiple units and tilting car body.

1. High-speed trains with power-dispersed multiple unit

High-speed trains with power-dispersed multiple unit comprise of several units, each of which comprises of several motor cars and trailers. Such train is characterized by mild interaction between rail and wheel, good cohesion and dynamic braking property, low technical requirement, high occupancy of passengers and large carrying capacity. However, it is disadvantaged by poor current collection condition, big noise and stronger vibration, poor comfort,

which requires high cost for manufacturing and maintenance.

Such trains are adopted in Japanese Shinkansen.

2. High-speed trains with power-concentrated multiple units

In high-speed trains with power-concentrated multiple units, power is concentrated at the head and tail of the train, i.e., cars at both ends are motor cars, the power facilities are set together in the motor cars, and trailers are laid out between motor cars. When the power of the motor cars is not sufficient, power bogies may be installed in trailers adjacent to the motor cars.

Power-concentrated multiple units trains are more favorable than power-dispersed multiple unit trains in high speed current collection, good environment protection, lower manufacturing cost and maintenance expense, and reducing shock absorption and noise reduction. However they are disadvantaged in bigger axle load, higher requirement for the line structure, and requiring more cost in the construction and maintenance of the permanent way. Fortunately, with the development of the technology, there are many improvements in reducing the weight of the motor cars and trailers, in the interaction and cohesion between wheel and rail.

3. Tilting car body trains

The tilting car body, radial bogie, and AC electric transmission traction technologies are the three major technical features of tilting car body trains. When the train negotiate a curve, tilting car body turns an angle of maximum 8° toward the center of curve under the computer command through hydraulic servo system, which enables the train to adapt with the radius of curve and the speed of

train so as to overcome the centrifugal acceleration resulted in the curve, thus ensuring the riding safety and comfort of the passenger train. The radial bogie can turn the two parallel axles installed on the bogie so that when the train run through the curve they form an angle and the extensions of the axes joins at the center of the circle of the curve. With tilting body car, when the radius of curve is over 800 m, the train speed can be increased by about 40%. Tilting car body trains require higher manufacturing (about 20%–30% more) cost and maintenance expense, but significant cost in the reconstruction of permanent way can be saved, especially the significant amount of investment in the infrastructure construction for a new line.

7.3.2 Advantages of High-Speed Railways and Preconditions for Construction

7.3.2.1 Advantages

Compared with other means of transportation, the high-speed railway has the following advantages:

1. Quick arrival: in the view of time saving, when the maximum running speeds are 200, 250, and 300 km/h, respectively, the high-speed railway is more favorable than the long distance coach when the distance are longer than 80, 100, and 130 km, and it is more favorable than air

transportation when the distance are within 600, 800, and 1000 km. With consideration of other factors, the high-speed railway can attract the passenger flow whose journey is between 80 and 1500 km from big and medium cities along the cities.

2. Large traffic capacity: take the Japanese Shinkansen as an example, every high-speed train carries 1000–1300 passengers in average, and every day there are about 300 train-time, so every year it can transport 110,000,000–140,000,000 person-time. The capacity is much larger than other transportations.

3. Low energy consumption: according to the statistics from Japan in recent years, take the energy consumption of 1 person/km by ordinary railway as 1, and then that by high-speed railway is 1.43, bus 1.45, vehicle 8.2 and airplane 7.44.

4. Less land occupation: normally the roadbed of a four-lane express way is 26 m wide, while the subgrade of a double track electric railway with the same capacity is only 14 m wide, i.e., the high-speed railway occupies about 1/2 less land area than the express way does. A big airport for air transportation normally occupies 20 km², and there must be at least two such big airports in a 1000 km airline, thus the total land occupation is 2–3 times of that of the railway.

5. Less comprehensive investment: talking about the comprehensive costs of different transportations with equal capacity (including all that is spent on fixed equipment and mobile equipment), high-speed railway and express way require the equal cost and both require less cost than air transportation does.

6. Less environment pollution: the line of electric railway is clean, there is no waste gas, and when the electromagnetic radiation is controlled within standard, there is little environmental pollution. As for noise pollution, it is about 10 times lower than that of airplanes and vehicles.

7. Safe and comfortable: according to over 10 years of operation experience from Japan and France, high-speed railway has obvious advantages in safety and liability compared with other means of transportation. In addition, high-speed trains provide much more space for passengers than vehicles and airplanes do, and the trains run stably with little vibration and swinging, providing more comfort to passengers thus making the travel less tiring.

8. Accurate and convenient: high-speed trains run in all-weather conditions, the line is totally enclosed, and advanced auto-control system is provided for the running and dispatching of trains so that safe and on-time operation of the trains are ensured. In big cities, high-speed railway stations are deep in the down town, so passengers can arrive and leave by metro or other urban transportation vehicles, which is much more convenient than taking a long distance coach at a suburban coach station or a plane at an even farther airport.

7.3.2.2 Timing and Preconditions for High-Speed Railway Construction

According to the analysis above, the high-speed railway has advantages in many aspects; however, the high-speed

railway requires significant investment in infrastructure construction, and it also requires significant cost to operate the high-speed railway system safely, accurately and stably with high service level. Therefore, the financial, economic and technical feasibility is the key factor that decides the opportunity for building the high-speed railway.

1. Transportation demands

The financial conditions of the high-speed railway mostly depend on the passenger flow volume it transports. With a clear passenger flow volume and ticket price, the income of the high-speed railway system can be evaluated. According to the service facilities provided, the investment cost and annual operational expense can be predicted, and then several possible plans can be proposed and the plan that can both attract large passenger flow and meet the expected profit target can be selected.

2. Main technical standards

The selection of main technical standards is decisive to the investment cost in preliminary construction and the operational expenditure after it is put into operation. When choosing the construction mode, it must be coordinated to select the line strike, maximum design speed, average running speed, line structure, traction power, formation of trains, total weight of train, and type of trains. It is also necessary to realize the optimal coordination of the application, maintenance of all technical facilities. Therefore, engineer should propose several possible coordination schemes to work out and then select the best one as recommended proposal.

3. Economic effect and construction years

The objective of constructing high-speed railway is to provide quick and convenient passenger transport service, and to reduce travel time by increasing the running speed, therefore the benefit obtained by saving the travel hours is very important to the economic effect of constructing the high-speed railway. To increase the running speed will cause increasing of investment cost and operational expenditure, so only if the travel time can be reduced sharply and a reasonable price is set for the passengers can the railway attract a large passenger flow in the transportation market with fierce competition and increase the volume of passenger transportation. As for the person-hour economic value and a reasonable price, they may vary with the development of the national economy and society as well as the improvement of per capita income, i.e., they are different in different computing years.

With fixed target speed and operation mode, regarding determined investment scale, the depreciation of fixed assets and maintenance cost normally takes up about 70% of the total cost, thus the break-even transportation price and corresponding years with break-even volume of transportation can be predicted, and passengers' bearing ability on the price can be assessed. If the year and price with break-even volume of transportation could be accepted, the earliest construction year can be reckoned.

4. City layout and construction of high-speed railway network

Researches and practices from abroad show that the most competitive transportation distance for high-speed railway is 300–800 km, and the passenger flow density is inversely proportional to the transportation distance. On such a basis, government usually take two cities that are 300–500 km far away from each other as the leaving and arriving point of

the high-speed railway, and start the construction and operation section by section beginning from the busiest traffic regions, and finally build them into a net.

7.3.3 Construction Mode

7.3.3.1 Construction Mode of High-Speed Railway in Europe and Japan

The development of high-speed railway is the major tendency of the development of railways in the world. However, what approach should be taken for developing high-speed railway should be subject to different national conditions and transportation background. In general, there are several modes as follows:

1. Construct new high speed passenger dedicated railway line

In the case a transportation trunk line has been developed where the economy is prosperous, the population is dense and the passenger and freight flows are increasing stably, but the passenger and freight transportation are highly concentrated, and the existing railway line is saturated, then a high speed passenger-only railway with maximum speed of 300–350 km/h should be built so that freight and passengers go separately so as to meet the ever developing transportation requirements. The infrastructures of the high speed passenger-only railway should be settled at one go,

and the railway should be started from the busiest areas section by section and line by line and finally a railway network should be developed.

2. Construct new high-speed railway for both passengers and freight

In the case where a transportation corridor has not been developed where the economy is prosperous, the population is dense and the passenger and freight flows are increasing stably, the new high-speed railway can be part of the freight-passenger railway network, supporting not only high speed passenger train, but also freight train. Transportation adjustment can be undertaken through the joint between the high speed passenger-freight railway and the existing railway in order to enhance the traffic capacity. On a newly built high speed passenger-freight railway, the passenger train runs at 200–250 km/h, and the freight train runs at 120 km/h.

3. Rebuild existing railway trunk line

This means rebuilding and increasing the speed of the railway network and trunk lines connecting central cities in developed regions and national metropolitans. The method is to enhance and straighten the existing line, namely, new superstructures and continuously welded rail will be adopted, and small-radius curves will be cut and straightened so that most nonstop express passenger vehicle can reach 200 km/h and above.

While rebuilding the existing line, a third or a third and fourth main line (including locally detouring line) may be added simultaneously so that the freight trains and the passenger trains can run separately or the high speed line is for passengers only while the normal line is for both slow

trains for passengers and freight trains. Compared with constructing new high-speed railway for passenger only, it is characterized by quick launch and lower cost. However, there are also the following difficulties:

(1) There are many intermediate stations and there is dense residence along both sides of the line, therefore the land acquisition for adding the third and fourth main line is difficult.

(2) When the third and the fourth lines are added, if there is a special line or goods yard at one side of an intermediate station, the trains on the other side needs to cross several main tracks to either pick or detach some freight vehicles, which is not convenient.

(3) It will disturb the daily operation when rebuilding the existing line, and the construction is also difficult to be carried out.

Therefore, such construction mode is proper for the existing trunk line that is located in a plain busy with passenger and freight transportation and that has low requirements for route technologies or for busy sections between some metropolitans. As for three parallel main lines, it is favorable only when there are only a few freight trains and there are many passenger trains.

4. Improve the rolling stocks

This requires neither building a new line or substantially rebuilding the existing line, but improving the existing rolling stocks. For example, controllable tilting car body electric motor units can run at high speed even on a curve. The tilting car body trains have good acceleration and braking characteristics, which may solve the problem of mixed passenger and freight line and the problem of

increasing the speed of the passenger train. However, in this case it requires introducing the tilting car body electric motor units which cost a lot of money and requires a lot of maintenance.

7.3.3.2 Construction of China's High-Speed Railway Network

The Chinese railway network is characterized by vast territory, regions differing from each other in economic development, long distances among metropolitans, and widely dispersed passenger flow resource points. Many passenger train crossing-over different railway system, and there no sufficient fund for railway construction. Therefore, the high-speed railways in China should be developed region by region, step by step, and subject to local conditions.

According to Plan for Railway Development in Medium and Distant Future issued in 2004 and revised in 2015, in order to meet the requirement of rapid increasing passenger transportation, China is building high speed passageway for passenger transportation among provincial capital cities and large and medium cities step by step, i.e., “Eight Longitudinal” and “Eight Transverse” high speed passageways for passenger transportation and nine intercity high speed passenger transportation systems, with a total length of 30,000 km high-speed railway. The details are as follows:

1. "Eight Longitudinal Lines," including Coastal trunk line connecting Coastal cities, Beijing-Shanghai high speed Line, Beijing-Wuhan-Guangzhou-Shenzhen-Hong Kong trunk Line, Beijing-Shenyang-Harbin (Dalian) high speed Line, Huhehaote-Nanning trunk line, Beijing-Kunming trunk line, Baotou-Haikou trunk line and Lanzhou-Guangzhou trunk line.

2. "Eight Transverse Lines," including Suifenhe-Manzhouli trunk line, Beijing-Huhehaote-Yinchuan-Lanzhou trunk Line, Shanghai-Hangzhou-Nanchang-Changsha-Guiyang-Kunming trunk Line, Qingdao-Shijiazhuang-Taiyuan trunk Line, Lianyungang-Xuzhou-Zhongzhou-Xian-Lanzhou-Wulumuqi trunk line, Shanghai-Nanjing-Wuhan-Chongqing-Chengdu trunk Line, Xiamen-Ganzhou-Changsha-Zhangjiajie-Qianjiang-Chongqing trunk line and Guangzhou-Nanning-Kunming trunk line.

3. Nanchang-Jiujiang Passenger Special Line, Liuzhou-Nanning Passenger Special Line, Mianyang-Chengdu-Leshan Passenger Special Line, Harbin-Qiqihar Passenger Special Line, Harbin-Mudanjiang Passenger Special Line, Changchun-Jilin Passenger Special Line, and Shenyang-Dandong Passenger Special Line

4. Nine intercity high speed passenger transportation systems, including Circum Bohai Sea Region, Yangtze River Delta, Pearl River Delta, Changsha-Zhuzhou-Xiangtan Region, Chengdu-Chongqing Region, Zhengzhou-Centered Central Plain City Cluster, Wuhan Metropolitan Area, Jinan-Qingdao Centered Guanzhong City Cluster, and Fuzhou Centered West Strait City Cluster, covering all the major cities and towns within the regions.

According to the Plan for Railway Development in Medium and Distant Future, based on the need of economic and

social development and the market, the railway passenger special lines are classified to the following categories:

1. 300–350 km/h high-speed railway (like the “Eight Longitudinal Lines” and the “Eight Transverse Lines”).
2. 200–250 km/h passenger-oriented freight-supported railways (even capable of supporting double layer of containers) (like Ningbo-Fuzhou-Shenzhen Railway, Shijiazhuang-Taiyuan Railway, Nanjing-Hefei-Wuhan, and Nanchang-Putian Railway).
3. 200–250 km/h intercity track transportation, like the intercity railways in Circum Bohai Sea Region, Yangtze River Delta and Pearl River Delta as well as Changsha-Jishou and Nanchang-Jiujiang Intercity railways.
4. Speed-up railways: from 1997 to 2007, after six times of speed increasing, in eastern and central China railways with maximum speed of 200 km/h have been developed.

The railways listed above form a complete high speed passenger transportation network with motor train units at 200–250 km/h running on the railways of 300–350 km/h and normal trains at 120 km/h or above running on the railways of 200–250 km/h. With such operation mode, maximum transportation efficiency and maximum transportation profit can be obtained. That a lot of passenger trains run overline is a necessity for the compatibility among national conditions, the railway background and the railway network, and it is also the biggest advantage of the unity of China’s railway network.

7.4 Railway Heavy Haul Traffic

7.4.1 Standards for Railway Heavy Haul Traffic

Railway heavy haul traffic refers to freight trains with large total weight and axle load or railway transportation with heavy traffic and big transportation volume. In the international annual meeting of heavy haul traffic held in 2005, railway heavy haul traffic was redefined that any railway that meets any two of the following three conditions is deemed as a heavy haul traffic line:

1. Frequently, regularly running or to-be-running unit train or multiple unit trains with at least 8000 t (previously it was 5000 t) of total weight;
2. On a section at least 150 km long with charged freight transportation over 40,000,000 t annually (previously it was 20,000,000 t);
3. Frequently, regularly running or to-be-running trains with axle load of 27 t and above (previously it was 25 t).

Heavy haul freight transportation is one of the important directions of the railway development in the world. The features of railway heavy haul transportation are longer train, heavier load, and nonstop before arrival. With large power AC transmission locomotives, trucks with heavy axle

load and light self-weight, and synchronized train control technology, the advantages of large transportation volume and low cost are more outstanding, thus the railway is more competitive in the market of mediate and long distance transportation with large freight volume. Since 1960s, railway heavy haul transportation has gained wide attention in many countries.

China has a vast territory. In the east there are developed industries and dense population, while in the middle and west, resources and energy are centralized. These objective factors decide the railway transportation of China is characterized with large volume and long distance. In the total railway freight transportation volume, coal and petroleum take up to about 49%, steel and minerals about 21%, construction materials, timber and cement about 11%, and grains and chemical fertilizers about 6%, totaling over 1.4 billion tons. In addition, there is stable freight source and centralized flow direction. The large volume of freight transportation provides a reliable basis of freight source for developing heavy load transportation.

There are two major approaches for China to develop heavy haul transportation:

- rebuild the existing trunk lines so that 5000 t heavy haul trains can run on existing busy trunk lines; and
- build new heavy load special line with big capacity and high standards, such as the Datong-Qinhuangdao double-track electric heavy load special line for coal transportation.

7.4.2 Organization Modes of Railway Heavy Haul Transportation

So far, there are three major modes of heavy load train organization both in China and abroad, namely, combined train, unit train and “whole-heavy load train.”

7.4.2.1 Combined Heavy Load Trains

The combined heavy load trains are made up of two or more ordinary freight wagons with the same travel direction connected one after another. This kind of heavy haul transportation started in the Soviet Union in 1964.

The combined heavy load trains can be used not only as emergency measures for blocking the line when the line is under medium maintenance or overhaul, but also as a temporary measure when there is seasonal increase of freight transportation. As a routine mean of transportation, it shows significant efficiency improving capacity and is available in both single track and double track lines.

There are three types of combinations: (1) original combined trains combined in the loading station; (2) technical combination trains combined in the marshaling yard; and (3) step-combination trains of which one train is marshaled in the technical station and then combined with another in an intermediate station. If combined heavy load trains run in a single track line, multiple track sections should be provided outside the leaving and arriving stations so that the combination and separation of the trains can be undertaken in the multiple track section. One of the arrival-departure tracks in a few of the intermediate stations should

be extended to ensure the combined trains meeting in the stations from opposite directions or express passenger trains from the same direction can surpass the combined trains in the station. As for ordinary stations, it is unnecessary to extend the siding; instead, ordinary trains can just wait till the combined trains pass the station. In order to confine the extending project within a certain scale, it is more favorable if the gradient of the line is flat. The control over two locomotives should be coordinated via radio or with wireless remote control. When the trains are pulled by electric or internal combustion locomotives, it is more convenient to have synchronized control.

The supporting facilities for running combined trains include the distribution of waiting stations, the designation of the combination station and the separation station, and the synchronized control facilities. In addition, consideration should be given to the impact of combined trains on the carrying capacity.

1. Distribution of waiting stations: on a busy double-track railway there are many pairs of passenger trains and freight vehicles, especially express trains and through trains, thus making it inevitable that waiting stations should be provided for combined trains. If the combined trains need to wait, a waiting station must be set, and the effective length of one of the arrival-departure tracks should be doubled, usually from 850 to 1700 m. There should not be too many waiting stations, though. It is proper to set 2-3 waiting stations in one section, otherwise it cannot evidently increase the number of running combined trains but in the same time require more investment. In China, on the Fengtai-Shacheng-Datong Railway and on the Beijing-Qinhuangdao Railway 10 pairs of combined trains run every day. The total length of the line is more than 600 km, and there are 12

stations with extended sidings, i.e., one station with extended siding every 50 km in average.

2. Designation of combination station and separation station: the combination station on a busy double-track railway can be chosen in the loading station or the marshaling station or in the station in front of the marshaling station. The effective length of one of the arrival-departure tracks should be doubled. As an emergency measure to run combined trains when there is medium maintenance or overhaul of the line, the combination and separation can also be carried out on the sidings of the combination station and the separation station. When the major locomotive and the locomotive in the middle of the combined trains are running, especially braking in an emergency, synchronized should be ensured. In America and Canada, radio remote control technology is adopted by adding a control vehicle to the combined trains so that the control vehicle can turn the control actions of the major locomotive into electric signals so that the auxiliary locomotive can be controlled simultaneously. This is a fairly advanced technology.

3. In order to run combined trains, the capacity of the traction substation should be expanded and the track structure should be enhanced.

4. The deduction coefficient of combined trains is normally between 1.15 and 1.50. It is not only related to the tracing interval but also subject to the number of pairs of express and through trains. When the tracing interval is 10 min, the deduction coefficient is about 1.15-1.20; when the tracing interval is 6-7 min, the deduction coefficient is about 1.4-1.5. Normally no more than 10-15 combined trains are allowed per day, and this is also subject to the number of pairs of express and through trains.

7.4.2.2 Unit-Heavy Load Train

Unit-heavy load train means a transportation unit comprising of fixed trains (high-power locomotive+certain number of special freight vehicles of the same type), and such a transportation is also taken as a unit for charging the operation. The unit-heavy load train runs between the loading station and the unloading station in cycles without stopping. This type of heavy haul transportation, adopted in America, Canada and Australia as well as on the Datong-Qinhuangdao Heavy Haul Special Line for Coal Transportation, is widely used and has significant economic efficiency.

The unit-heavy load train can sharply increase the carrying capacity of the railway, improving the operation efficiency, and reduce the transportation cost. It is suitable for railways with large freight flow volume, unitary freight variety, and centralized flow directions. Other than the Datong-Qinhuangdao Railway, Shenmu-Huanghua Harbor Railway and Datong-Zhunge'er Railway are also ready for running unit-heavy load trains.

The unit-heavy load train adopts fixed train set and runs on a fixed line in cycles. Quick loading and unloading facilities with big capacity should be provided at the stations at both ends of the line, and cars corresponding to the unloading method should be adopted so expedite the circulation and improve the transportation efficiency. For example, a loop line should be built in a large mine so that the whole train can be loaded while running slowly under the loading hopper, requiring no separation or stopping. Normally, after

the train runs 800 m, 7000 t materials can be loaded. In some unloading stations, loop lines are built, and gate-at-bottom cars are adopted so that the train can keep running while unloading the goods. For example, in a port in America for transshipment of iron sand, it takes only 8–9 min to finish unloading a train with 140 freight cars. In some cases dump cars are adopted for the train so that it takes only 15s or even 10s to unload each train. When American Union Pacific Railroad transports coal on a line of 1240 km, the turnover time can be reduced to 4 d from 16–20 d for mixed unit train.

Unit-heavy load trains run on a special line with fixed route, and the transportation organization requires coordination with other technologies.

Regarding transportation organization, the coordination among production, transportation and sales should be properly handled, the three links of loading, transportation, and unloading should be enhanced, the coordination between points and line of the railway itself should be strengthened, and coordination among the mine, harbor and factory should be close.

7.4.2.3 Whole-Heavy Load Train

The whole-heavy load train is a train mixed with different kinds of freight wagons with different loads to meet the heavy haul standard, organized in the same way as an ordinary train, pulled by one or more high-power locomotives at the head. In China, most of the heavy load

trains on those busy trunk lines are such whole-heavy load trains.

The departure, arrival, marshaling, loading and unloading of the whole-heavy load train are the same as ordinary freight vehicles, with the only difference of obviously increased total weight. Pulled by one or two high-power locomotives, the train carries freight as heavy as possible as long as the maximum gradient of the line and the effective length of the siding permit. In plains and hill regions, the train may reach 5000 t while in mountainous area it may reach 3000 or 4000 t. It is an effective method for greatly improving the transportation capacity of those busy trunks in a large scale, and it is the main mode for developing heavy load transportation in the future.

The marshaling and organization of the whole-heavy load train is the same as the ordinary freight vehicles. Factors restricting the traction tonnage are still the power of locomotives, strength of car couplers, braking capacity, maximum gradient of line, and the effective length of the arrival-departure tracks. Usually the minimum traction tonnage is taken as the tonnage rating on the basis of the calculated traction power of the locomotive and the maximum gradient of the line and reckoned with other restricting factors.

Usually the continuous traction power is used to calculate the traction tonnage of electric or internal combustion locomotives, and in this case, overheat of electric motor would not occur when the train runs on a continuous big up slope. If the hourly traction power is used for the calculation, the temperature rising of the electric motors in the locomotive when the train runs on a continuous big up slope should be reckoned.

The number of locomotives of a super-loaded train pulled by multiple locomotives is subject to the car coupler strength, so a super-loaded train requires adding auxiliary locomotives in the middle and in the tail. However, as the train is too long, coordination between the major locomotive and the auxiliary locomotives is poor, thus radio remote control becomes necessary. The auxiliary locomotives are not driven by people, the positions of the hand shank are turned into radio signals via the remote control panel, and then the radio signals are turned back into control actions of the auxiliary locomotives via the remote control equipment so that the auxiliary locomotives and the major locomotive are synchronized and that accidents due to broken vehicle coupler can be avoided. When it requires slow down or stopping, the major locomotive and the auxiliary locomotives can brake simultaneously, which solves the problem of the braking pipe of a long train being too long and the problem of slow decompression. In this way, the expense for the crew members on the auxiliary locomotives is saved the operation cost is reduced.

It requires enhancing the track structure and repaving heavy load rails in order to run heavy load trains. Level crossings should be rebuilt into flyover crossings whenever possible. On busy trunk lines such as Beijing-Shanghai Railway, Beijing-Guangzhou Railway, and Beijing-Shenyang Railway, all crossings are to be rebuilt into flyover crossings step by step.

With the increasing of the tonnage of the heavy load trains, there is a tendency of increasing station-to-station distance. Nowadays the calculated speed of both high-power electric locomotives and internal combustion locomotives is high, electric locomotives at about 50 km/h and internal combustion locomotives at more than 25 km/h. The technical speed can be increased accordingly so that longer

distance between stations can be set. Meanwhile, if the station-to-station distance is short, there will be frequent slow down and acceleration when the train enters and exits the station, consuming more energy and time while losing more kinetic energy, which not only increases the operation expense but also reduces the transportation efficiency. Therefore, it is economic and reasonable to extend the station-to-station distance.

7.4.3 Requirements on Railway Technical Facilities for Heavy Haul Transportation

The railway technical facilities are the material and technical basis for developing heavy haul transportation. Now all countries in the world are developing heavy haul transportation and actively researching and developing technical facilities for heavy haul transportation.

1. Requirements on railway engineering and electric facilities for heavy haul transportation

- Requirements on railway engineering for heavy haul transportation

In order to ensure the safe operation of heavy load trains and to reduce the maintenance cost, the bearing capacity of the heavy haul railways and the bridges must be enhanced so that they are highly endurable, reliable, smooth and stable.

- Requirements on railway power supply equipment for heavy haul transportation

According to the characteristics of heavy haul transportation, it requires developing and perfecting the electric railway in order to carry out heavy haul transportation. The electric railway power supply system comprises of the external network (national power supply system) and the internal network (the traction power supply system). When there is sufficient power supply from the external network, the railway departments should enhance the reconstruction of the internal network and greatly improve the power supply capacity of the railway power supply facilities. The capacity of the substations and the length of the supply arms should be designed according to the standards for heavy load train traction and train tracking intervals in order to make sure the length of the power supply sections and the size of the running area are well coordinated so that it is convenient for the cooperation between operation and maintenance.

2. Requirements on railway locomotive equipment for heavy haul transportation

In order to run heavy load trains, high-power electric or internal combustion locomotives must be used. Electric pneumatic braking technology and synchronous operation system “locotrol” under wireless remote control should be adopted, and shunting locomotives that are able to pull or push the heavy load trains also should be available.

3. Requirements on wagons for heavy haul transportation

Normally large four-axle freight wagons with big capacity, high strength and small coefficient of dead weight are adopted for heavy load trains. Corrosion resistant steel

structure and aluminum alloy materials are substantially used for the bath-tub-type vehicle body for its high strength and light weight. In addition, the car is equipped with radial bogies or bogies with small dynamic effect, new type pneumatic braking devices, high strength vehicle couplers and high capacity and high performance buffers.

(1) Axle load of vehicles should be increased. In 1994, the International Heavy Haul Association raised the standards of axle load for heavy load trains from 21 to 25 t. Now some countries have raised the axle load to 25 t, some even 35 t. Nevertheless, the economy and applicability of freight cars with higher axle load are under further research.

(2) Dead weight of cars should be reduced, which, realized mainly through the application of light and strong structure materials for the car body such as fire resistant steel, low alloy steel and aluminum alloy materials as well as by improving the carrying type of the car and optimizing the design for the car structure, is an effective way to raise the net carrying capacity of the cars.

(3) Dynamic effect of cars should be reduced, which can be realized by reasonably optimizing the vehicle structure such as adopting hinge joint bogies, self-directing radial bogies, gapless drawbars with new structure, and aerodynamic design for the body, and shortening the length of the train, etc.

(4) Car coupler strength and buffer capacity should be improved. The car coupler strength can be improved by selecting better coupler material and optimizing the coupler structure. In the view of operation safety, the longitudinal force on the couplers should be optimized and the buffer capacity should be raised.

4. Requirements on braking system for heavy haul transportation

Heavy load trains have higher requirements for the braking system, and many countries are carrying out technical research and innovation. With the development and application of microcomputer control technologies, America, Germany, and Japan have developed electric pneumatic braking devices used for freight vehicles. In China, the ECP electric control pneumatic braking system for heavy load trains has been introduced and tests have been carried out. Motor train units (passenger train) are now using the electric pneumatic braking devices.

5. Requirements on railway depot reconstruction for heavy haul transportation

In order to ensure a smooth arrival, leaving, and passing of the heavy load trains with related technical operations handled properly, the depot configuration of stations related to heavy load transportation and the effective length of tracks should meet the requirement of the trains for the traction length and should ensure the berth and operations of the heavy load trains, for example, the arrival, departure, separation, marshaling, overtaking running in middle way and technical examination for the whole-heavy load trains, the combination, separation, overtaking running in middle way and technical examination for the combined-type heavy load trains, as well as the arrival, departure, loading, and unloading operations for the unit-heavy load trains.

Chapter 8

Design for Reconstruction of Existing Railways and Building Out of Second Railway Lines

Abstract

The chapter starts by looking at design for reconstruction of existing railways. Existing railway line reconstruction includes plane reconstruction, profile reconstruction, and cross section reconstruction. Railway line reconstruction is often studied together with other strengthening measures, such as replacing traction type, extending arrival and departure track, adding stations, etc. Building out the second railway line is the most effective way to enhance the traffic capacity of the existing lines. In order to ensure the normal operation of the existing lines, and reduce the interference between construction and operation, it is usual to build the second line first, after the second line project completed and put into operation, then reconstruct the existing line. On a busy line located in a developed urbanization zone and national important economic regions with dense population, concentrated industry, and developed economy, passenger and freight traffic volume grows very fast. In order to meet the requirements of the quick development of traffic in these regions, third, fourth, and branching lines as a further capacity expansion measures need to be constructed.

Keywords

Design; Reconstruction; Existing railways; Second railway line; Branching line

8.1 Design for Reconstruction of Existing Railways

Existing railway line reconstruction includes plane reconstruction, profile reconstruction and cross section reconstruction.

Railway line reconstruction is often studied together with other strengthening measures, such as replacing traction type, extending arrival and departure track, adding stations, etc. The design of the second line is also worked out on the basis of the existing line reconstruction.

Reconstruction design of the existing line can be generally divided into two stages: preliminary design and construction detail design. Reconstruction design of the existing lines shall conform to the basic requirements and related standards of Technical Regulations and Code of Railway Design. Because of the low standards of the existing line, in most cases, reconstruction is needed. During the period of reconstruction, the normal operation and running safety of trains must be secured, as a result, the condition of construction becomes more complex, and the cost gets increased. In order to save funds, it is practical to make the best use of the existing buildings and equipment, and allow the standard of reconstruction design being lower than that of the newly built railway lines. Reconstruction design of the existing line shall be conducted on the basis of thorough investigations, and the following jobs should be carried out properly:

(1) To collect economic and technical information. First to collect the economic and technical data about passenger and freight traffic volume, traffic organization, and so on by economic investigation and studying the operation conditions of the existing line; then, based on these data, to study the measures to raise the capacity of railway, and to put forward a strengthening scheme in stages.

(2) Conduct engineering geological investigation. First, identify the unfavorable geology region restricted the existing line and geological conditions of key projects; then, based on studying of geological data, work out proposals of line reconstruction sections and line detouring sections (In case of build out the second line, the recommendation on locating the second line side, to the left or right side of the existing line shall be included). The engineering geological investigation shall also provide all kinds of geological data, as may be required for designs of bridges, tunnels and subgrade, and provide information of construction materials such as sand, stone and others.

(3) Existing line survey and investigation. These works include plane survey and mapping, profile survey, cross-section survey, topographic survey and mapping, and all the other types of investigations. These data are the basis to determine the line design standards, study the line reconstruction proposals, as well as to design the plane and profile.

(4) Investigation on existing individual engineering structures. To conduct a detailed investigating to the design, construction and use conditions of bridges, culverts, tunnels and subgrade, so as to determine the relevant rules about their usage, reinforcement or reconstruction. In case to build the second line, it is also necessary to collect information by the side of the existing line through the tunnels and bridges for locating the second line, as well as the required interval distance between centers of tracks.

(5) Investigation of construction organization and budget data. A budget estimate shall be made on the basis of the investigation data, and the project cost shall be calculated at the time when comparing the economic schemes.

(6) Collecting relevant drawings.

For the detailed requirements on each survey, engineers can refer to regulations written by each design institute.

8.1.1 Profile Design for Reconstruction Existing Railway

8.1.1.1 Reasons of Reconstruction

During operations on existing railway, the subgrade of a few individual sections could deform due to subsidence or frost damage. In the process of routine maintenance, due to the replacement of ballast, up ballast, and down ballast, the elevation of rail top would be changed as well. So the existing rail profile is much different from the original design, and the original design standard has become lower in many cases, it does not conform to the current Code of Railway Design Standard. Sometimes, to extend a station, sides may need to be used to prolong the length of a station yard, giving rise to profile reconstructions at the two ends of the station yard. Sometimes, to cut down a limit-over grade, the elevation of subgrade need to be raised or reduced. Finally, sometimes, when a section of railway line is threatened by flood, the related subgrade shall be elevated. All these cases mentioned hereby shall lead to a profile reconstruction.

When designing the profile for reconstructing existing line, it should be completed by considering the changing magnitude of present rail top level, and using the proper methods such as the ballast raising of track, the permeable soil raising of track, and the raising or lowering subgrade surface, respectively, which shall be selected by taking an technical and economic comparison in terms of the degree of interference between the normal operation and construction, and the amount of engineering cost.

8.1.1.2 General Regulation

1. Maximum gradient and algebraic difference between adjacent gradients

(1) When reconstructing existing lines, some grade section with over-ruling grade could be retained if reduce grade would cause difficult work, and the practical operation and traction calculation both prove that the train can utilize the momentum to overcome the over-ruling gradient in speed no less than the calculated one. But for existing double-track lines, the over-ruling grade section shall not obstruct use of the automatic block.

(2) For existing maximum-grade section to be reconstructed, if it may cause huge engineering work to conduct curve or tunnel gradient compensation according to the new

standards, the original standards can be retained.

(3) In the profile segments to be reconstructed, original value of algebraic difference between adjacent gradients may be retained in the event of sufficient technical and economic basis when reconstruction of the existing line.

2. Length of grade section

During the reconstruction of an existing line, 200 m can be applied as grade length in difficult conditions when the design speed is no more than 160 km/h; when the design speed is 200 km/h, the minimum grade length normally shall not be less than 600 m or not be less than 400 m in difficult conditions, and the number of grade sections with length of difficult conditions shall not exceed two in series.

3. Vertical curve

(1) Sections with design speed greater than or equal to 160 km/h and algebraic differential grade greater than 1‰, circular-type vertical curve must be set up, and the minimum length of vertical curve should not be less than 25 m. The radius of vertical curve should not be less than 15,000 m.

(2) Sections with design speed no more than 160 km/h, the original connection type can be retained if existing adjacent grades was connected with parabolic vertical curve and the curvature radius of vertex is not less than the value defined in standards. Parabolic vertical curve consists of 20 m continuous slope segments with grade change rate γ (‰), its line-type is close to circular curve, the corresponding vertical curve radius RV at the top is

$$(8.1)$$

For example, when $\gamma=2\text{‰}$, $RV=10,000$ m; when $\gamma=4\text{‰}$, $RV=5000$ m.

When reconstructing an existing railway line, the position of the vertical curve may not be restricted by location of easement curve in difficult conditions. The sections can be maintained where passenger train speed is less than or equal to 100 km/h, if reconstruction cause project difficulty at the place where vertical curve overlaps turnout, and the vertical curve radius not less than 10,000 m.

4. Profile altitude data

The altitude data of rail top shall be referred when taking profile design for reconstructing the existing line. The altitude of rail top shall be obtained through a profile survey along the line. Line profile survey includes altitude survey of benchmarks, hundreds meter stakes and additional stakes. Elevation of hundreds of meter stakes and additional stakes are the altitudes of an existing rail top, it is the level of left side rail top for straight sections; and for curve sections, it is the level of inner rail top.

5. The restrictions of construction method on profile design of reconstruction

The profile design of reconstruction shall be combined with construction method when reconstructing the profile. In general, ballast shall be used to lift track when the height of track lifting is less than 50 cm. Soils with good infiltration shall be used to lift track when the height of track lifting is between 50 cm and 100 cm; and the work shall be done by

lifting or cutting the subgrade surface, when the height of track lifting is greater than 100 cm or the thickness of lowering track ballast is less than the prescribed standards.

6. The requirement for elevation of rail top

When designing, for convenience of construction and the minimization of disturbance on operation, the method of cutting subgrade is generally not adopted to reduce the elevation of rail top, it can only be adopted at the sections, which are controlled by the limitation of buildings and construction of structures, and the sections with subgrade defects which shall be eliminated. In order to avoid undercutting ballast and impact on normal operation, the level of an existing rail top shall not be reduced in design. To avoid the reconstruction of bridges or culverts or to cut the rail bed, or to reduce the workload of reconstruction of lines, only in a few sections, it is allowable to reduce the level of rail top level. The thickness of rail bed shall only be allowed to reduce 5 cm in comparing with the one as required by standards, but the minimum thickness of rail bed shall not be less than 25 cm.

8.1.1.3 Profile Design Drawing With Enlarging Scale

1. Mode of profile design drawing with enlarging scale

The reconstruction design of an existing profile must be worked out in detail and accurate to make the most use of the existing buildings, and reduce the quantities of reconstruction. For these reasons, the profile drawing with enlarging scale shall be used when design. The scale of the enlarged scale profile is: a distance of 1:10,000, the height of 1:100 (or 1:200), so to make it easy to study the elevation rise and fall of an existing rail top in details, and make profile design more economic and reasonable.

The down part of profile design drawing with enlarging scale (see Fig. 8.1) shows the basic information and data of profile design. In a bottom-up order, the figure includes each of the following columns: existing plane, hundreds and additional stakes; ground surface altitude, the thickness of the existing ballast, elevation of rail top, design gradient of rail top, design elevation of rail top, lifting or lowering value of an existing rail top, sections of subgrade defects, and engineering geological characteristics.

The upper half of the profile design drawing with enlarging scale is the railway profile diagram. It should draw out of the ground line, the existing ballast bottom line, existing rail top line, calculation rail top line, design rail top line; and shall indicate the characteristics of buildings, such as stations, the crossing center mileage, the tunnel length and tunnel portals mileage, and bridges and culverts type, aperture, center mileage and the design flood level elevation, etc.



As for existing profile design, the rail top grade should be first determined on enlarged scale profile, and then summarize the design data to draw a detailed profile. Design methods and steps of enlarged scale profile are as follows:

Ground elevation is generally taken the elevation of side slope foot of embankment or side slope top of cutting on the left side of line. When building the second line, it should be filled

out with the elevation of side slope foot of embankment or side slope top of cutting on the existing line side; it should be filled out with the actual ground elevation of river bottom or gutter bottom at bridge and culvert sections, while it should be filled out with the elevation on topographic map at tunnel sections.

(2) Computing method for the elevation of ballast bottom and calculated elevation of rail top, as shown in Fig. 8.2. Elevation of ballast bottom=elevation of the existing rail top–height of the existing track.

Elevation of calculated rail top=elevation of ballast bottom +height of design track (including the rail height, plate thickness, tie height and thickness of ballast bed)

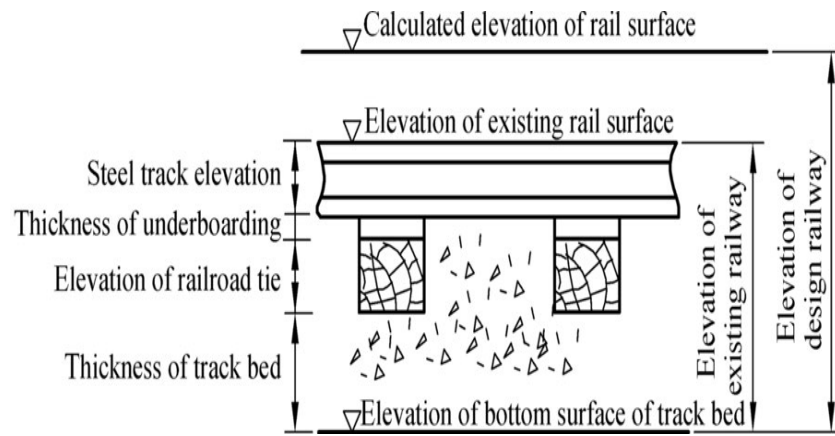


Fig. 8.2 Indicative diagram of rail elevation.

(3) To draw ground line according to the elevation of ground; draw the existing rail top line according to elevation of the existing rail top; draw the line of ballast bottom according to the elevation of ballast bottom; draw calculated rail top line according to the calculated elevation of rail top. Mark the station, the center mileage of the crossing, the mileage of tunnel portals and the length of tunnel, the type, aperture, center mileage of bridges and culverts.

(4) To design grade sections starting from bridges, tunnels or throat of stations by means of required design elevations, and draw preliminarily the designed top line of rail on the profile map with enlarged scale. Designed top line of rail should comply with the design standards, and make it as close as possible but still be above the existing top line of rail and calculated top line of rail. If it is below the existing top line of rail, the thickness of ballast should be thinned when constructing, thus affecting the operation. If it is below the calculated elevation of rail top, the thickness of ballast is lower than the design standards so as to reduce the track strength. If the designed top line of rail is too much higher than calculated top line of rail, it would lead to a waste of ballast. If individual sections have special needs, it is allowed that the designed top line of rail is slightly lower than calculated top line of rail, but the elevation difference should not be greater than 5 cm to ensure the necessary strength of track. If the thickness of the existing ballast is much greater than the thickness of design ballast, in order to guarantee the smooth of design profile, it also can make the design top line of rail be under the existing top line of rail, but construction for thinning the ballast may influence the normal operation somehow.

(5) The design grade of the rail top should be determined according to the roughly design top line of rail, gradient should be in multiples of 0.1‰; grade length usually adopts in multiples of 10 m.

Calculating and marking elevations of design top of rail at hundred-meter and additional stakes, elevation should be accurate to cm.

Vertical curve should be set up when gradient algebraic differential Δi of gradient change point is larger than 3‰. Vertical curve elements (radius of vertical curve R_V , vertical curve tangent T_V , the elevation change value y of the point of gradient change due to the vertical curve) and the design elevation H of rail top, should mark in both sides of vertical line at point of gradient change.

At the beginning and end of reconstruction section, we should pay attention to the cohesion of elevation.

(6) The last step is to compute the value of elevation raising or lowering of the existing rail top, namely the difference between elevation of design top of rail and elevation of calculated top of rail. The lifting or lowering value of the rail top elevation should be calculated based on the design elevation of rail top with vertical curve.

8.1.1.4 Attention for the Profile Design of the Existing Line Reconstruction

1. Bridge and culvert

On a ballast track bridge, the profile shall be designed according to the elevation of calculated rail top. Generally, it is not allowed to low the elevation level of the existing rail top, so as to avoid reducing the top heights of piers and abutments, and construction difficulty. If necessary, track lifting method can be used to raise rail top elevation, at this point, the sidewall to the beams of bridge shall be raised higher in most cases, to avoid overflowing of ballast. The lifting values of the rail top are generally limited to 10–15 cm, so as not to affect the stress and stability of the bridge after thickening ballast. When the lifting height of rail top is relatively large, as the elevation of pier top need to be raised, construction becomes difficult. To raise the elevation of pier top surface, when the lifting value is within 0.4 m, it is generally allowable not to check and calculate. Should the value get more than 0.4 m, then a calculation shall be carried out for verification purposes.

On ballastless deck bridges, changing the elevation of rail top can cause difficult work in raising or lowering the pier top surface. Therefore, a profile should be designed based on elevation of the existing rail top. In culvert sections, the elevation of the existing rail top is allowed to be lifted or lowered appropriately as required. But if the lifting value is too large, it often required to reconstruct the side wall and wing wall of the culvert, even extend the length of culvert. If the existing rail top should be lowered a lot and digging embankment is required, the minimum filling height from the culvert top to the ballast bottom should be guaranteed.

2. Tunnel

Inside the tunnel, when it is required to improve the tunnel clearance, or to lower the gradient in the tunnel, the general method is to lower the track, so as not to destroy the arch ring of the existing tunnel. But the reduction value should be within 0.4 m in order to protect the foundation of the tunnel wall.

3. Station site

Line profile within station site should not be too much elevated or lowered, lest it should cause the reconstruction of station buildings such as the station line, the throat area, the platform, over bridge, signal and water supply equipment, etc.

When the station site profile needs reconstruction caused by reducing grade of station site, extending the length of station site, adding stations, or cutting ruling grade, the project should be fully considered to minimize the whole work quantity of reconstruction.

When raising or lowering the main track of station, sidings can be used as temporary traffic route when constructing.

4. Subgrade

Profile reconstruction, will cause the elevation change of design subgrade shoulder. Shoulder elevation at two sides of low-lying areas and bridges and culvert, should be higher than the hundred-year flood level plus hammed water height and wave height of 0.5 m. But design based on this often need to lift bridge embankment and raise subgrade, causing additional reconstruction work quantity. After sufficient demonstration, the clearance under the bridge and shoulder height can be determined according to highest flood level on records, in order to avoid a large number of reconstruction project. If the section has no water disasters records, it is no necessary to design subgrade by means of hundred-year flood period

In retaining wall, slope protection section, when lifting track, it should be guaranteed that the side slope foot of filling mound should not cover the retaining wall and grade protection. When necessary, stones are applied to steepen the side slope.

At subgrade disaster sections, such as sand defect, snow damage, and the frost damage caused by the capillary water rise or mud pumping, can be removed by elevating the tracks.

A ballast sac is usually caused mainly by poor soil of subgrade formation and poor drainage of ballast. Lowering of the track can be employed to removed such disasters.

When lowering of track at cutting section, the construction will disturb the operation while expanding cutting, especially stone cutting, which needs shooting, the disturbance is more serious. In addition, the stability of side slope of cutting and level of underground water should be taken into account. If the designed height of subgrade shoulder is below the underground water level, measures for lowering underground water level should also be considered.

When elevating track at embankment section, the impact that widening the subgrade has on the stability of subgrade, especially in the high-embankment section, should be considered.

8.1.2 Plane Design for Reconstruction of Existing Railways

8.1.2.1 Surveying and Mapping of Plane

Plane surveying and mapping includes the following work:

1. Kilometer measurement

The kilometer should be measured through the whole line and the results should be checked up with existing buildings' kilometers such as bridge, tunnel, station, etc. The kilometer can be measured along the left rail top on straight segments, and along the center line on curves. The kilometer should be measured by two survey teams, and the data difference obtained by two teams should not be larger than 1/2000.

Hundred stakes are set every 100 m on a straight line, and densified stakes are set every 20 m on a curve. Additional stakes should be set at places such as station center, center of bridge and culvert, bridge parapet walls, abutment and trailing edge, tunnel entrance and exit, start and end point of subgrade protection and reinforcement project, crossing center, the highest and lowest point of embankment and cutting, terrain sharply changing points, etc. Additional stakes should be written in special record book. Marks and kilometers of hundreds and additional stakes should be marked on the outside waist of the left rail.

2. Setting offset stake

From survey to construction, there always has a time interval. In this period, movement of the existing track is unavoidable after operation or maintenance, so central line offset stakes should be set parallel with the existing lines, as the basis of the control of the center line of the existing lines.

Offset stakes are set in the direction perpendicular to the center line at straight section, generally at the left side of direction of forward motion, while at the second line side when building the second line. Offset stakes should not be less than 2 or 3 at each straight section, a stake should be set every 400–500 m at long straight section. At curve sections, offset stakes should be set in the normal direction of curve; at the instrument position of curve measured should set offset stakes.

The shifting out distance of offset stakes is general 2.50–3.00 m, located at foot of ballast slope. Shifting out distance of offset stakes at the same straight segment should be strived to equal.

3. Annotation of route

For reconstruction of the existing line, engineers should annotate buildings within 20–30 m on both sides of line to obtain data of major control points, such as the demarcation point between embankment and cutting, kilometers and building types at the beginning and the end points of various kinds of tracks, bridges, tunnels, retaining wall, slope protection and subgrade protection engineering, the route marks, crossing, communication lines, power lines, signal and other ground features which influence the existing railway reconstruction. These data should be annotated according to the line kilometers and the distances from

the center of the line, written in the notebook, as the basis of plane and profile design of railway reconstruction.

4. Curve survey

Under the dynamic action of the trains, the track deformation accumulates continuously. The stress conditions of the curved tracks are much more complex than that of the straight tracks and their deformations are more rapid. Misalignment of the curved tracks is the case most commonly met with by the railway engineers. In order to ensure the steady and safe operation of trains, it is necessary to shift existing misaligned track back to the original projected position with specified radius of the curved tracks. The purpose of curve survey is to measure the geometric shape of the existing curve, to determine its deflection angle, radius and the length of easement curve, so that on this basis to design the new curve radius and the easement curve, and calculate the throw of track to shift the existing curve to the design curve.

In recent years, a method of deflection angle has commonly been used to survey the existing curve, as shown in Fig. 8.3. In the first segment of survey, deflection angle of every 20-m point along the curve (the angle between the tangent line and the chord connecting the instrument position and each measure point) should be surveyed. In each segment of survey after transiting instrument position, it is required to measure the angle between chord line of instrument positions and the chord line of instrument position to each of the 20 m measure points. For the last instrument position, it is required to measure the angle ϕ_{ZH} between the chord line of instrument position and tangent line. If each angle at instrument position is denoted with $\phi_A, \phi_B, \phi_C, \dots, \phi_{ZH}$, the deflection angle of the existing curve is equal to the sum of the above angle.

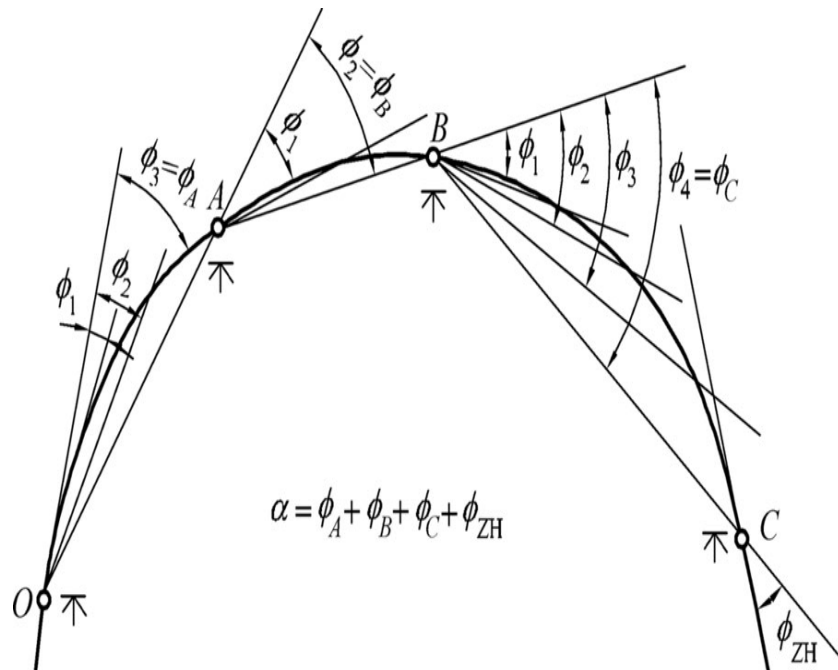


Fig. 8.3 Measurement of the existing line.

$$\alpha = \phi_A + \phi_B + \phi_C + \dots + \phi_{ZH}$$

The first and last instrument positions should be located outside the curve, at 20 m measure point about 0–60 m outside of the T.S. and the S.T. The second and the penultimate instrument point are best located at the measure point near the S.C. and the C.S. about 20 m. The rest of the instrument positions should guarantee the observation visibility and clear; the distance between instrument positions usually should not be longer than 200–300 m.

The deflection angle between instrument positions should be observed with telescope in normal and reversed position respectively, and it should take the average value when the difference within 40'. If there are some buildings, such as bridges, at curve restricting the shifting distance of the existing line, the deflection angles of middle point of curve, or that of start and end point (plus stakes) should be measured.

If the line of sight is obstructed, the transit may be moved ahead to one of the points already established. The transit is moved to the last station established. A backsight, transit inverted, is taken on the former position with the total deflection to the station to which the transit has been moved on the plates. The transit telescope is again reversed and the full deflection to the next station is laid off. The procedure with the successive deflection angles as computed then continues.

Curve is usually surveyed along the outer rail, sometimes also along the centerline of track. On traffic busy line, it can also be surveyed along offsetting stakes for safety.

8.1.2.2 Modes of Curve Reconstruction

The plane reconstruction of the existing lines mainly refers to the reconstruction of curve and its adjacent sections. The corresponding reconstructing method should be selected based on different reconstructing reasons.

(1) Curve adjustment: during operation, under the dynamic action of the trains, the curve track deformation accumulates continuously so as to cause the curve deviates from the projected position. In reconstruction, in order to ensure the steady and safe operation of trains, it is necessary to shift the misalignment of the existing curved track back to the original projected position with specified radius of the curved tracks, as shown in Fig. 8.4A.

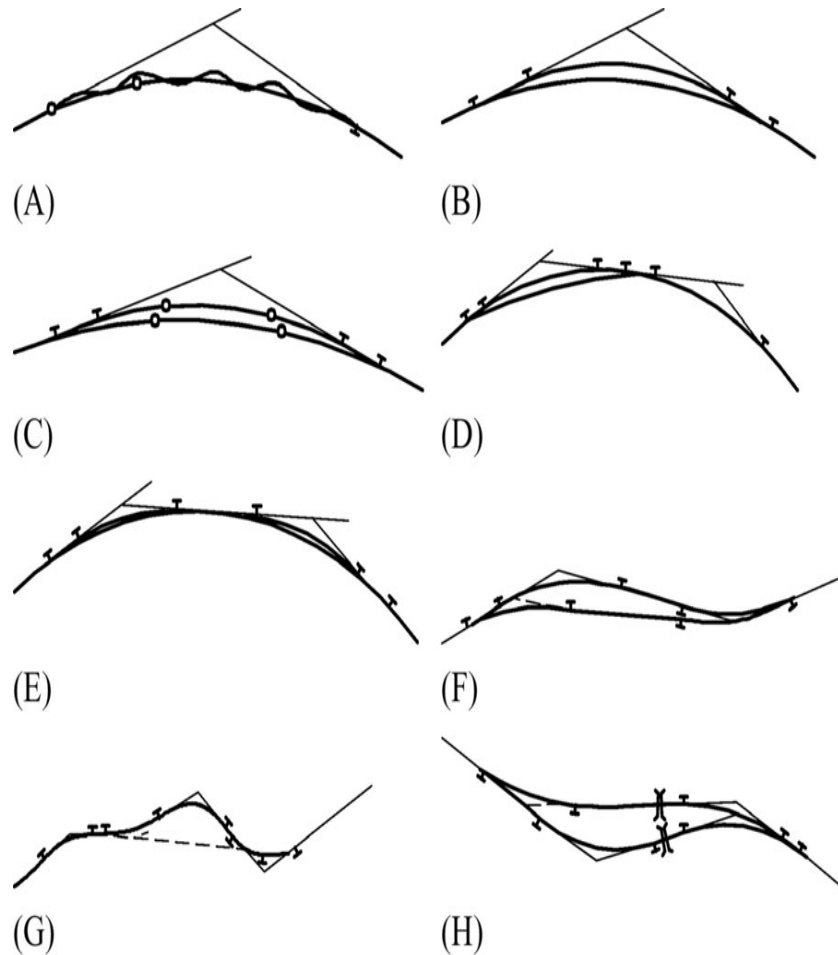


Fig. 8.4 Schematic diagram of plane reconstruction. (A) Curve adjustment, (B) increase curve radius, (C) lengthen easement curve, (D) lengthen the intermediate straight line, (E) converted two curves into one, (F) extended intermediate straight line between reverse curves, (G) replace curves with straight line, (H) bridge address causing line reconstruction.

(2) Raise the line standard: due to the increase of traffic volume, running speed, design standard of the reconstructed railway should be improved accordingly. For example, increase curve radius, lengthen easement curve and intermediate straight lines, could cause line reconstruction. Fig. 8.4B-D indicate the schema of increased curve radius, lengthen the easement curve and lengthen intermediate straight lines, respectively. Fig. 8.4E indicates that the length of straight line between two curves is not enough and then they are converted into a single curve. Fig. 8.4F indicates that the intermediate-straight line between two reverse curves is not enough and lengthen the intermediate straight line by moving middle tangent line.

(3) Replace curve with straight line (or dismantle bending straightening): if the standard of an existing line is too low or too circuitous, curves would be dismantled and are replaced with a segment of newly built straight line, as shown in Fig. 8.4G. Sometimes, changing position of individual buildings such as bridge and tunnel will cause the reconstruction of adjacent routes, as shown in Fig. 8.4H.

8.1.2.3 Technical Requirement of Plane Reconstruction

1. Curve radius

When reconstructing existing line, the minimum curve radius should be determined based on the speed of the passenger and freight train, combined with the comparing with feature and engineering condition of the existing lines. In the reconstruction section with 200 km/h design speed, the minimum curve radius is commonly 3500 m, 2800 m under difficult conditions. At reserve curve with radius 2500 m of the existing lines, train could negotiate with speed of 200 km/h. For sections with design speed lower than 160 km/h, under difficult conditions, if reconstructing based on new standard will lead to huge engineering, the minimum radius for plan reconstruction can be determined by technical and economic comparison.

The maximum speed of passenger train on a reconstructed existing line should be carefully determined according to transport demand, terrain along the line, operating conditions, and the difficulty of reconstruction. The minimum curve radius should not limit the maximum speed of passenger trains.

At these segments that passenger train speed is not high, such as both ends of large stations where all trains will stop, the summit of convex profile, continuous steep grade sections (the ascending speed is limited by locomotive traction, descending speed is limited by braking conditions), etc., designed radius of curve can somehow less than the minimum curve radius.

Curve with radius that limits the speed, if it is particularly difficult to reconstruct or the basis is well-founded, the original curve radius can be retained without reconstruction, and stipulating that trains negotiate the cover in limited speed.

For curves with smaller radius, if reconstruction can significantly increase the running speed, and the work quantity is relatively acceptable, or reconstruction can shorten travel time of the limited section, can increase carrying capacity of the whole district, it is necessary to reconstruct these curves.

Electric locomotive would be exerted great lateral thrust on small radius curve. When radius is 300–350 m, curves would aggravate wear and breakage of rail, widen gauge, pull break gauge tie rod, displace track laterally. These defects would be more serious in segments of steep grade sections as track creeping. So during the electrification of existing railways, the minimum curve radius should not be less than 300–350 m.

2. Compound curve

Reconstruction of existing railways, in difficult conditions, the existed compound curve can be reserved in order to reduce engineering work of reconstruction.

When keeping the compound curve, whether to set middle transition curve should be determined by the curvature difference of the two circular curve compared to critical value of K

$$K = \frac{3.6L(b+0.5f)}{11.8V_m^3}$$

where L is the length of car body (m), for the general passenger car, it takes 24 m; b is the change rate of deficient superelevation per second in mm/s, generally take 45 mm/s, 52.5 mm/s under difficult conditions; and f is the change rate of superelevation per second in mm/s, generally take 32 mm/s, 36 mm/s under difficult conditions; 40 mm/s under special difficult conditions.

(1) When $\leq K$, there may no need to set easement curve in the middle of compound curve. At this case, the length of easement curve at the ends of compound curve, in theory, should guarantee that the two single curve has the same offset from the tangent to the spiral, that is , or , therefore

(8.2)

When designing, an easement curve length can be selected first, then to calculate the length of another easement curve according to the above equation.

(2) When , it is necessary to set a middle easement curve. Transition curves at the two ends and in the middle of compound curve should theoretically have the same change rate of easement curve radius C, namely . When designing, it can choose a first easement curve length, then according following equation calculate the length of another easement curve and middle easement curve.

(8.3)

(8.4)

where IM is the length of middle easement curve.

The length of middle easement curve should meet the requirements of slope of superelevation, and is determined based on calculation. Under special circumstances, the original compound curve can be reserved.

(3) Easement curve and intermediate straight line

If easement curve length based on new reconstruction standard leads to large work quantity, shorter easement curve length can be applied. Its length should be calculated and determined based on real superelevation and slope rate of superelevation (see Table 8.1).

Table 8.1

The Maximum Slope of Superelevation for Reconstructed Existing Lines and Build Second Line at Parallel Section

Design speed of passenger train (km/h)	160	140	120	100	80
Maximum superelevation rate (‰)					
General section	1/(10 V)	1/(9 V)			
Difficult section	1/(8 V)	1/(7 V)			

Note: if the calculating result of the maximum slope of superelevation is greater than 2‰, 2‰ is selected, V is section design speed, in km/h.

$$(8.5)$$

where h is superelevation of outer rail. If speed is not limited by the radius of curve (mm) (V_{RMS} is the root mean square speed of section, in km/h).

When curve limits speed, it is difficult to reconstruct as restricted by track conditions and buildings, the curve can be reconstructed by setting different length of easement curve at the two ends of the circular curve.

The reconstruction segments with design speed of 200 km/h, the minimum length of intermediate straight line and circular curve is $0.7 V_{max}$, and $0.5 V_{max}$ in difficult conditions; at the existing reserved segments, it can be $0.4 V_{max}$.

When design speed is not more than 160 km/h, after changing the length of easement curve, circular curve and intermediate straight line should satisfy the design standard of newly built railway. In special difficult conditions, for sections with a design speed of passenger train less than 100 km/h, if the technical and economic bases are well founded, the length of circular curve and intermediate straight line cannot be restricted by design standard of newly built railway, but it should not be less than 25 m.

8.1.3 Design and Survey Method for Curve Reconstruction

Curve surveying and designing for reconstruction railway can employ the following two methods according to special situations:

- (1) When the distance between the existing lines and reconstructing lines is larger, the reconstructing line can be surveyed and designed with the method for newly built railway;
- (2) For the reconstruction of curve and its adjacent sections, it usually shift misalignment existing track to the designed position. When designing, it needs to calculate the throw of track for every stakes.

There are many methods to calculate the throw of track. For regular maintenance and repairing, string lining of curves is generally applied. For overhauling and rebuilding, the involute principle is applied to calculate throw.

8.1.3.1 Involute Method

1. Involute feature

The geometric significance of involute can be indicated in Fig. 8.5.

Curve OA is an arbitrary curve, which is non-deformable. When the curve segment OA is unfolded towards the tangent OA' "with the path travelled by point A perpendicular to the tangents at various points of the segment OA, then the path travelled $AM_1M_2M_3\dots A'$ " is called the "involute of point A of curve segment OA."

The Involute and the tangent of point O intersect at point A', the length of curve segment AA' is the length of involute for start tangent OA'.

The basic characteristics of the involute is as follows:

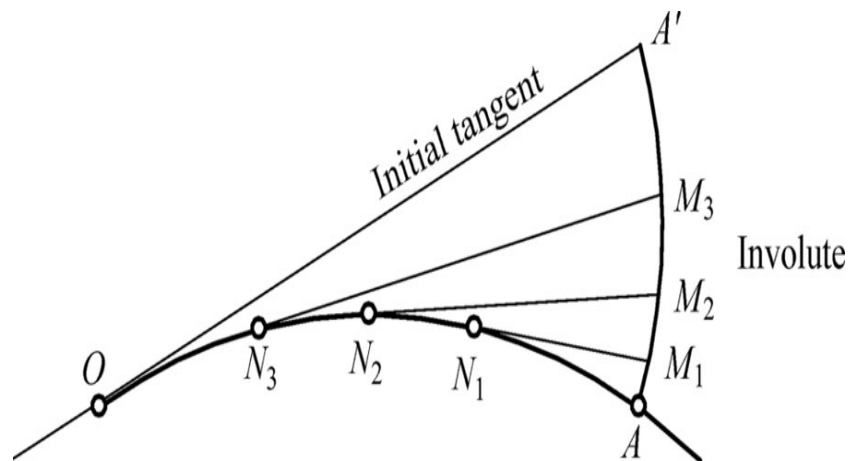


Fig. 8.5 Involute.

(1) Normal (M_3N_3) of point (M_3) on involute is the tangent of corresponding point (N_3) on curve OA;

(2) the curvature radius of involute is gradual, the curvature radius of point (M_3) on involute is the length (M_3N_3) of point (M_3) of normal to corresponding tangent point (N_3) of curve OA;

(3) the incremental ($M_3N_3 - M_2N_2$) of curvature radius of two points (M_3, N_3) on involute is equal to the arc length increment between corresponding point (N_3, N_2) on curve OA.

2. Calculation of involute length of standard curve

For a smoothness standard railway curve, the calculation equation of involute length can be deduced as follows.

(1) The length of involute E is the definite integral of central angle (rad) of curve OA on the corresponding arc segment (see Fig. 8.6).

The curvature of the involute is gradually changing. When $\Delta\alpha$ is very small, involute ΔE can be considered as circular arc segment, when points x_2 infinitely close to point x_1 , curvature radius of involute of curve segment Δl is ρ , then

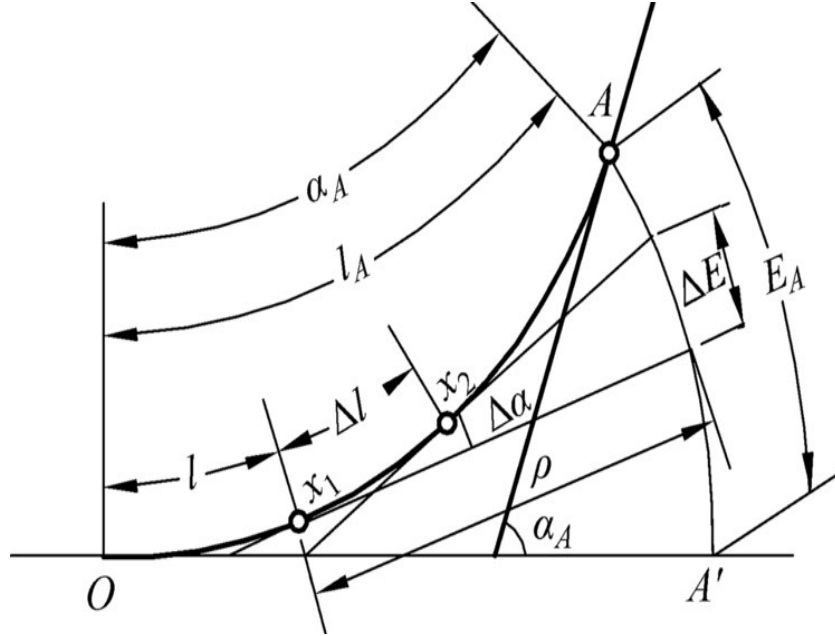


Fig. 8.6 Relationship between involute length and central angle.

$$\Delta E = \rho \times \Delta\alpha = (l_A - l)\Delta\alpha$$

$$E_A = AA' = \int_0^{\alpha_A} (l_A - l) d\alpha = \int_0^{\alpha_A} l_A d\alpha - \int_0^{\alpha_A} l d\alpha = l_A \alpha_A - \int_0^{\alpha_A} l d\alpha$$

(8.6)

As l is a function of α , employ integration by parts on the second item above equation, then

$$E_A = l_A \alpha_A - \left(l_A \alpha_A - \int_0^{l_A} \alpha dl \right) = \int_0^{l_A} \alpha dl$$

(2) The central angle α_A of curve OA (rad) is the definite integral of the curvature K on the corresponding segment of OA (see Fig. 8.7).

(R is the radius of calculation point on curve OA)

(K is the curvature of calculation point on curve OA, $K=1/R$)

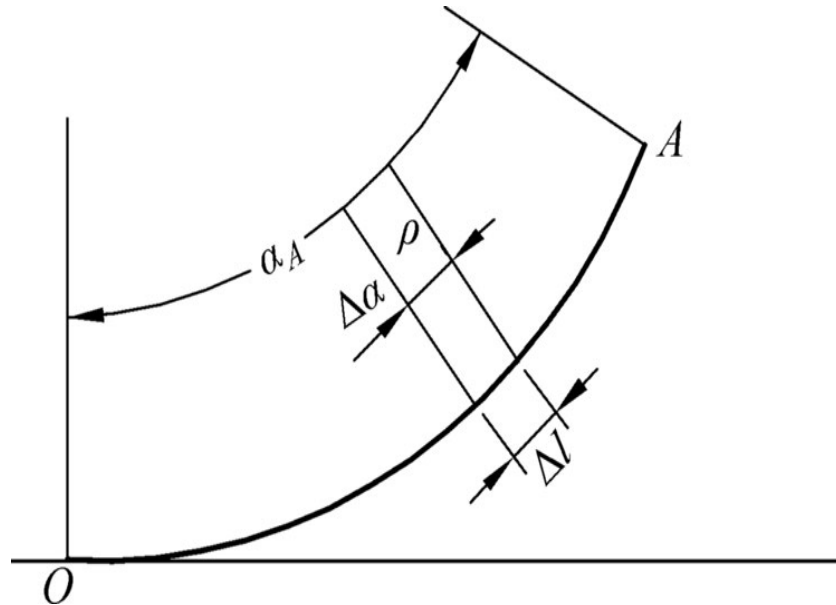


Fig. 8.7 Relationship between central angle and curvature.

(8.7)

(3) Curvature of circular curve and cubic parabolic curve

Let curve OA express the centerline of track on curve segment, the curve OA consists of easement curves and circular curve. Curvature of circular curve is constant K, $K=1/R$. Curvature of easement curve K is a variable, changing with the length l from calculation point to point TS (or ST), . C is radius change rate of easement curve, R is circular curve radius, l_0 is the length of easement curve.

(4) Calculation equation of involute length

Based on curvature K of the circular curve and easement curve, calculation equations of involute length of circular curve and easement curve can be deduced with formulas (8.6) and (8.7), as shown in Table 8.2.

Table 8.2

Equations for Computing Involute Length

Physical Significance	General Equation	Equation of
1	Curvature K	K
2	Central angle α (rad) is definite integral of curvature K	
3	Involute length E is definite integral of central angle α (rad)	
Significance of symbol	I —Length of curve K —Curvature α —Central angle (rad) E —Involute length	R —Radius of

(5) Practical calculation equation of involute length

Comprehensive analysis of curve features of every curve, both ends of circular curve have easement curve, practical calculation equation of involute length are listed in Table 8.3.

Table 8.3

Practical Calculation Equation of Involute Length

Measuring Point Range	Calculation Equation of Involute Length	Significance of Symbol
TS—SC		l =station point kilometer—TS kilometer
SC—CS		L =station point kilometer—TC kilometer
CS—ST		L =station point kilometer—TC kilometer
After ST	$E=X\alpha$	X =station point kilometer—CM kilomete

Here R is curve radius (m), l_0 is easement length (m), and α is angle (rad), .

3. Calculation of the length of involute of the existing curve

The deflection angle of each 20 m station points has been measured on the curve survey in field, as shown in Fig. 8.3. These deflection angles are the basic data to calculate the involute length of the existing curve.

1) Deriving calculation equation

(1) Basic equation

Although the existing curve track has been misaligned, its shape is still close to the projected curve, so that it can still be calculated according to the character of easement curve and circular curve. According to the calculation equation of involute length in Table 8.2, the basic equation of involute length may be as follows:

① The involute length of circular curve is

$$E = \int_0^L \alpha dL = \int_0^L \frac{L}{R} dL = \frac{L^2}{2R} = \frac{1L}{2R} \times L = \phi L$$

where ϕ is deflection angle of station point,

② The involute length of easement curve is

$$E = \int_0^l \alpha \times dl = \int_0^l \frac{l^2}{2Rl_0} dl = \frac{l^3}{6Rl_0} = \frac{l^2}{6Rl_0} \times l = \phi \times l$$

where ϕ is deflection angle of station point,

③ Accordingly, no matter for circular curve or easement curve, involute length of the existing curve at a station point is

$$E = \begin{matrix} \text{the deflection angle(rad) of station point} \\ \times \text{curve length from station point to instrument position.} \end{matrix}$$

(2) The calculation equations of various instrument positions

① If the instrument position is set on the beginning tangent line, as shown in Fig. 8.8, the basic equation can also be used to calculate the length of involute and the error is very small. Because the involute length EA is very short, EA is approximately equal to the corresponding length of circular arc, and the curvature of starting curve segment is small, chord length OA is approximately equal to arc length IA . Therefore,

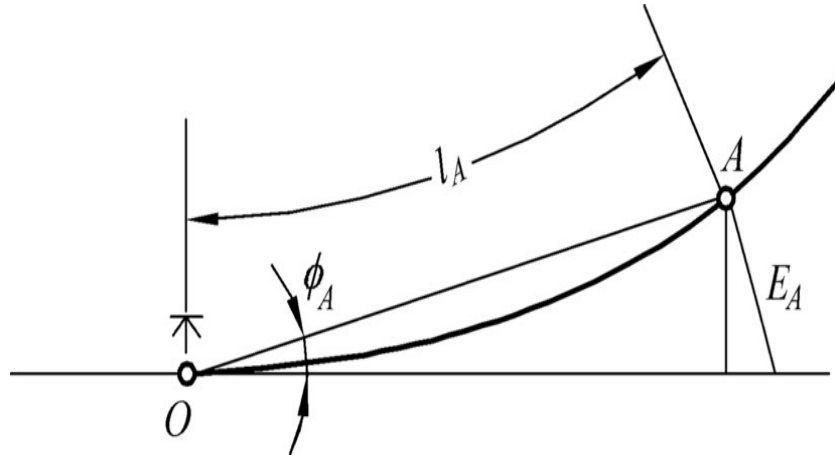


Fig. 8.8 Instrument position on beginning tangent.

$$E_A \approx OA \times \phi_A \approx l_A \times \phi_A$$

② The instrument position moved to point A, as shown in Fig. 8.9, after measuring the deflection angle of point B, then the involute length of point B can be calculated by using $BB' + B'P$, BB' can be calculated with basic equation, $B'P$ is the involute length for OA and AB' .

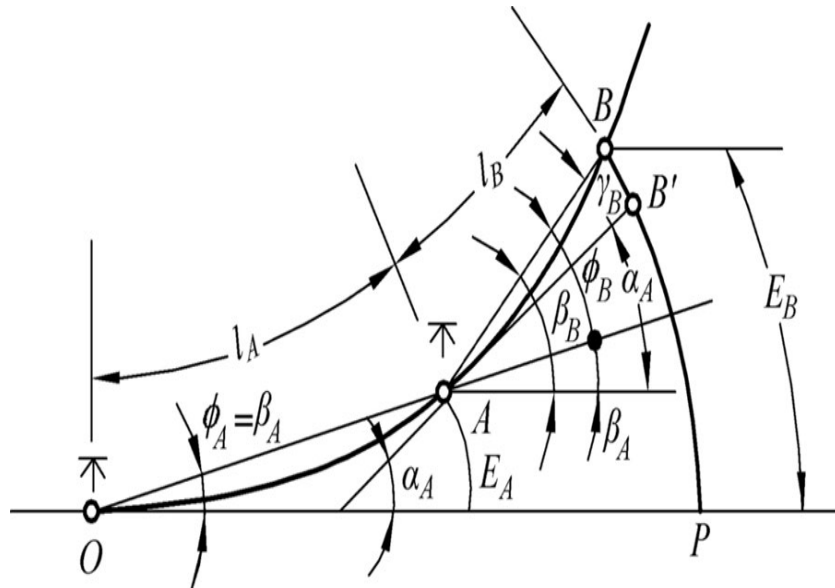


Fig. 8.9 Instrument position A on curve.

$$\begin{aligned}
E_B &= BB' + B'P = BB' + \int_0^{l_A + AB'} \alpha dl = l_B \times \gamma_B + \int_0^{l_A} \alpha dl + \int_{l_A}^{l_A + AB'} \alpha_A dl \\
&= l_B \times \gamma_B + E_A + l_B \times \alpha_A = E_A + l_B(\gamma_B + \alpha_A) \\
&= E_A + l_B \times \beta_B
\end{aligned}$$

where E_A is the involute length of instrument position A; l_B is the curve length from instrument position A to station point B; γ_B is the angle of chord AB and tangent AB; α_A is the angle of tangent AB' and the beginning tangent; β_B is the angle radian number (rad) of chord AB and the beginning tangent,

$$\beta_B = \beta_A + \phi_B = \phi_A + \phi_{B\odot}$$

③ Instrument position move to point B, as shown in Fig. 8.10, after measuring the deflection angle ϕ_C of point C, the involute length of the point C E_C is calculated by using available $CC' + C'P$, $C'P$ is the involute length of OAB and BC' .

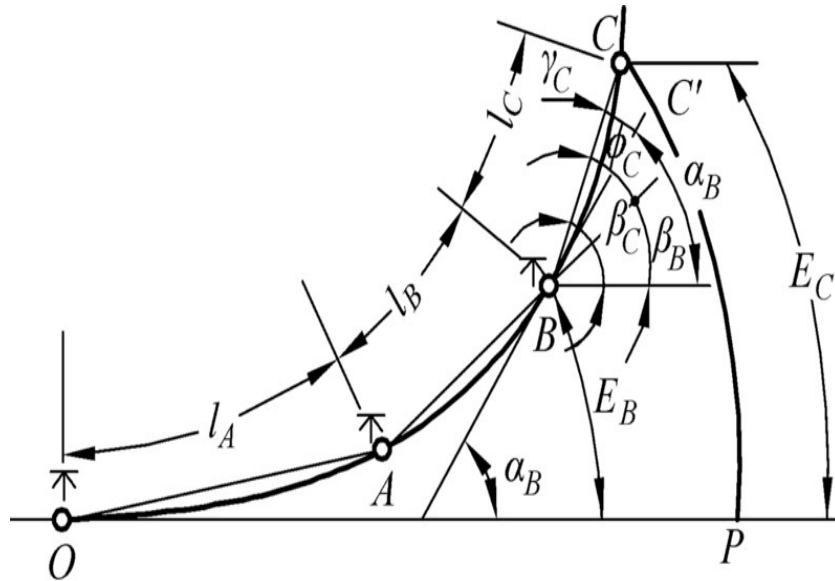


Fig. 8.10 Mirror point B on curve.

$$\begin{aligned}
E_C &= CC' + C'P = l_C \times \gamma_C + \int_0^{l_A + l_B + BC'} \alpha dl \\
&= l_C \times \gamma_C + \int_0^{l_A + l_B} \alpha dl + \int_{l_A + l_B}^{l_A + l_B + BC'} \alpha_B dl \\
&= l_C \times \gamma_C + E_B + l_C \times \alpha_B = E_B + l_C(\gamma_C + \alpha_B) \\
&= E_B + l_C \times \beta_C
\end{aligned}$$

Throw Calculation of the Existing Curved Track (Curve No. 27; Turning direction: left)

Survey Data of the Existing Curve	Involute Length of the Existing Curve	Kilometer of Main Points of I
Instrument Point	Station Kilometer	ϕ (° ' ")
+	—	
1	2	3
	K9+960	
	+980	0 00 10
	K10+000	0 00 20
	+020	0 01 30
	+040	0 09 20
	+060	0 24 50
	+080	0 49 00
	K10+100	1 21 40
	+120	5 31 00
	+140	6 39 40
	+160	7 48 30
	+180	8 57 20
	+200	10 06 10
	+220	11 14 40
	+240	12 23 40
	+260	13 32 20
	K10+280	14 41 00
	+300	11 23 00
	+320	12 17 00
	+340	13 02 20
	+360	13 38 30
	+380	14 05 30

	K10+400	14 24 10
	Front view point	1 33 10

Notes: $\alpha = 32^{\circ}00'00'' = 0.558\ 505\ 4\ \text{rad}$, $RSD = 500$, $LD = RSD\alpha = 279.252\ 7$, distance from last station point to CM $X = 210.382$, $CM = K10+189.618$, $l_0 = 100$, $= 0.833$.

4. Calculation of adjusting distance

1) Conditions for calculating adjusting distance

The basic theory and basic method of adjusting distance calculation described in this section is applicable to correct the general misaligned curved track in plane reconstruction. The following points should be paid attention in design.

(1) Precondition

To restore the misaligned existing curved track back to the acceptable smoothness with the involute method, the length of curve should basically remain unchanged to ensure the accuracy of the necessary calculation. Therefore, the following method can only be applied to the curve reconstruction design to restore the misaligned existing curved track back to the acceptable smoothness, and the curve length will not be much different before and after curve shifting. If the angle of the existing curve is bigger, and the curve radius needs to be increased, the length of plane alignment will be shorter after reconstruction. In this case, to compute the throw by means of involute method will produce very big error, the throw should be calculated employing other special methods.

(2) Ensure the end tangent line not to be shifted

Firstly, ensuring the deflection angle of the existing curve shall not be changed, in order to avoid the end tangent being turned around. To meet this condition, the design should guarantee that the deflection angle of design curve is equal to that of the existing curve.

Secondly, the throw of last station point of the existing curve must be zero, lest causing parallel movement of the end tangent, therefore, it is required to make the involute length of design curve be equal to that of the existing curve at the last station point, i.e., .

(3) Making effort to reduce the work quantity of curve reconstruction

To reconstruct an existing curve, as different radius and different length of easement curve of the design curve shall affect the throw and shifting direction of the existing curved track, so when choosing radius of and the easement curve length of design curve, the following factors shall be considered to strive to reduce the reconstruction work.

① If there are permanent buildings located in curve segment such as bridges, tunnels, the design should make the centerline of bridges or tunnels not to be realigned as far as possible, or control the throw within 5 cm, in order not to cause reconstruction of bridges and tunnel.

② If there are retaining walls, slope protection or protection engineering works at one side of the subgrade, the existing line shall be shifted to the other side, so as to avoid destroying any original works.

③ At sections of deep cut, or high embankments, the amount of throw shall be reduced as much as possible to avoid large earthwork.

④ If the width of the subgrade surface of existing railways is not meet the standards, all the throw should be completed by moving existing track to one side, avoiding widening both sides of subgrade. If the subgrade was constructed on the slopes with good geological conditions, it is appropriate to move the alignment upon to the slope, in order to reduce subgrade widening engineering. Under special circumstances, the direction and throw of track shifting should be determined on the cross section diagram with the conditions of subgrade reconstruction.

2) Select radius of design curve

(1) Estimate radius of the existing curve

Before selecting the radius of design curve, the radius of the existing curve should be estimated. Radius of the existing curve provided by technical data of railway administration and the field marks of curve, can be used as reference data for selecting radius for design curve.

A lot of methods can be applied to estimate the radius of the existing curve, but the principles are roughly the same, three methods are introduced here.

• Average deflection angle method

In field surveys, if there is a instrument position A in the range of circular curve, the deflection angles $\phi_1, \phi_2, \dots, \phi_n$ of station points $a_1, a_2, \dots$, within the circular curve can then be measured, as shown in Fig. 8.11A. The chord length between two station points is $\Delta L = 20$ m, the average deflection angle between two station points is $\Delta\phi$ is corresponding inscribed angle faced by the y the short chord ΔL , which should be equal to the half of central angle $\Delta\alpha$ faced by short chord ΔL , thus $\Delta\phi = \frac{1}{2}\Delta\alpha$. As shown in Fig. 8.11B, the estimation of the existing curve radius R_j is

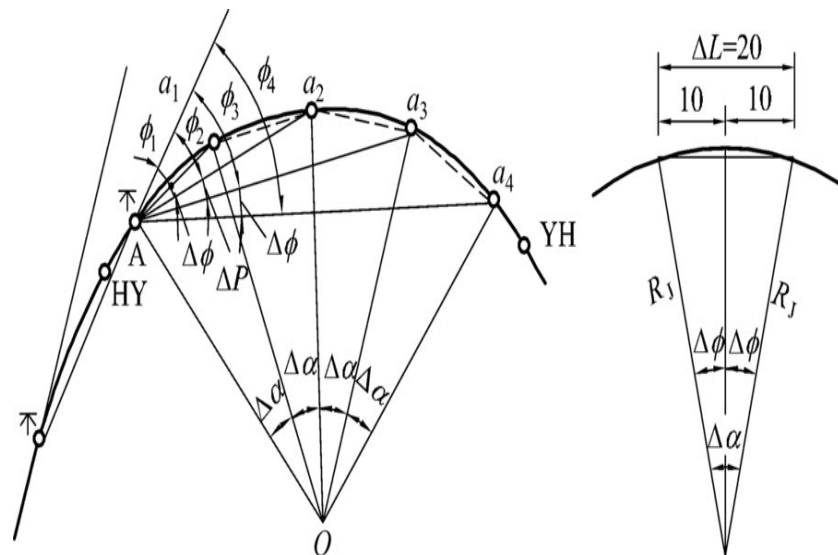


Fig. 8.11 Average deflection angle method.

As in the instance in Table 8.4, from K10+100 to K10+ 280 is circle curve section,
 $\phi_1=5^\circ31'00''$, $\phi_9=14^\circ41'00''$.

$$\Delta\phi = \frac{\phi_9 - \phi_1}{9 - 1}$$

$$= \frac{14^\circ41'00'' - 5^\circ31'00''}{9 - 1} = 1^\circ08'45''$$

$$R_J = \frac{10}{\sin 1^\circ08'45''} = 500.07 \text{ (m)}$$

- Three-point method

As shown in Fig. 8.12, within the circular curve range of the existing curve, select three station points with equal spacing, $AB=BC=L$, namely the involute of three station points are

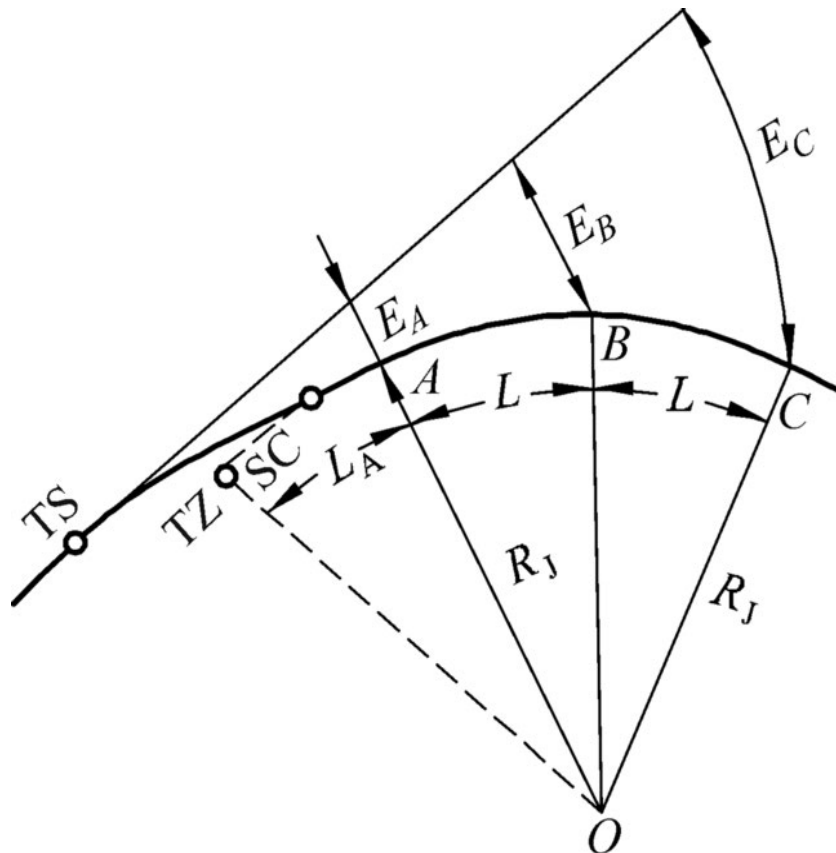


Fig. 8.12 Three-point method.

$$\begin{aligned}
E_A &= \frac{L_A^2}{2R_J} + p_J, \quad E_B = \frac{(L_A + L)^2}{2R_J} + p_J, \quad E_C = \frac{(L_A + 2L)^2}{2R_J} + p_J \\
E_B - E_A &= \frac{(L_A + L)^2}{2R_J} - \frac{L_A^2}{2R_J} \\
E_C - E_B &= \frac{(L_A + 2L)^2}{2R_J} - \frac{(L_A + L)^2}{2R_J} \\
E_C + E_A - 2E_B &= \frac{(L_A + 2L)^2}{2R_J} + \frac{L_A^2}{2R_J} - 2 \frac{(L_A + L)^2}{2R_J} = \frac{L^2}{R_J} \quad (\text{m})
\end{aligned}$$

(8.11)

- Method of second-order difference

The above equation is essentially deduced with the concept of the second-order difference.

Three-point method only uses the data of the three points, which cannot fully reflect the geometrical characteristic of the existing circular curve. If the existing curve has been misaligned seriously, the different selection of the three station points would get different projected radius by means of three-point method., in order to consider the whole influence of all station points in existing curve, we can estimate the radius of the existing curve based on the average value of second order difference of involute length of every point within the existing curve. At this moment, the length between each station point is ΔL , $\Delta L=20$ m, the number of second order difference is n , and the average value of second order difference is $\Delta^2 E_p =$. The radius of the existing curve may be estimated using the following formula:

$$R_J = \frac{(\Delta L)^2}{\Delta^2 E_p} = \frac{n \times (\Delta L)^2}{\sum_1^n (\Delta^2 E)} = \frac{400n}{\sum_1^n (\Delta^2 E)} \quad (\text{m})$$

(8.12)

Take Table 8.4 for example; the circle curve segment is from K10+100 to K10+260. Using three-point method, take K10+100 as point A, involute length at A is, $E_A=3.326$; take K10+180 as point B, $E_B=17.731$, take K10+260 as point C, $E_C=44.935$; the distance from A to C is $L=80$. Then the radius of the existing curve is estimated as

$$R_J = \frac{L^2}{E_C + E_A - 2E_B} = \frac{80^2}{44.935 + 3.326 - 2 \times 17.731} = 500.04 \quad (\text{m})$$

There are nine station points from K10+100 to K10+260 the number of second order differences is $n=7$, the sum of second order differences is $=5.597$, then the estimated radius by Eq. (8.12) is

$$R_J = \frac{400n}{\sum(\Delta^2 E)} = \frac{400 \times 7}{5.597} = 500.27 \text{ (m)}$$

(2) Rules for integer of the estimated curve radius

The radius of the design curve should usually be close to the estimated radius of the existing curve; for the convenience of calculation and survey, radius of design curve should be taken as an integer. The precision in rounding can take data in Table 8.5 as reference. The instance of design curve radius in this section was preferable whole RS=500 m.

Table 8.5

Precision in Rounding Curve Radius

Angle (°)	<10	10~20	20~30	30~50	>50
Precision (m)	±25	±10	±5	±2~±1	Select by specific situation

3) Calculation of kilometer of CMP

The selected radius of design curve can ensure that the design curve arc is close to existing curve arc, but has not yet determined the definite location of the design curve. Therefore, the kilometer of midpoint of curve CMP of the design curve should be calculated.

The kilometer CMP should ensure the end tangent line of curve would not be moved, namely the deflection angle of curve remain unchanged after track lining (), and the adjusting distance of last station point is zero ().

Involute length of last station point of design curve is , let , then

$$X = \frac{E_J}{\alpha} \text{ (m)}$$

Kilometer of CMP = kilometer of last station point – X

(8.13)

where X is the distance from last station point to point CMP (m); E_J is the involute length of the last station point of the existing curve (m); and α is the deflection angle of curve (rad).

In the instance of this section: deflection angle $\alpha = 32^\circ 00' 00'' = 0.558\ 505\ 4$ rad, kilometer of the last station point is K10+400, the involute length of the existing curve is 117.499 m, so

$$X = \frac{E_J}{\alpha} = \frac{117.499}{0.558\ 505\ 4} = 210.382 \text{ (m)}$$

4) Selecting the length of easement curve

According to the technical data of railway administration or the field curve marks, the original projected length of the existing easement curve can be obtained, which can be used as a reference to design the length of new easement curve.

When the radius of design curve has been determined, in order to reduce the adjusting distance, the following methods can be adopted to select the length of easement curve.

① Calculating the length of projected circular curve: $R_D \times \alpha$, and according to the kilometer of point CMP to calculate the kilometer of point TC:

$$\text{TC kilometer} = \text{CMP kilometer} - (R_D \times \alpha) / 2$$

② To select three station points in circular segment as the basic data points, and compute their involute length of design curve using the equation, where L is kilometer of station

point as a known number; as l_0 need to select, pD is unknown now.

③ For each of these selected station points, let $ED=EE$, $pD=pE$, then the offset of spiral at each selected point can be calculated.

④ Find out the average of pD of three selected points pD , from the equation , the length of design easement curve can be calculated.

We can obtain the length of the design easement curve by taking l_0 to 10 m integer. The length of the easement curve should usually comply with the standard of reconstruction.

In the instance of this section: $RD=500$ m, $\alpha=0.558\ 505$ rad, CMP kilometer is K10+189.618. The following two points are applied to calculate the length of easement curve, K10+100, $EE=3.326$; K10+260, $EE =44.935$.

$$R_s \times \alpha = 500 \times 0.558\ 505 = 279.252$$

$$\begin{aligned} ZY \text{ mileage} &= QZ \text{ mileage} - \frac{R_s \times \alpha}{2} = K10 + 189.618 - 279.252/2 \\ &= K10 + 49.992 \end{aligned}$$

$$K10 + 100: L = 50.008, p'_s = E_J - \frac{L^2}{2R} = 3.326 - \frac{50.008^2}{2 \times 500} = 0.825 \text{ (m)}$$

$$K10 + 260: L = 210.008, p''_s = E_J - \frac{L^2}{2R} = 44.935 - \frac{210.008^2}{2 \times 500} = 0.832 \text{ (m)}$$

$$p_s = (p'_s + p''_s) / 2 = 0.829 \text{ (m)}$$

$$l_0 = \sqrt{24R_s \times p_s} = \sqrt{24 \times 500 \times 0.829} = 99.74 \text{ (m)}$$

So, the length of easement curve is 100 m.

5) Calculating the kilometers of main point of design curve

Calculating the kilometer of main point of design curve, fill the calculation results in 9th column of Table 8.4, which main point range close to the station point, it fill in the row of the station point.

6) Calculating involute length of design curve

According to the equation listed in Table 8.3, calculation steps and methods are shown 10th to 15th in Table 8.4.

7) Calculation of throw

(1) The value and direction of throw

As shown in Fig. 8.13, the curve correcting is to shift point every 20 m on the existing curve such as b_1 and b_2 to b_1' , b_2' on design curve, throws respectively are b_1b_1' and b_2b_2' , namely the difference between involute length of design curve a_1b_1' or a_2b_2' with involute length of the existing curve a_1b_1 or a_2b_2 .

throw of point b1:

throw of point b2:

So the throw=involute length of design curve—involute length of the existing curve

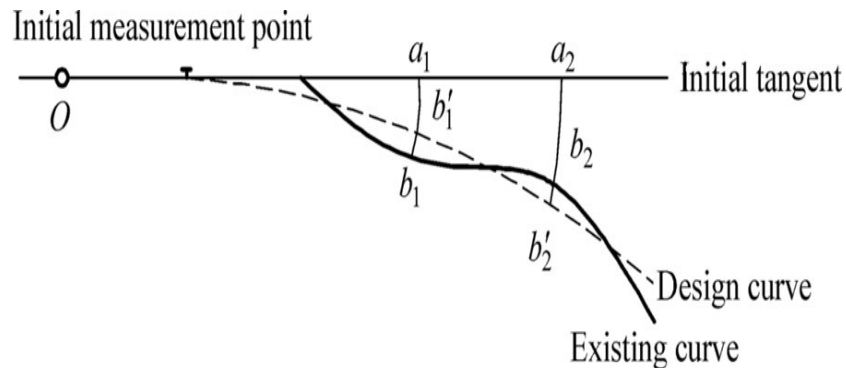


Fig. 8.13 Curve correction.

$$\Delta = E_S - E_J$$

Δ is positive, such as b_2b_2' , means shift track toward circle center (curve dent); and

Δ is negative, such as b_1b_1' , means shift in tangent direction (curve protruding).

Strictly speaking, shifting direction is moving in the direction of the involute. But because the throw is very small, involute direction can be completely considered to be the same as the normal direction of the existing curve. So in the practical work, existing curve can be corrected along the normal direction.

When calculating the throw of track, assume the length of curve does not change after shifting. Of course for a certain point, the line will be lengthened if the station point is outside the curve, inside the curve the line will be shorten. But for the whole curve, some points are outside, the others are inside, and each throw will not be very big. So the assumption of constant curve length before and after the shifting can satisfy the accuracy requirement of the throw calculation.

In the throw calculation, 20 m chord length is used to replace the curve length. Because the curve radius is much larger than 20 m chord, so 20 m chord almost the same length as its relative curve, using 20 m chord length instead of the curve arc length would not affect the calculation accuracy.

(2) Steps for calculating throw of track

- ① Calculate involute length EE of each station point on existing curve;
- ② Selected radius of design curve RD;
- ③ Calculate involute length ED of each station point on design curve;

- ④ Calculate throw at station n (positive implies shifting outwards and negative inwards) Δ ,

$$\Delta = E_D - E_E.$$

the throw $\Delta = E_D - E_E$, fill in 16th column of the Table 8.4. Numerical in 16th column = numerical in 15th column – numerical 8th column.

Δ is positive value, it means $E_D > E_E$, the shifting direction of station point is toward the center of circle (curve is pressured to internally);

Δ is negative value, it means $E_D < E_E$, the shifting direction of station point is toward tangent (Curve outside pick).

8.1.3.2 String Lining of Curves

The method of “string lining of curves” is most generally used among all other for the correction of the alignment of the curved tracks. The mid-ordinate of the curve is corrected by means of the relationships between the mid-ordinate and the radius of curvature of the curve to recover its specified radius of curvature. The misaligned track is then shifted back to its original projected position with appropriate throws.

Before the track realignment, the mid-ordinates at all station points should be measured first. The outer rail of the curved tracks is generally taken as the datum line and station points are marked every 10 m on the rail. A 20 m non-deformable string is stretched between alternate stations 16 mm below the surface of the outer rails and the distance between the string and the gauge side at the intermediate station (called measured mid-ordinate) is measured and recorded. It is specified that, when the errors of the measured mid-ordinate exceeds the limit as shown in Table 8.6, it should be corrected without delay.

Table 8.6

Limits for Errors of the Measured Mid-ordinate (units in mm)

Limits for Errors of the Measured Mid-ordinate (units in mm)		
Radius of Curve (m)	Allowable Error (Transition Spirals)	Allowable Error (Success
Main Lines Receiving Departure Sidings	Other Sidings and Lines	Main Lines, Receiving De
250	7	8

251-350	6	7
351-450	5	6
451-650	4	5
650	3	4

The mid-ordinates at all stations required after the misaligned curved track is corrected are called the “projected mid-ordinates.” When the measured and projected mid-ordinates are different from each other, the “throw” at all stations should be calculated using the relations between the mid-ordinate, radius of curvature and the throw, and the curve realigned. In order to clarify the fundamental principles of the method of string lining of curves, the method of calculations of the projected mid-ordinates for circular as well as easement curves and that of the throw are outlined as follows.

1. Calculation of projected mid-ordinates for circular curves

For circular curves where the radius of curve R is far greater than the mid-ordinate f_0 , their relations can be expressed by the following equation with sufficient accuracy.

$$(8.14)$$

In which,

L —chord length used for the measurement of mid-ordinates, taken as 20 m.

Substitute into Eq. (8.14), we have

$$f_0 = \frac{20 \times 20}{8R} \times 1000 = \frac{50000}{R} \text{ (mm)}$$

$$(8.15)$$

In which, f_0 is the mid-ordinates of the circular curves, mm; R is the radius of the circular curve, m.

The mid-ordinates f_0 at all stations on the circular curve, with the exception of T.C. and C.T. should be equal to each other. At T.C. and C.T., the mid-ordinate is different from f_0 because the radius of curvature on both sides of the station are unequal. When no easement curves are used, the relations between the mid-ordinate f_0 at T.C. and that of the circular curve f_0 can be obtained from Fig. 8.14.


$$f_c = y_1, f_0 = \frac{1}{2}y_1$$

(8.16)

2. Calculation of projected mid-ordinates for transition spirals

Fig. 8.15 shows a part of the transition spiral and its nearby straight line. T.S is the beginning of the transition spiral, designated as station 0 and 1,2,... are successive stations on the transition spiral. Let $f_0, f_1, f_2, \dots$ be the mid-ordinates at stations 0,1,2,..., respectively. Also, let λ be the distance between successive stations, equal to one half of the chord length L , $L=2\lambda$; $y_0, y_1, y_2, \dots$ be the tangent offsets at the respective stations. For cubic spirals, the tangent offset y can be calculated by the following equation.

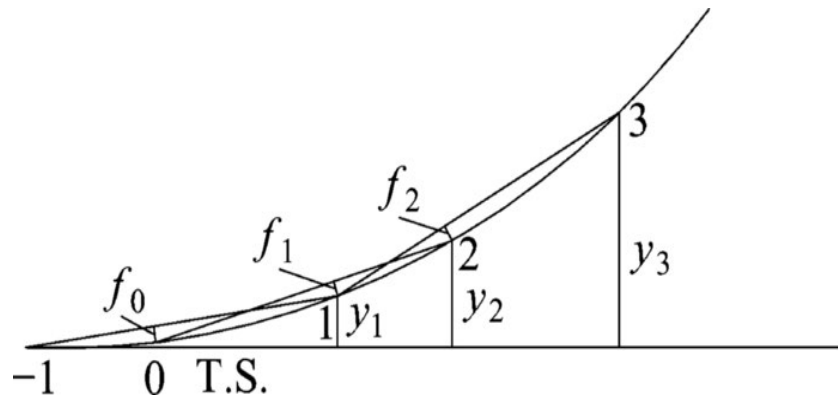


Fig. 8.15 The tangent offset.

$$y = \frac{l^3}{6R_0l_0}$$

In which, l is the length of arc from T.S. to the station point in concern. Take approximately, from which we have,

$$y_1 = \frac{\lambda^3}{6R_0l_0}$$

$$y_2 = \frac{(2\lambda)^3}{6R_0l_0} = 8y_1$$

Since at the end of the transition spiral (S.C.), the angle of inclination ϕ_0 with respect to the tangent is very small, it can be accurate enough to recognize that $f_1, f_2, \dots$ falls on the line of prolongation of $y_1, y_2, \dots$ (see Fig. 8.15), from which we have

$$(8.17)$$

$$(8.18)$$

that is to say, the mid-ordinate at T.S. is equal to one sixty of the mid-ordinate f_1 at the first station ahead of T.S. f_1 is also called the rate of increase of the mid-ordinates on the transition spirals, designed as f_0 . This is because of the fact that, to the left of T.S., ALL mid-ordinates on the straight line is equal to zero; while to the right, the mid-ordinates on the transition spiral increase proportionately with the increase of the distance from T.S. In case the end of transition spiral S.C. also falls on a regular station point, the same thing will

happen. Since to the right of S.C., all mid-ordinates on the circular curves are equal to f_0 ; while the left, the mid-ordinates on the transition spiral decrease proportionately with the increase of the distance from S.C. Therefore, according to the same argument, the mid-ordinate at S.C. will be less than f_0 , equal to , In case, S.C. does not fall on a regular station point, it could be calculated separately, see 8.1.3.2, 3 of this section.

Since the radius of the transition spiral p is variable for all stations, it is natural that the mid-ordinate f is also variable. From Eq. (8.10), we have

$$f_1 = 3y_1 = 3 \frac{\lambda^3}{6R_0 l_0} = \frac{\lambda^3}{2R_0 l_0} = \left(\frac{\lambda^2}{2R_0} \right) \div \left(\frac{l_0}{\lambda} \right) = \frac{f_0}{n}$$

(8.19)

where f_1 is the mid-ordinate of the circular curve, ; and n is the number of segments of the transition spiral,

$$n = \frac{l_0}{\lambda}.$$

[Fig. 8.15 also shows that](#)

$$f_2 = 2f_1, f_3 = 3f_1,$$

We call the mid-ordinate of the first station ahead of T.S. f_1 as the rate of increase of the mid-ordinate spiral, designed as f_a ,

(8.20)

Thus, the mid-ordinates at all station on the transition spiral can be rewritten as

$$f_0 = \frac{f_a}{6}, f_1 = f_a, f_2 = 2f_a, \dots$$

It is clear that the mid-ordinates on the transition spiral increase proportionately. Once the value of f_2 is calculated from Eq. (8.13), those at other stations can be readily calculated.

3. Ditto, while station points do not coincide with the beginning or end of curve

It is assumed before that the length of the circular curve is multiples of 10 m, while it is not so in actual practice. As a result, the beginning and end of the second transition spiral (C.S.

and S.T.) will not coincide with the regular station points marked on the rail. Hence the mid-ordinates at station to the left and right of C.S. and S.T. (and possibly also that of T.S. and S.C.) should be calculated specifically.

1) Calculations of mid-ordinates at stations to the left and right of T.S. or S.T.

For the case of presentation, the first transition spiral is taken as the example. In the case of the second transition spiral, the something holds, except S.T. and C.S. are used instead of T.S. and S.C.

As shown in Fig. 8.16, T.S. dose not coincide with the regular station point but is in-between station 0 on the straight line and station 1 on the transition spiral, with distances A and B from them respectively. The mid-ordinates at 0 and 1 are f_a and f_b . λ is the half chord length, equal to .

It is clear from Fig.8.16 that,

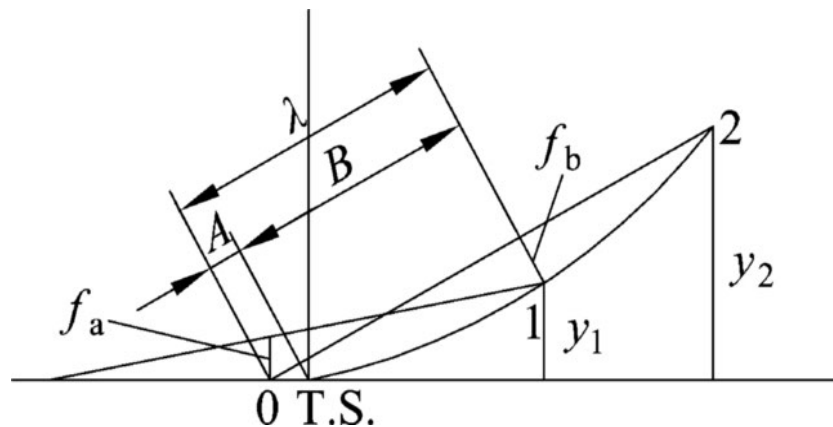


Fig. 8.16 The mid-ordinates at 0 and 1.

$$f_0 = \frac{1}{2}y_1 = \frac{1}{26Rl_0}B^3$$

Since, , , , substitute into the above equation, simplify, we obtain,

$$(8.21)$$

In which, is the “correction factor” used for the calculation of the mid-ordinate f_a at station 0 to the left of T.S. α_a can be calculated directly or prepared in tabular forms with different values of ready for use. Similarly, . Substitute, , , , into the above equation, simplify, finally we obtain

$$f_b = \frac{1}{6}f_s \left[\left(1 + \frac{B}{\lambda}\right)^3 - \left(\frac{B}{\lambda}\right)^3 \right] = \alpha_b f_s$$

(8.16)

where is the “correction factor” for the calculation of the mid-ordinates f_b at station 1 to the right of T.S.

2) Calculation of mid-ordinates at stations to the left and right of S.C or C.S.

As shown in Fig. 8.17, S.C. does not coincide with the regular station point, but is in-between station a on the circular curve and station b on the transition spiral, with distances A and B from them, respectively. The mid-ordinates at station a and b are f_a and f_b .

Following the same reasoning as before, we have

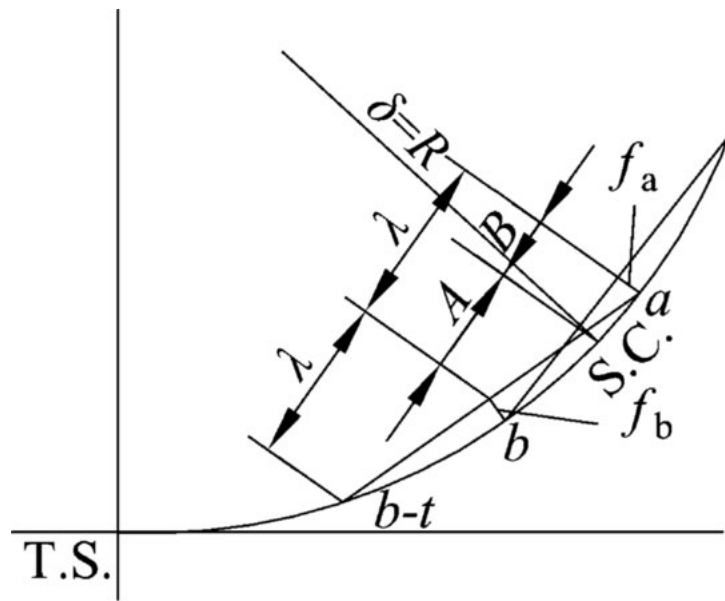


Fig. 8.17 The mid-ordinates at station a and b.

$$f_b = f_c - f_s \frac{1}{6} \left[\left(1 + \frac{B}{\lambda}\right)^3 - \left(\frac{B}{\lambda}\right)^3 \right] = f_c - \alpha_b f_s$$

$$f_a = f_c - f_s \cdot \frac{1}{6} \left(\frac{B}{\lambda}\right)^3 = f_c - \alpha_b f_s$$

(8.22)

where α_a and α_b are the “correction factor” for the calculation of the mid-ordinates f_a and f_b at stations a and b to the right and left of S.C., respectively.

3) Calculation of mid-ordinates at all other stations on the transition spiral

Projected mid-ordinates at all other stations on the transition spiral can be calculated according to the principle of linear proportionality of the mid-ordinates at stations with respect to their distances from T.S. as follows.

$$(8.23)$$

In which, f_i -mid-ordinate at station i -distant l_i from T.S. and other symbols same as before.

4. Calculation of throw

In order to restore the misaligned curved track back to its acceptable smoothness, the overall realignment of the track should be proceeded. In Fig. 8.18, full line represents the position of the misaligned curve before it is realigned and dotted line represents that of the curve after it is realigned. In this connection, different throws are required at different stations, some of which direct outwards and others direct inwards.

For instance, at point n , the track should be shifted outwards a throw e_n in order to reach its correct position n_1 . when the segment A_n of the misaligned curve is unfolded towards the tangent A_n “with the path travelled by point n perpendicular to the tangents at various points of the segment A_n , then the path travelled nn_1 ” is called the “involute” and its length E_n the “the length of involute” of the curve segment A_n . Similarly, n'_1n and are the involute and length of involute of the curve segment $A_{n'}$ after it is realigned. From which, the throw e_n at station n will be , positive e_n implies that the curve should be shifted outwards, otherwise, inwards.

The method of calculation of the length of involute at any point on the curve is as follows.

In Fig. 8.19, $0, 1, 2, 3, \dots, n$ are the station points on the curve and $f_0, f_1, f_2, f_3, \dots, f_n$ their respective mid-ordinates and $E_0, E_1, E_2, E_3, \dots, E_n$ their respective length of involute.

It can be seen from the figure that

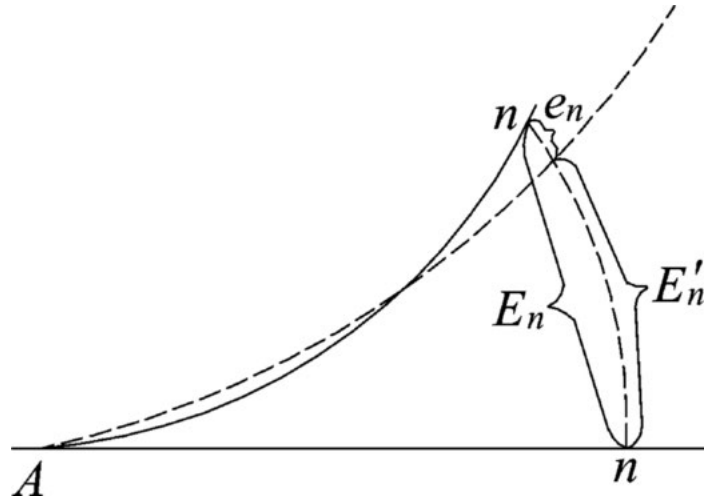


Fig. 8.18 The 'length of involute' of the curve segment A-n.

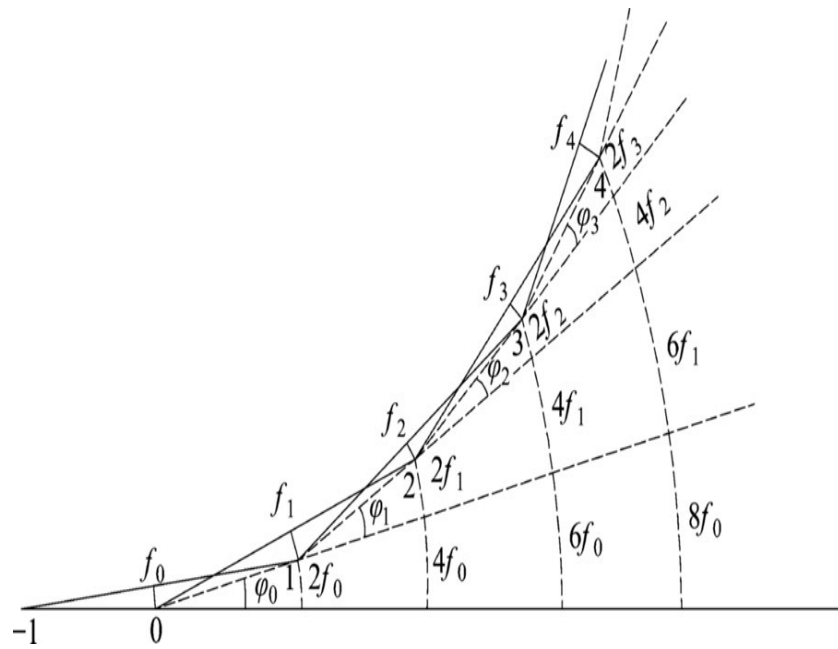


Fig. 8.19 The calculation method of the involute length at any point on the curve.

$$E_1 = 2f_0$$

$$E_2 = 4f_0 + 2f_1 = 2(2f_0 + f_1)$$

$$E_3 = 6f_0 + 4f_1 + 2f_2 = 2(3f_0 + 2f_1 + f_2)$$

$\vdots$

$$E_n = 2(nf_0 + (n-1)f_1 + (n-2)f_2 + \cdots + f_{n-1}) = 2 \sum_{0}^{n-1} \sum_{0}^{n-1} f$$

(8.24)

That is to say, the length of the evolvent at point n is equal to two times the double summation of the measured mid-ordinate f from stations 0 to (n-1).

Similarly, the length of the evolvent E_n' at point n' of the realigned curve with projected mid-ordinates f is equal to

$$E_n' = 2 \sum_{0}^{n-1} \sum_{0}^{n-1} f'$$

From this, the throw e_n' at station n will be

$$e_n = E_n - E_n' = 2 \sum_{0}^{n-1} \sum_{0}^{n-1} (f - f') = 2 \sum_{0}^{n-1} \sum_{0}^{n-1} df$$

(8.25)

where df is the difference between the measured and projected mid-ordinates, abbreviated as "mid-ordinate difference."

The calculation of the throw e_n can be more clearly proceeded in Table 8.7.

Table 8.7

Procedure of Calculating the Throw

Station	f	f'	df	2		
1	2	3	4	5	6	7
0	f0	f0'	df0	df0	0	0
1	f1	f1'	df1		df0	2df0

2	f2	f2'	df2			
3	f3	f3'	df3			
⋮	⋮	⋮	⋮			
n	f _n	f _n '	df _n			2[ndf0 + (n-1)df1 + ... + df _n -1]

5. Influence of throw on mid-ordinates at stations ahead and behind.

It is clear from Fig. 8.20 that, when any station point n on the curve is shifted, not only the mid-ordinate at station n , but also the mid-ordinates at stations ahead $(n+1)$ and behind $(n-1)$ will be altered appropriately.

If the station point n is shifted outwards a throw e_n , with all other stations remain unmoved, the mid-ordinate at station n will be increased by $e_n/2$ simultaneously. Similarly, if stations $(n-1)$ and $(n+1)$ are shifted outwards with throws e_{n-1} and e_{n+1} , respectively, the mid-ordinate at station n will be decreased by an amount equal to $e_{n-1}/2 + e_{n+1}/2$. Hence, when there are throws at each station on the curve, the mid-ordinate at any station n after the curve is realigned may be calculated by the following equation

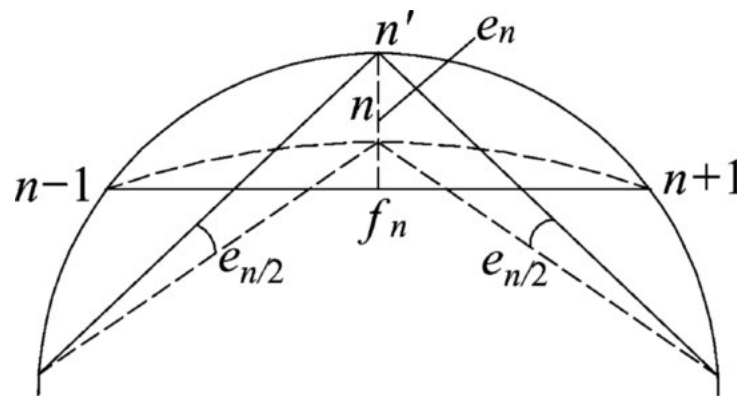


Fig. 8.20 Diagram for calculating the mid-ordinate at any station n after the curve.

$$(8.26)$$

in which, f_n is the projected mid-ordinate at station n ; f_n is the measured mid-ordinate at station n ; e_n is the throw at station n (positive implies shifting outwards and negative inwards); e_{n-1} and e_{n+1} are the throws at stations $(n-1)$ and $(n+1)$ respectively.

6. Restrained conditions for calculation of throw

(1) To ensure that there will be no changes in the tangent directions before and after the realignment of curves.

Since, the intersection angle I between the tangents at both ends of the curve is equal to the sum of all deflection angles ϕ between the lines joining any two successive station points, or, also, the deflection angle ϕ_i between lines joining stations $(i-1)-(i)$ and $(i)-(i+1)$ is equal to I/n (see Fig. 8.19)

$$\varphi_i \approx \sin \varphi_i = \frac{2f_i}{\lambda}$$

where λ is the distance between two neighbouring stations, hence we obtain

$$(8.27)$$

The above equation shows that, the intersection angle I between the tangents at both ends of the curve can be represented by the summation of mid-ordinates at all stations on the curve multiplied by a constant. Hence, the condition for ensuring that there will be no changes in the tangent directions before and after the realignment of the curves is

$$\sum f = \sum f'$$

or

$$\sum (f - f') = 0, \sum df = 0$$

(2) To ensure that there will be no changes in the position of T.S. and S.T. before and after the realignment of curves.

Evidently, the restrained condition can only ensure that there will be no changes in the tangent directions at both ends of the curve. If the positions of T.S. and S.T. have to be remain unaltered, the throw at S.T. should be equal to zero or .

(3) To ensure that all controlling points (such as minor bridges and culverts, level crossing) on the curve have to be remain unaltered due to the restrictions of concrete conditions, their throw should be equal to zero.

7. Revision of projected mid-ordinates

The projected mid-ordinates fulfilling restrained condition 1 or do not generally fulfill the restrained condition 2 and under ordinary circumstances, this is always the case. In this connection, it is necessary to revise the mid-ordinates as originally projected so that this requirement can be ultimately fulfilled.

The revision of the projected mid-ordinates is to fulfill the requirement that, at the end of the S.T., the throw will be equal to zero (i.e.,). Since , it is clear that, if the projected mid-ordinate at some station (i) is increased (or decreased) by a mm, at the same time, that at station (i+m) distant m stations ahead of (i) is decreased (or increased) by a mm, the condition of remains unchanged on the entire curve. It is also clear from the method of calculation of that, if at a pair of stations (such as i and i+m), the projected mid-ordinates are increased first and decreased next, the value of df at the station in front will be decreased by a mm and at the station in the rear will be increased by a mm, as a result, the value of at the end of the curve S.T. will be decreased by m. a mm. Conversely, if the

projected mid-ordinates at the pair of stations are decreased first and increased next, it will be increased by m . a mm. Therefore, in case the value of e_n is remained as positive, the revised projected mid-ordinates for the pair of stations should be increased first and decreased next, otherwise, decreased first and increased next.

In cases where there are controlling points on the curve where no throw or only very small throw is allowed, further revisions should be made under the premise that the condition of $e_n = 0$ at the end of curve S.T. has been already fulfilled. The method generally used is to select two pairs of stations, one before and another after the controlling point on concern. On the first pair of stations, the projected mid-ordinates are increased first and decreased next by a mm if the value of e_n at the controlling point is positive (otherwise, decreased first and decreased next). While on the second pair of stations, the increase or decrease of the projected mid-ordinates will be acted in a diametrically opposite way, at the same time, the values of ma should be exactly the same for both pairs of stations. Thus both restrained conditions of $e_n = 0$ and $e_c = 0$ at the end of curve S.T. will be satisfied.

In order to preserve the smoothness of the curve to the greatest extent, the value of a should be as small as possible (preferably 1 mm) and the value of m should be as large as possible. In cases where one pair of stations is not enough, two or more pairs may be used, so as to achieve the goal that the throw at the end of curve is equal to zero.

8. Method and procedure for string lining of curves.

(1) With the gauge line of the outer rail of the curved track as the reference line and the beginning of the transition spiral T.S. as station 0, successive stations are marked and numbered at 10 m intervals. The distance A and B between the C.S.S.C. and S.T. to their neighboring stations are recorded respectively. After that, the mid-ordinates at each station are measured and recorded by means of 20 m chords successively.

(2) The projected mid-ordinate of the circular curve f_0 and the rate of increase of the mid-ordinate of the transition spiral f'_0 are calculated according to the data given, from which the projected mid-ordinates f' at all stations on the curve with the exception of station 0 (T.S.) and stations to the left and right of S.C., C.S. and S.T. can be determined.

(3) The correction factors are calculated directly or taken from tables in accordance with the values of A and B and the projected mid-ordinates of all other stations to be determined are calculated.

(4) Calculate the mid-ordinate difference at all stations.

(5) Calculate the sum of the mid-ordinate difference at all stations. In case that the end of the curve, e_n , the projected mid-ordinates f' should be revised appropriately, so that the restrained condition on the entire curve will be satisfied.

(6) Calculate the double summation of the mid-ordinate difference at all stations. In case at the end of the curve, one or several pairs of stations should be selected for the further revision of the projected mid-ordinates, until the restrained condition at the end of the curve is ultimately satisfied.

(7) In case there are other restrained conditions, the projected mid-ordinates should be still further revised until they are wholly satisfied.

(8) Calculate the throw (or half throw e_n). The curve is shifted outwards when e_n is positive and inwards when it is negative.

(9) Check the mid-ordinates at all station after the curve is realigned by means of Eq. (8.21) to verify the correctness of the calculation.

(10) Curve posts are set outside of the curved track opposite each station point, and the track is shifted carefully according to the calculated throws. Before track shifting, the rail gaps should be reregulated in accordance with the direction of the track shifting, so that the rail gaps will fulfill all specified requirements after the track is realigned.

9. Example

For the case of check and revision, the calculation can be proceeded, preferably in tabular form, as shown in Table 8.8. In this example, the radius of curve is $R=600$ m and the length of the transition spiral on both sides of the circular curve is 50 m. The measured mid-ordinates at all stations is entered in column (2) of the table. Other related data are entered in column (18) entitled "remarks." Station 8 is a minor bridge where the shifting of the track is not allowed.

Table 8.8

Example for Calculating Curve Throw with String Lining

Station	f	f'	df		First Revision	Second Revision	e	f
a	f'	df'		a	f''	df''		
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	
1	0	0	0	0		0	0	
2	5	3	+2	+2		3	+2	
3	10	17	-7	-5	-1	16	-6	
4	40	34	+6	+1	-1	32	+7	
5	45	50	-5	-4		30	-5	
6	75	67	+8	+4		67	+8	
7	77	81	-4	0		81	-4	
8	80	84	-4	-4		84	-4	

9	100	84	+16	+12		84	+16	
10	70	84	-14	-2		84	-14	
11	85	84	+1	-1		84	+1	
12	89	84	+5	+4		84	+5	
13	75	84	-9	-5		84	-9	
14	96	84	+12	+7		84	+12	
15	70	84	-14	-7		84	-14	
16	73	81	-8	-15		81	-8	
17	82	67	+15	0	+1	68	+14	
18	43	50	-7	-7		50	-7	
19	40	34	+6	-1	+1	35	+5	
20	10	17	-7	-8		17	-7	
21	11	3	+8	0		3	+8	
22	0	0	0	0		0	0	
	1178	1176	+79 -79	+30 -59		1176	+78 -78	

8.1.4 Design for Cross-Section Reconstruction

The design of cross-section reconstruction shall be carried out based on the actual cross-section obtained by surveying. The railway cross-section refers to the subgrade cross-section perpendicular to railway central line. A cross-section survey and mapping shall be done to the points of hundred-meter stakes and additional stakes, as well as other locations, such as terrain change point, zero fill and zero cut points, high fill and deep cut point, both ends of bridge, tunnel portal, crossing center, etc. A surveyed cross-section is shown in Fig. 8.21.

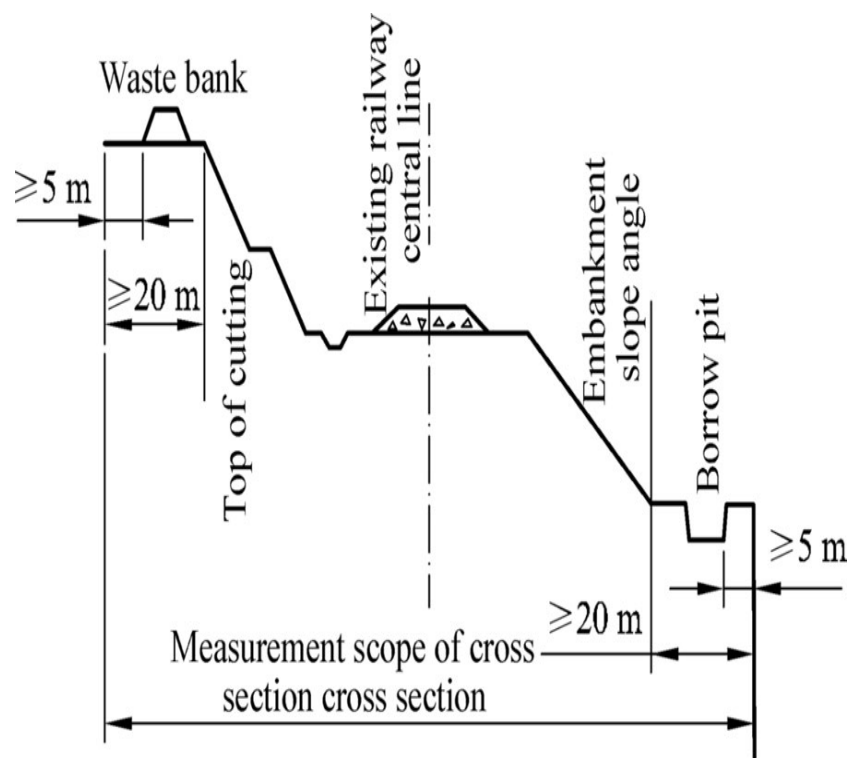


Fig. 8.21 Cross-section.

Reconstruction of the existing profile and plane, often need to changing the rail top elevation and shift the center line, so it need to rebuild cross-section of existing railways. The design for cross-section reconstruction must be in closely coordination with the profile and plane reconstruction design, only in this way can obtain the economic and reasonable scheme.

The design mode for cross-section reconstruction may be carried according to specific conditions such as the lifting or lowering size of the existing rail top elevation, the quantity of lateral shifting of the center line, the construction methods, etc. Its design features and methods are introduced according to the following several common typical case.

8.1.4.1 Non-Shifting the Central Line of Existing Railways

1. Raising the elevation of the existing rail top

1) Using ballast to raise the elevation of rail top

When lifting height is less than 0.5 m, the track can be lift with ballast, as shown in Fig. 8.22, the appropriate height for track lifting should be 0.15 m once a time, thus can perform the construction work by making use of the intervals between running trains, and it won't interfere with the operation business a lot. When using ballast to lift the rail, the necessary width of subgrade shoulder shall be guaranteed. Under normal circumstances, the shoulder width of embankment shall not be less than 0.6 m, not be less than 0.4 m under difficult conditions, and the shoulder width of cutting shall not be less than 0.4 m. If the required width can't be guaranteed, the subgrade should be widened, and when widening embankment, the widened part of subgrade top should not be less than 0.5 m, the width of bottom shall be determined according to the requirement of design slope, but it shall not be less than the widening value of the top. Before widening, the slope of original embankment shall be dug into steps of 1 m width; and if there are slope protections, the slope protections should be removed first.

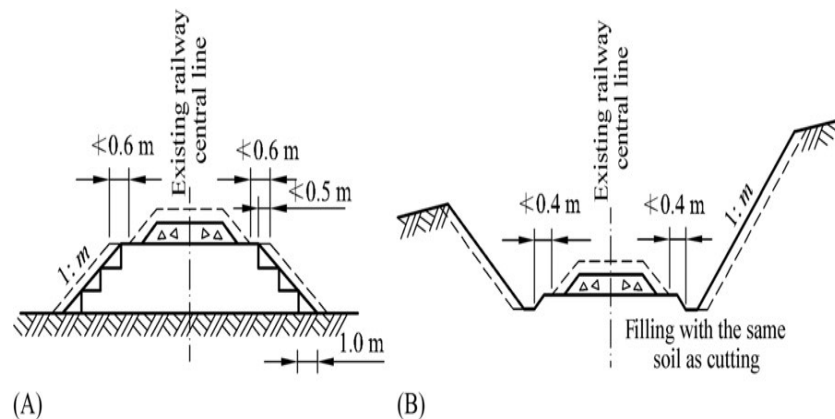


Fig. 8.22 Lifting elevation of rail top without shifting central line of existing railways.

2) Lifting subgrade with permeable soil

When a lifting height reaches 0.5–1.0 m, generally, the track can be lifted by using permeable soil to raise subgrade, as shown in Fig. 8.23. If the subgrade is to be raised using ordinary soil, the existing ballast bed must be cleared first, interrupting the trains operation; moreover, it is difficult to compact the subgrade and will generate ballast capsule easily.

Lifting the track with permeable soil can take advantage of operation interval to work. The lift height should not be more than 0.15 m each time, lest it cause difficulties to the construction and operation.

Lifting the track with permeable soil, the bellowing subgrade surface with impermeable soil should be designed as the lateral tilting of 1%~4% drainage transverse slope.

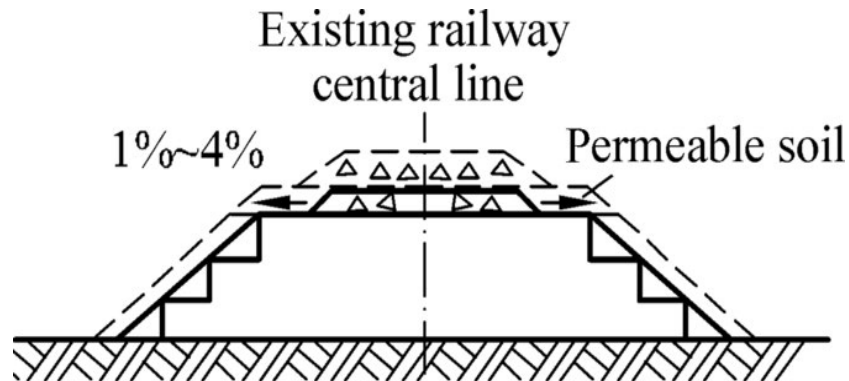


Fig. 8.23 Lifting with permeable soil.

3) Raising the subgrade

When the lift height is more than 1.0 m, it is not an economic choice to lift the track using permeable soil, generally, the track should be lifted by raising subgrade with ordinary soil. For raising embankment, it generally needs to widen the original subgrade, the original embankment slope should be dug into the steps of the 1 m width. As shown in Fig. 8.24, before construction, it needs to remove ballast bed and to regulate roadbed diseases, for the purpose, the first thing is to construct a temporary line for keeping operation. The scheme's disadvantages are that the engineering cost of constructing temporary line is high, and the speed is limited.

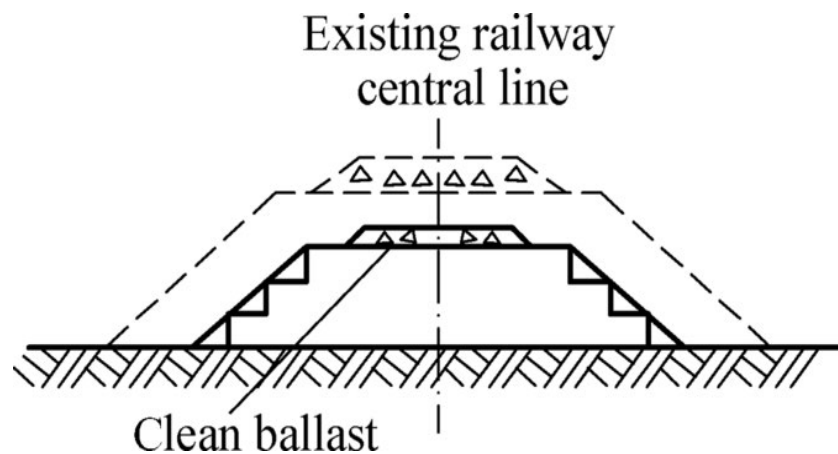


Fig. 8.24 Raising embankment.

2. Lowering the elevation of the existing rail top

1) Thinning thickness of ballast bed

If the lowering value of rail top is very small, and existing ballast bed is thicker than standard one, the under cutting of track can be implemented by thinning ballast bed, so as not to dig and cut subgrade, caused a large number of projects. The ballast thickness in thinned segments could be thinner than specified standard thickness. The thinnest thickness of ballast bed should not be less than 25 cm.

2) Lowering track by cutting subgrade

If the elevation of rail top needs to be lowered a lot, and thinning thickness of ballast cannot meet the requirements, it needs to adopt the method to lower the track by cutting subgrade, as shown in Fig. 8.25. In this case, a temporary line should be constructed to maintain operation, which should not be commonly use as the higher construction cost.

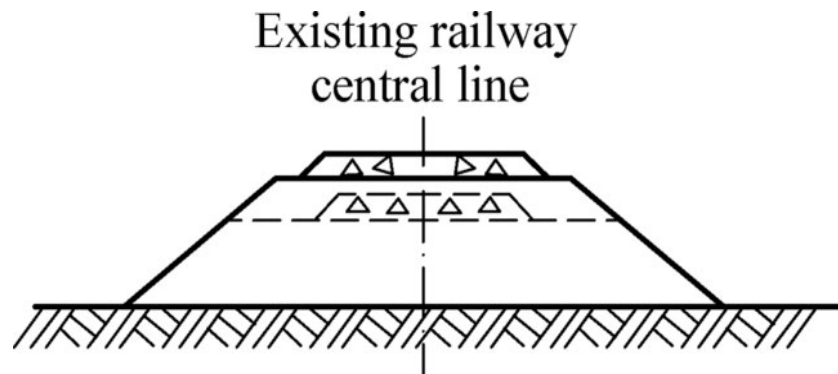


Fig. 8.25 Lowering track by cutting the subgrade.

8.1.4.2 Changing the Elevation of Track Together With Existing Central Line Shifting

1. Keep one slope side of subgrade without reconstruction

The design diagram of cross-section shown in Fig. 8.26 is suitable for the reconstruction of big lifting or dropping the elevation of the rail top, and remaining one side slope of subgrade without changing. The lateral shifting distance D of the existing center line is decided by subgrade slope rate m and raise value Δh , the value shall meet $D \geq m \times \Delta h$. With this reconstruction method, it is necessary to build a temporary road in order to maintain temporary train running by an existing line.

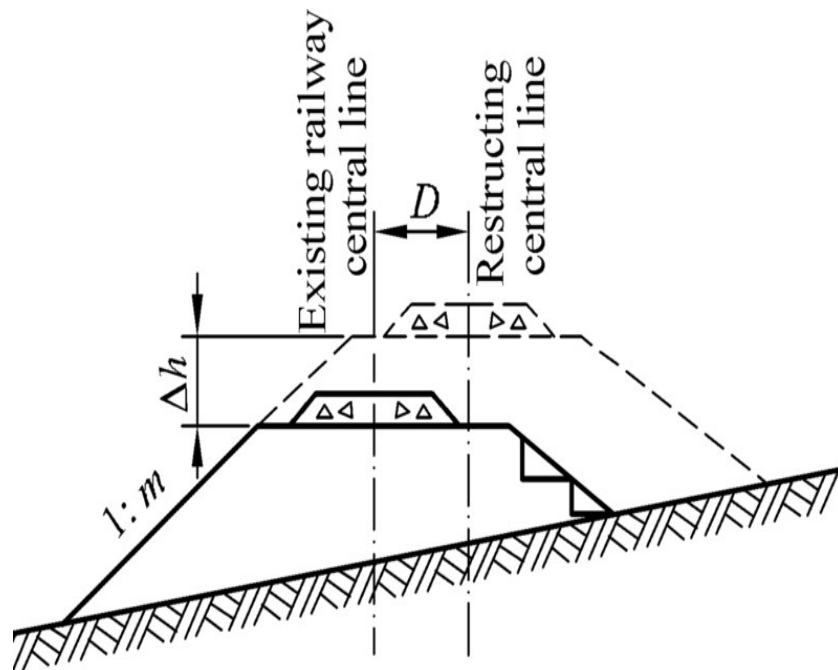


Fig. 8.26 Elevating and lowering the subgrade.

2. Raising and cutting subgrade in the case of normal operation

For raising or lowering subgrade without building temporary road for constructing, a cross-section type can generally be used, as shown in Fig. 8.27. The advantage of this method is that construction has no impact on normal operation, the interference between construction and operation is small, and it saves temporary line engineering. The disadvantages are that part of the existing subgrade earthwork would be wasted and the existing track should be dismantled.

The lateral shifting distance D of the existing center line can be calculated according to the following equation:

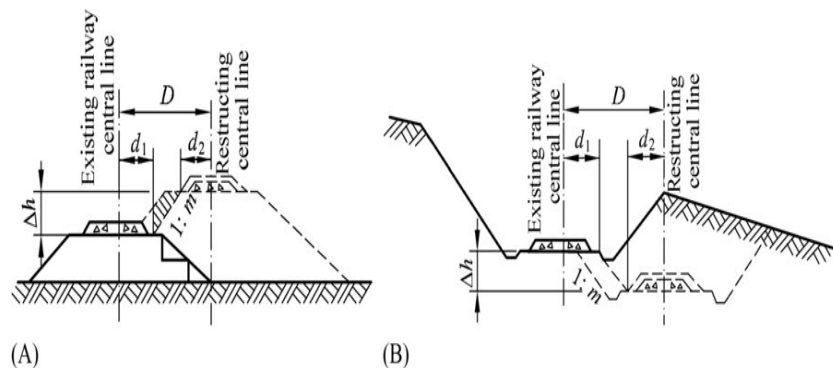


Fig. 8.27 Raising or lowering subgrade without constructing temporary line.

$$D \geq d_1 + d_2 + m \times \Delta h$$

where d_1 is the temporary width of the existing subgrade on the side near the reconstructing line, thus is the half width of the existing ballast bed bottom plus 0.2 m of the temporary shoulder width, generally is about 2.5 m. When raising embankment, in order to make full use of some existing subgrade earthwork, d_1 value can also be reduced under the condition of no interfere with existing operation. d_2 is the temporary width of the reconstruction subgrade on the side near existing subgrade, according to the half of the minimum width of subgrade, generally is about 2.2 m (according to the thickness of ballast is 0.25 m, subgrade slope is 1:1.5, top width of ballast bed is 2.8 m, shoulder width is 0.2 m); When raising embankment, in order to avoid later widening subgrade (widened part is the shadow in diagram), it can also be calculated according to the standard cross section of subgrade; m is the slope rate of subgrade between the two lines, if using straw bag or sheet pile to reinforce the slope, its value can be reduced; and Δh is the raising or lowering values of subgrade.

8.1.4.3 Integrated Design of Profile, Plane and Cross-Section

The reconstruction design of profile, plane and cross-section is an integrated whole, which must be carried out combining with the specific conditions. The general steps are shown as follows:

- (1) The design of profile with enlarged scale must fully consider influences affected by buildings of track, bridges, tunnels, stations, and subgrades, etc.
- (2) It is necessary to selected the design type of the cross-section, and calculate the shifting distance of the center line of existing railways based on the lifting or lowering value.
- (3) The plane design should ensure the necessary lateral shifting distance of cross-section design on the premise of comply with the design standards to.
- (4) Cross section of hundred-meter stakes and additional stakes should be designed based on the lifting and lowering value of designed profile and lateral shifting distance of center line determined in plane designing.
- (5) The integrating design result should be improved repeatedly on analyzing the technical and economic rationality of profile, plane and cross-section design comprehensively, if problems are found the integrating design must be further modified.
- (6) After the completion of the design for reconstruction, compiling the comprehensive design drawings, thus detailed profile.

8.2 The Design of the Second Railway Line

To build out the second railway line is the most effective way to enhance the traffic capacity of the existing lines.

When building out the second line, in order to ensure the normal operation of the existing lines, and reduce the interference between construction and operation, it is usual to build the second line first, after the second line project completed and put into operation, then reconstruct the existing line. The method introduced in this section can also be applied to designing the second line when building a double line.

8.2.1 Profile Design of the Second Line

8.2.1.1 Selecting the Ruling Grade of the Second Line

The ruling grade of the second line should be usually the same as that of the existing line. In order to avoid causing a large amount of reconstruction engineering in reducing the gradient, the existing over-ruling gradient on individual segments can be retained, used for train running on a descending grade direction; the second line shall be constructed at the side of the ascending grade direction, adopting single detouring and designing in ruling grade, used for train running on ascending grade direction.

If the freight volumes on both directions of design line are unbalanced, and the ruling grade of the existing limit is not easy to reconstruct, the ruling grade of the existing line can remain the same, and the second line design is designed in the heavy traffic direction by using smaller ruling grade. In designing the second line, we should strive to make the tonnage of traction be consistent with that of adjacent line so as to reduce weight changing work at junction station.

When the freight volumes of both directions are all very large, and the ratio of ruling grade sections of the existing line is not high, the second line could be designed with smaller ruling grade, after construction of the second line is completed and put into operation, then reduce the ruling grade of the existing line, making both direction of double-track railways has the same ruling grade.

8.2.1.2 Method for Profile Design of the Second Line

1. The second line and existing line running in parallel with the same elevation

When the distance between centers the second line and the existing line is not more than 5.0 m, two lines are built on the common subgrade, and the rail top elevations is the same, it is called running in parallel with the same height. Two lines are designed running in parallel with the same height, not only it can reduce the land area and the quantity of retain fill, but also it helps the subgrade drainage, to prevent snow buried, line maintenance, arrangement of crossing, etc.

In segments of double lines running in parallel with the same height, the profile design of the second line should be based on the reconstruction design of profiles of the existing line, the design is usually carried out on the profile with enlarged scale and with reference of rail top elevation. In general, designed rail top elevation of two lines should be strived to equal, namely the second line and existing lines should be in the same of gradient, length of grade section and vertical curve form. The profile must be designed to match the plane layout, make the grade compensation and the point of gradient change can meet the requirements of two lines at the same time.

In some times, reconstruct existing line might become difficult, a few individual over ruling grade sections or other substandard sections should be retained in this case. An elevation difference of rail top at the meeting point on bridge or its approach, due to the distinctive structures of two on-line bridges, however, for whatever cases, the elevation difference shall not be more than 30 cm.

In several sections vulnerable to snow, according to local conditions such as snow, wind direction, wind power and terrain, etc., the rail surface elevation difference between two lines should be reasonably determined, but the maximum value should be less than 15 cm.

The rail top elevation at crossing of two lines had better be equal. Under difficult conditions, the elevation difference between two rail surfaces should be less than 10 cm.

At segments of running in parallel with the same height, the format of amplifying profile of the second line is basically the same as that of the reconstruction existing line.

2. The second line and existing line runs in parallel and have different elevation

The second line runs in parallel to existing line but the elevation of subgrade shoulder is different, which is called lines running in parallel with different elevation. At segments of lines running in parallel with different elevation, the cross-section type of subgrade of two lines is shown in Fig. 8.28. Its disadvantage is that lateral drainage is difficult. Vertical drainage ditch should be set up to make rainwater flowing from the subgrade slope of higher line to the subgrade surface of the below line into seepage wells, rainwater can outflow from below subgrade. It increases the quantity of work and influences the stability of subgrade. In heavy-snow regions, the below line can be easily buried by snow; meanwhile, the work for the routine maintenance, as well as for the large or medium-scaled maintenance of railway line, cannot be done as conveniently as the maintenance work of lines running in parallel with the same elevation. Therefore, in the design of the second line, usually should be only under conditions as reducing ruling grade, changing of ruling grade, and leading area of bridge and tunnel and other special circumstances etc., the subgrades for both the second line and the existing lines shall be constructed in different elevations.

If the distance between the center lines of the second line and the existing one is fairly large, subgrade of the second line needs to be constructed separately, this is known as "the second line detouring around."

In lines running in parallel with different elevation and the second line detouring around sections, it is necessary to draw assistant-detailed profile diagram, which the graph type and requirements is the same as the newly build single track railway, and is designed based on the elevation of subgrade shoulder.

When Design, at the beginning and the end points of segments of the parallel and different elevation and second line detouring sections, grades should be connected smoothly, and consider the relationship of broken chain within the grade section. The design elevation of subgrade shoulder at beginning point and ending point should be calculated based on the design elevation of correspond point of rail top.

Shoulder elevation= design elevation of rail top - track height (including the thickness of the plate)-tie height - thickness of ballast bed - road arch height

The kilometer of the beginning and ending point of parallel and different elevation and second line detouring sections shall be indicated in the profile diagram with enlarged scale.

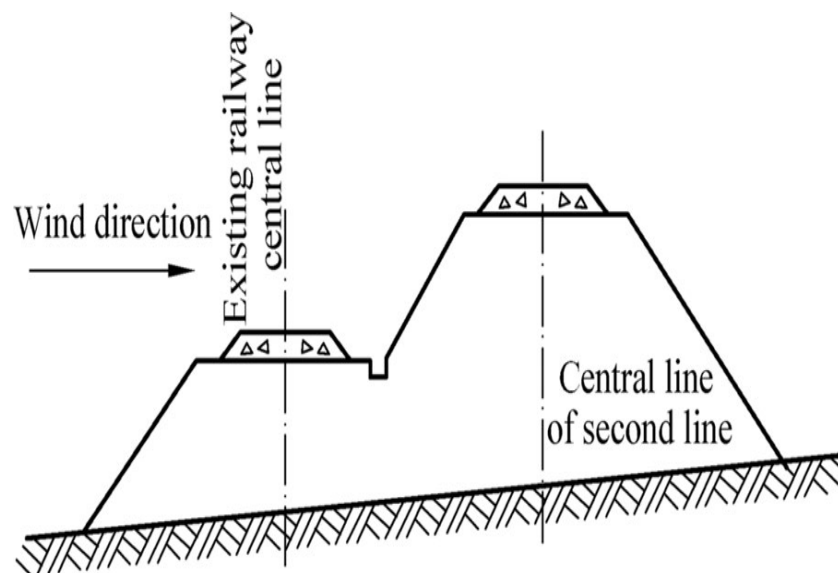


Fig. 8.28 Parallel cross section with unequal elevation.

3. Detailed profile diagram of the second line

After finished the designing of profiles in enlarged scale of the parallel with the same elevation of second and existing lines and the assistant profile diagram of parallel and different elevation and detouring section of second line, the detailed profile of the second line should be summarized and compiled.

Detailed profile diagram should mark kilometers of the beginning and ending point of parallel and detouring section of the second line.

8.2.2 Plane Design of the Second Line

8.2.2.1 Choice of Running in Parallel and Detouring Segments

The second line is usually built in parallel to the existing lines. To make two lines running in parallel would occupy less farmland, saving cut-fill work of subgrade, and is convenient for operation management. However, the second line detouring scheme should be adopted under conditions such as in sections with reducing ruling grade of the second line, with reserving the over-ruling grade of the existing line, with detouring from the existing bad geological regions, with bridge and tunnel lead regions, and other segments with lower standard, difficult terrain, or difficult reconstruction.

Generally, if the distance between two center lines is more than 20 m, it should be considered a detouring segment. When only the second line is constructed, it is called the single detouring; when both lines require construction (existing line is abandoned), it is called double detouring.

Running in parallel and detouring schemes should be comprehensively selected based on other problems such as the ruling grade of the second line, the side selection of the second line, the minimum curve radius selection of the second line, etc. After the scheme is determined, plane and profile design work should then be carried out.

8.2.2.2 Side Selection of the Second Line

Side selection of the second line has a significant impact on the structure stability of the existing lines, engineering quantity of the second line, interference of construction and operation during the construction period of the second line, and the operations work after being put into use.

If the position of the second line was reserved when existing line was built, the sides of the second line can be determined based on the reserved position. But in general, it is not the case. Therefore, it requires a comprehensive study on the following factors, comparing the pros and cons of various schemes, carefully select the sides of the second line.

1. The side selection of the second line in segments of retaining over-ruling grade of the existing lines

In the segment of over-ruling of the existing line, it should make over-ruling grade as descending grade path, new second line adopts a gentle gradient for ascending grade paths. In this way, according to the left hand driving principle, the side of the second line can be determined, as shown in Fig. 8.29.

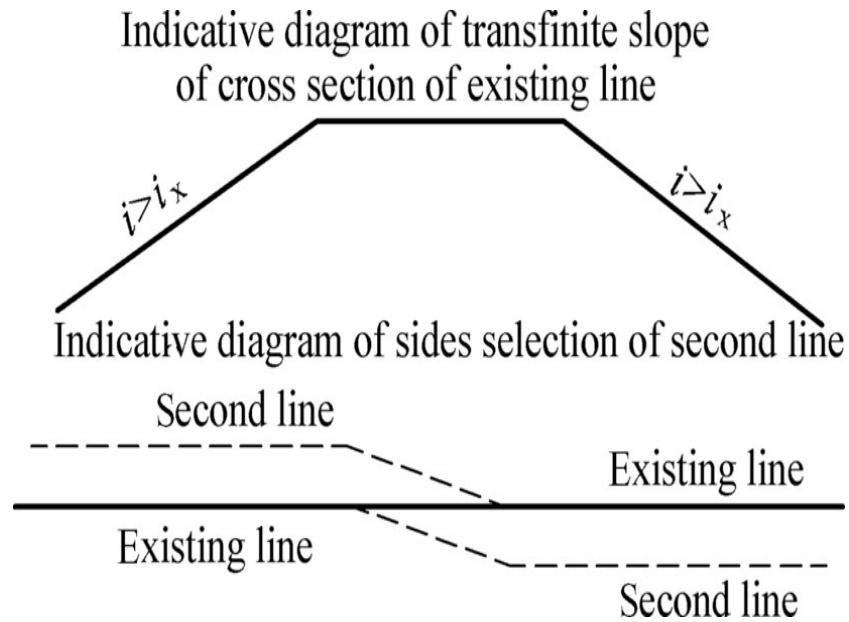


Fig. 8.29 Side selection of segment of retaining over-ruling grade of the existing lines.

2. The influence of the main goods direction on the side selection of the second line

When the volume of freight flow between two directions of design line varies a lot, the second line should be designed on the large volume side. Because of the design criteria of the second line generally is higher than that of the existing line, the operation indicators are higher, and transportation cost is lower. It is advantageous to layout the second line in large freight flow direction.

3. Reasonable sides of the second line inside station

Reasonable sides of the second line within the range of stations, should be decided according to the category of the station and the layout.

Within intermediate station, generally the second line should be set at the other side of the passenger station building, to retain the original passenger equipment and freight yard, as shown in Fig. 8.30A and B.

Within the range of the district station, it is better to put the second line at the same side of the passenger station building, in order to retain the exit of district station and throat area. If traffic operational quantity at district station is big, the second line can be layout on the line around outside of the district station, so as to reduce interference to the throat area of the turnout causing by the departure trains from the second line, and to avoid the reconstruction of the throat area of station, as shown in Fig. 8.30C.

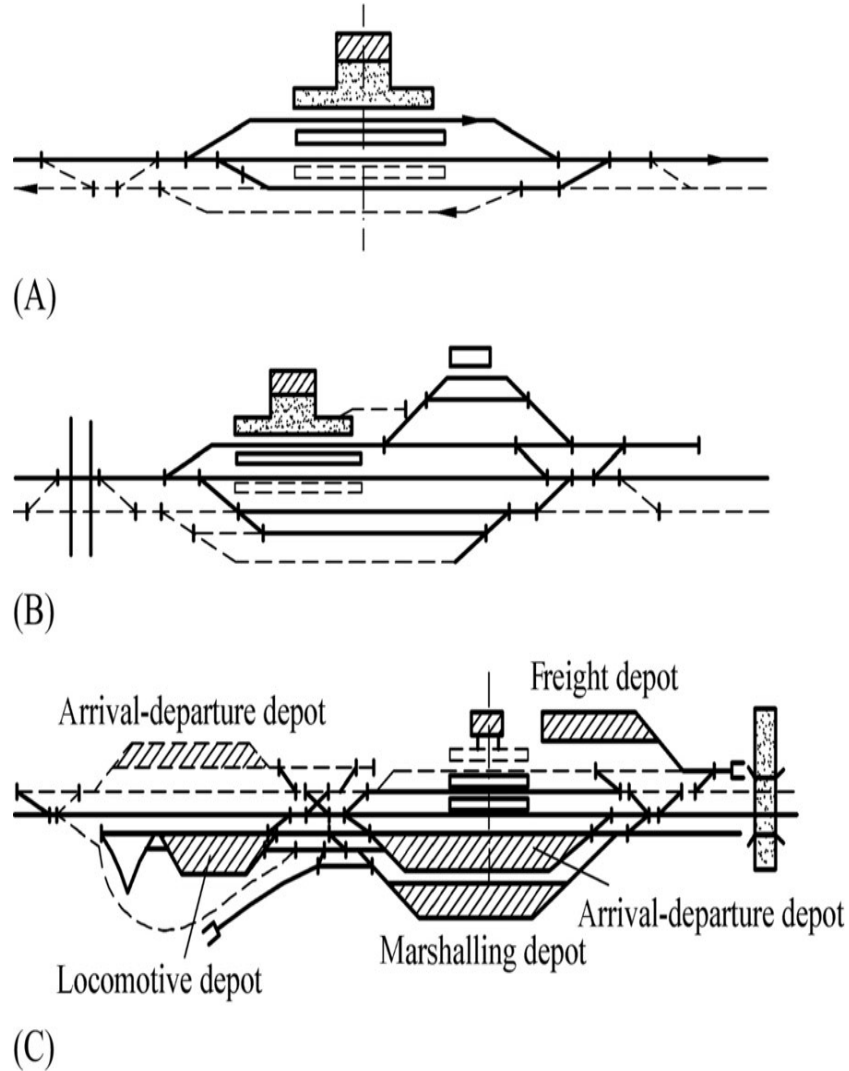


Fig. 8.30 Side selection of the second line inside station.

4. Side selection of the second line within sections

For side selection of second line within sections, there are some principles, such as taking farmland as little as possible, keeping original project as much as possible, and according to the topography and geological conditions, striving to reduce the engineering quantity, to guarantee the stability of subgrade. In segments of large and middle bridges, sites of bridges and the side of the second line should be selected based on these conditions such as hydrological, geological conditions and requirements of combat readiness. If the above conditions are roughly the same, the second line usually should be located in downstream side of the bridge, in order to avoid abandoning or destroying the diversion constructions, subgrade protection of bridge ends or the bridge pier protective to break ice.

At tunnel segments, the second line should be chosen as far as possible at the side with good geological condition, shorter tunnel length, and construction convenience.

In unfavorable geological regions, the second line is not able to detour; the side selection of second line should be advantageous of prevention and control of geologic hazard. Fig. 8.31A shows the diagram of the reasonable position of the second line through the non-active landslide area.

In subgrade defect segment, the side selection of second line should be good for repairing work of the existing lines, striving to combine the construction of the second line to regulate defects. Fig. 8.31B shows the diagram of the reasonable position of second line in segments with diseases of ballast groove and cutting slope sliding.

In steep slope segments, if the existing line is an embankment, the second line should be located in the upper part of the hillside. If the existing line is a cutting, it should be set in the lower part of the hillside. In this way, the quantity of earth and rock works to construct the second line may be decreased, as shown in Fig. 8.31C.

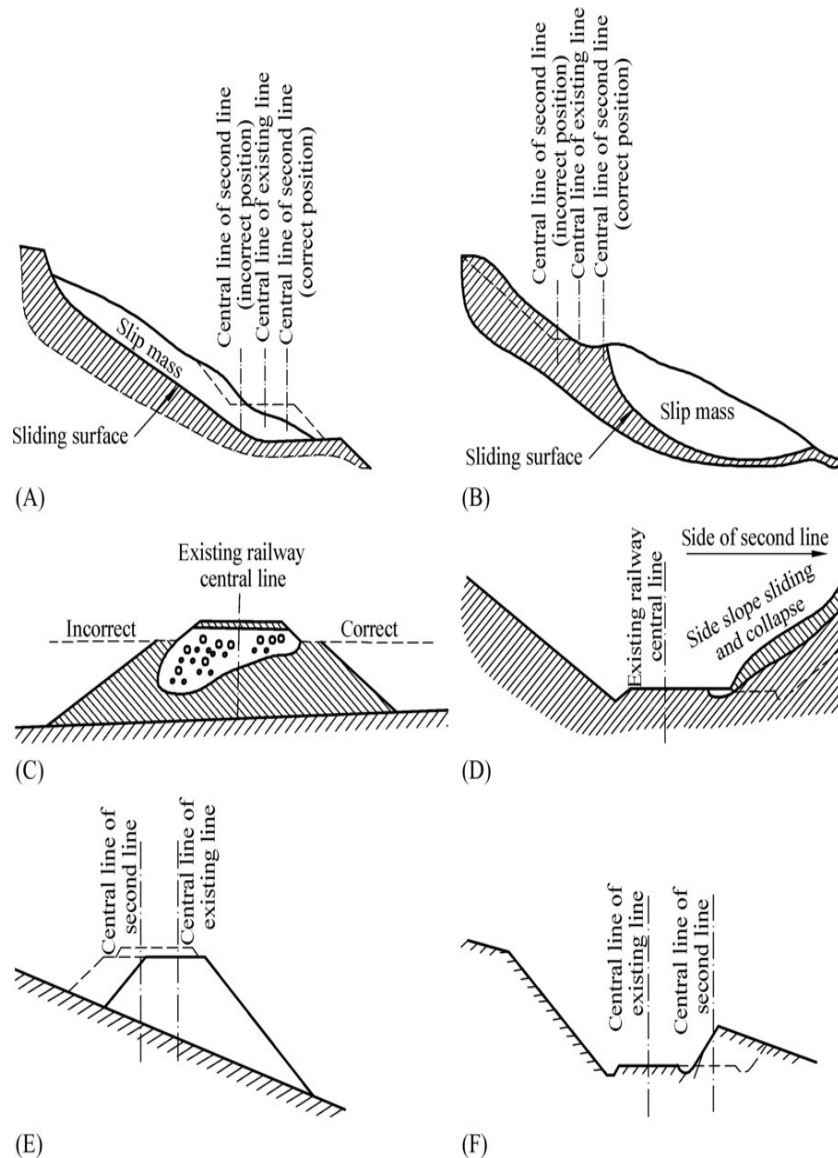


Fig. 8.31 Side selection of second line in special subgrade segments: (A) Side selection of the second line in sliding section, (B) Side selection in subgrade defect region, (C) Side selection in steep slope region.

8.2.2.3 Changing Side of the Second Line Relative to Existing Railway

After selecting sides of the second line side, at some segment, it may be more reasonable at the right side of the existing lines while at other segments maybe the left side is more beneficial. In this way, it is necessary to change side of the second line relative to existing railway.

Positions to change side of the second line should be better at these places such as:

- (1) With low embankment or light cutting for stable subgrade, while at high embankment sections, sides should not be changed for fear that the settlement difference of the existing and new subgrade affecting the stability of the subgrade and safety of train running.
- (2) Segments without raising or lowering of profile elevation can avoid building temporary line in construction.
- (3) Segments of curve or double line detouring can avoid adding curves, as shown in Figs. 8.32A and B. When changing side at straight segment, it needs to increase a set of reverse curves, which can only be used under special circumstances, as shown in Fig. 8.32C.

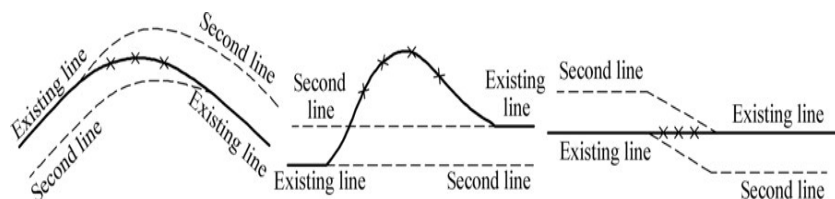


Fig. 8.32 Changing side of second line. (A) Curve section, (B) Double line detouring section, (C) Straight line section.

To change sides on curves outside stations, combining with widening the distance between center lines, can reduce the impact on transporting the construction material and track-laying, as shown in Fig. 8.33A. Changing side within the station can cause the deceleration of the train running through a turnout branch, as shown in Fig. 8.33B; it should therefore not be a common way.

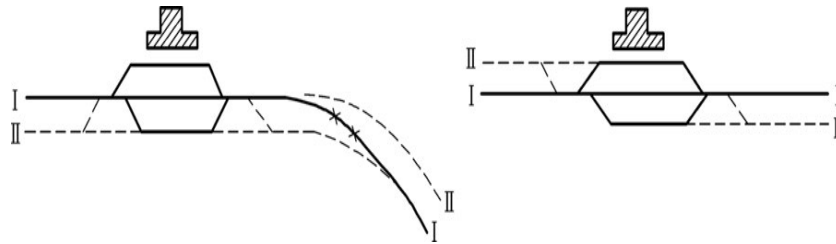


Fig. 8.33 Indicative diagram of station changing. (A) Side changing outside the station, (B) Side changing inside the station.

8.2.2.4 The Distance Between Centers of the Second Line and the Existing Line

In addition to the detouring segments, the position of the second line should be decided according to the distance in normal direction between second center line and existing center line. The distance between two center lines in normal direction of the existing line is known as the distance between lines. The distance between lines in a straight segment is determined based on the rolling stock clearance limit and the safety distance between clearance limits, which, in sections, should meet the requirements of Table 8.9, i.e., a design speed of 200 km/h shall not be less than 4.4 m. A design speed of 160 km/h shall not be less than 4.2 m. The design speed is not more than 140 km/h, nor less than 4.0 m. In the following cases, the distance between the two lines should be widened.

Table 8.9

Minimum Distance Between Adjacent Single-Line Tunnels

Surround Rock Class	Structure Characteristics and Block State of Surrounding Rock
Straight	Curve
VI	Hard rock is cut into a whole of huge block structure
V	Hard rock is cut into a whole of huge block structure; Soft rock is cut into a whole of huge bl
IV	Hard rock is cut into inlay structure of blocks and cobbles; Soft rock is cut into a whole of hu

III	Hard rock is cut into cobbles with broken structure; Soft rock is cut into inlay structure of blo
II	Surrounding rock shows as loose structure with cobblestone; Non-cohesive soils (including g
I	Surrounding rock shows as loose structure with cobblestone; cohesion soil shows as plastic a

1. Curves with minimum distance of lines at two ends of curve

The widening method employs the method described in the second section of Chapter 3.

2. Bridge segments

The distance of centers of the second line and the existing line at the bridge segment should be decided according to these factors such as the requirements of national defense, navigation conditions, geological conditions, basic types, etc.

The minimum distance between two lines at small and medium-sized bridges, is mainly determined by construction conditions. When constructing the bridge foundation of the second line, the steady of the subgrade of the existing lines and bridge pier foundation should be protected from harmful deformation.

When bridge foundations of both lines are solid bedrock, minimum distance between lines is often determined by construction conditions of the second line.

When bridge foundations of both two lines are non-rock soil, and open cutting is used for the pier foundation construction, the minimum distance between the two lines can be calculated according to the following method.

1) Construction without setting protective sheet pile (see Fig. 8.34)

Minimum distance of lines is

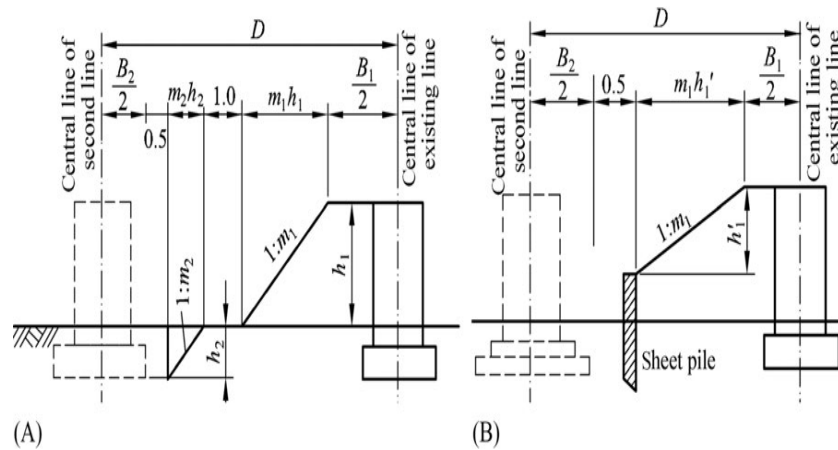


Fig. 8.34 Distance of lines at bridge segment. (A) Without setting protective sheet pile, (B) Setting protective sheet pile.

$$D = \frac{B_1}{2} + \frac{B_2}{2} + m_1 h_1 + m_2 h_2 + 0.5 + 1.0 \text{ (m)}$$

(8.28)

where B_1 , m_1 are the embankment width and slope rate of the existing line; B_2 , m_2 are the foundation width and foundation pit slope rate of second line; h_1 , h_2 are the embankment height and foundation embedment depth; 0.5(m) is the amount of surplus of excavation foundation pit; and 1.0(m) is the Berm width with dynamic load acting on the foundation pit top.

2) Construction by setting protective sheet pile (see Fig. 8.34)

The minimum distance of lines is

$$(8.29)$$

where h_1' is the height from the shoulder to the sheet pile top.

The meanings of the other symbols are the same as Eq. (8.28).

The minimum distance between two lines through large and superlarge bridges should be determined based on the selection of bridge position of second line, and more commonly according to single line or double line detouring section.

3. Tunnel segments

When building out tunnels of the second line, the stability of tunnel structure and the operating safety of the existing line should be ensured. Minimum distance of centers between two adjacent tunnels should be decided based on factors such as geological conditions of surrounding rock, tunnel excavation cross-section, construction method, etc. For a rough estimate, the reader can refer to the data in Table 8.9.

4. Other segments requiring widening line space

At station leads, bridge leads, tunnel leads and segments of parallel with different elevations, the widen value of distance between the two lines is larger, usually widening distance of lines by using following two methods.

(1) Curves, with not big widen value of distance of lines, is more commonly realized by extending length of internal easement curve, as shown in Fig. 8.35A.

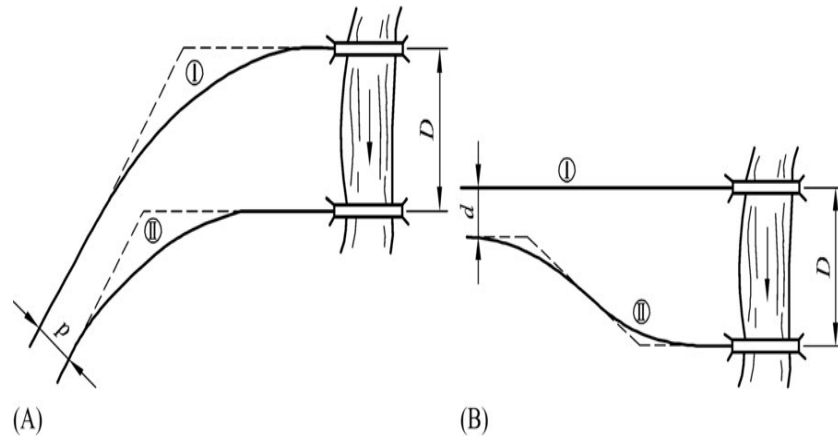


Fig. 8.35 Widening method of distance between centers of tracks.

(2) If there is a curve nearby, the distance of lines should be widened at curve segment; If there is no curve can be used, a set of reverse curves can be laid out on straight line to widen the distance of lines, as shown in Fig. 8.35B.

When widen distance of lines by using reverse curve, if the length of circular curve is limited by the minimum length requirement of circle curve, may not set easement curve, but radii of the reverse curves are generally not less than 4000 m, and 3000 m under difficult conditions.

8.2.3 Cross-Section Design of the Second Line

There are four types of subgrade cross section for designing the second line. When designing, the reasonable type of cross section should be selected according to the specific situation.

8.2.3.1 Running in Parallel With Equal-Elevation

The second line and the existing lines run in parallel and have the same elevation of rail top, which refers to parallel with equal-elevation. This form is applied for most subgrade of the second line. When constructing, generally the second line is built first and then is put into use, while the existing lines can be reconstructed.

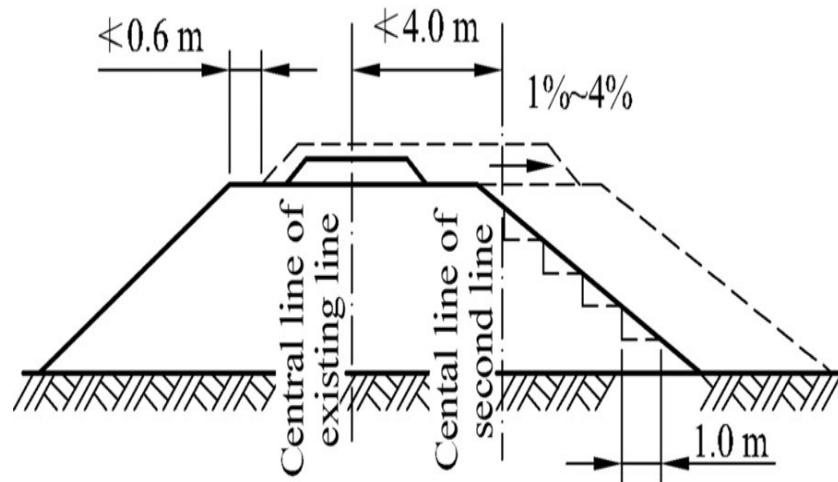
According to the possible situations, such as whether the existing central line shift or not, whether the subgrade elevation raises or not, and whether the second line shift or not, there are three types of cross-section.

(1) The existing line does not shift, the subgrade elevation does not raise or lower, the central line of second line constructs in designed position.

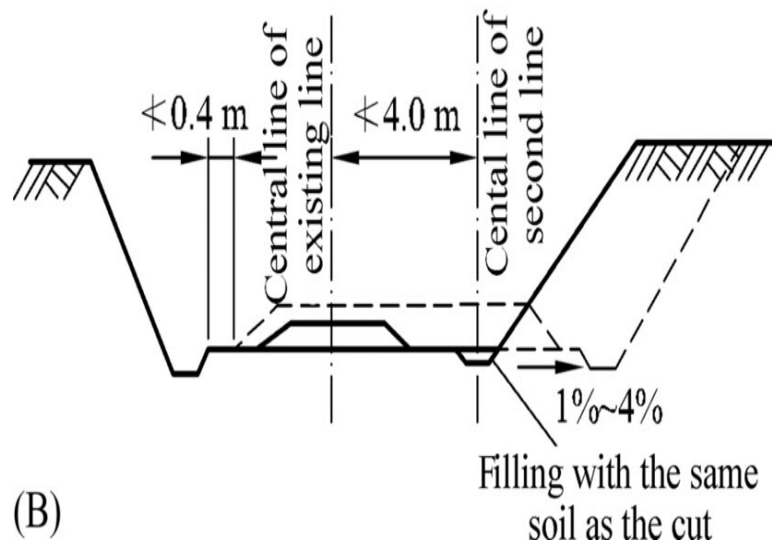
This kind of cross section of subgrade can be applied to the situation that the center line is not shift and the raise of rail top elevation is little. The ballast can be used in lifting track, and therefore, the construction is relatively convenient.

Fig. 8.36 shows the cross section diagram for existing line without widening the subgrade. To build the second line, for the shoulder width of the existing subgrade, the general embankment is not less than 0.6 m, and the cutting is not less than 0.4 m. In a difficult segment, the embankment is less than 0.4 m. If the subgrade formation of the second line is soil, a transverse slope inclined to the outer side for drainage purpose shall be built with a slope of 1%-4%.

As shown in Fig. 8.37, existing subgrade with insufficient width requires the widening of cross section. When widening existing embankment, top width of widening section should not be less than 0.5 m, bottom width can be widened according to the requirement of side slope, but should not be less than the widening value of the top. Before widening, the original embankment slope should be dug into the steps with width of 1 m. If there is a protection slope, it should be removed. When the subgrade surface of the second line is higher than existing subgrade surface, the protruding part should be filled with permeable soil for drainage. Under the permeability soil, the top of the subgrade should be constructed as drainage transverse slope with 1%-4% of gradient.



(A)



(B)

Fig. 8.36 Subgrade cross-sections of the existing line without widen. (A) Embankment, (B) Cutting.

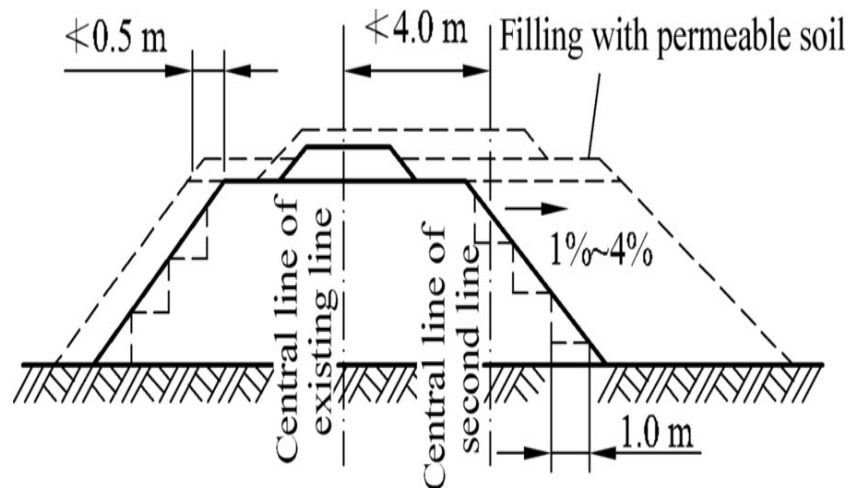


Fig. 8.37 Cross-section with roadbed widening.

(2) The center line of the existing line shifts, the lateral subgrade slope retains, and the second line should be constructed according to its design position.

This kind of subgrade cross section, the middle line of the existing lines shift to the second line direction, may retain existing roadbed lateral slope. When the lifting or lowering value of the existing subgrade is large, in order to guarantee the normal operation of the existing lines when the second line in construction, it should keep necessary temporary distance between the two lines, the construction process is to build the second line first, after it can be put into use, the existing subgrade can be reconstructed.

[Fig. 8.38 shows that the lifting value of the existing rail top is not big and only the ballast is applied for lifting the track.](#)

The temporary distance between two lines during construction is

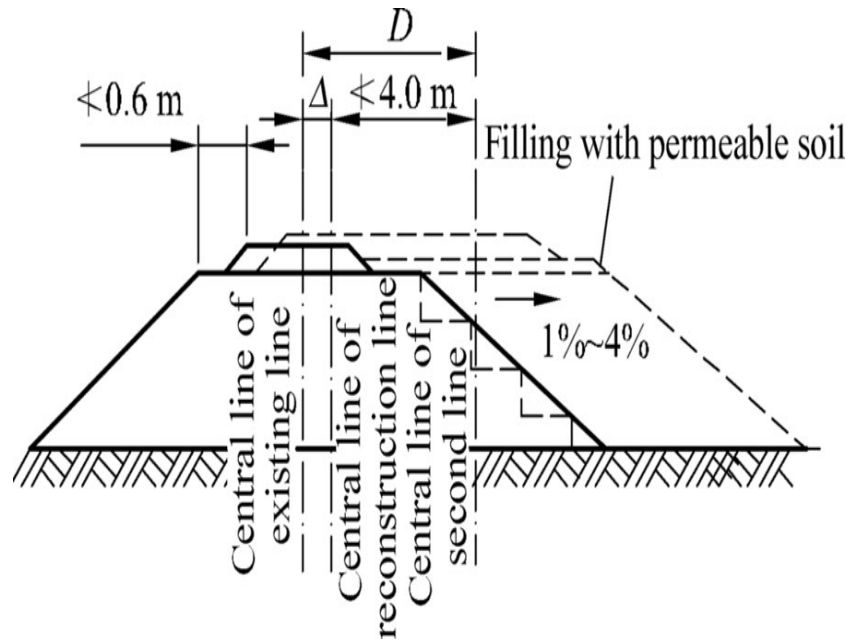


Fig. 8.38 Lifting track with ballast.

(8.30)

where Δ is the throw that shift existing line toward the second line side.

As shown in Fig. 8.39, it is suitable for the condition that lifting value of the existing rail is big and subgrade filling is required. As shown in Fig. 8.40, it is suitable for the condition that the lowering value of the existing rail top is big, the subgrade requires cutting. When constructing, the provisional minimum distance between two lines is

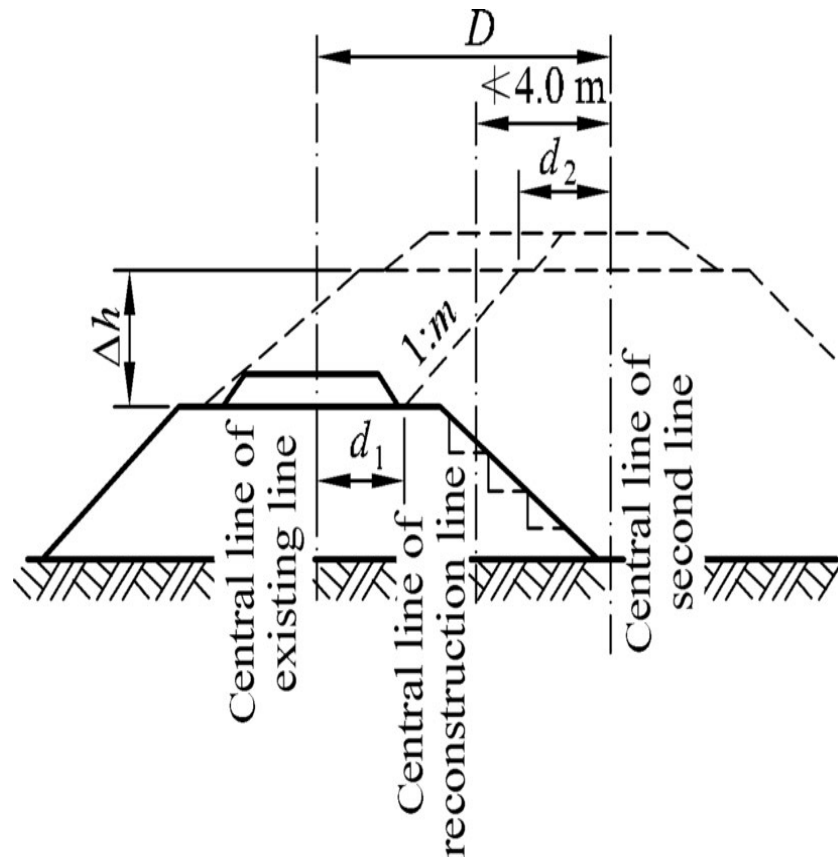


Fig. 8.39 Lifting subgrade.

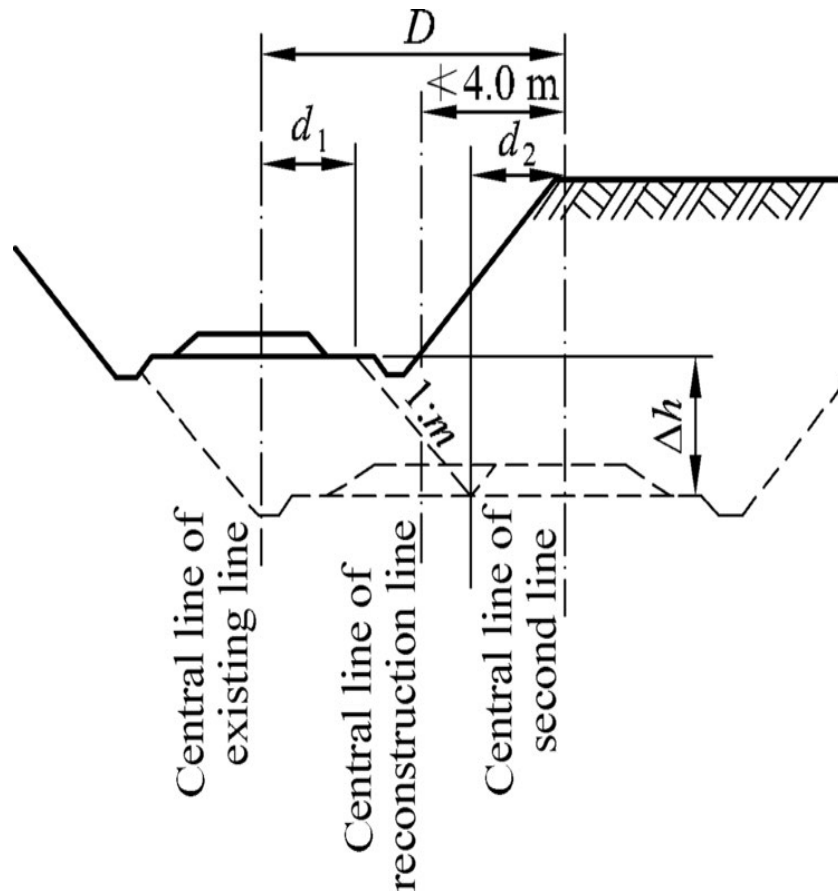


Fig. 8.40 Cutting subgrade.

(8.31)

where d_1 is the half of the temporary subgrade width of the existing line, generally is about 2.5 m; d_2 is the half of the temporary subgrade width of second line, generally is about 2.2 m; m is the subgrade slope rate, generally is 1.53; and Δh is the height of lifting or lowering value of the existing subgrade surface (m).

(3) The existing line does not shift, but lifting or lowering value is large. The center line of second line constructs according to temporary position firstly, after completing reconstruction work of the existing line, the second line can be shifted to its design position.

This kind of subgrade cross section can cause a waste of earthwork, and the track of second line needs to be dismantled and laid again. When constructing, calculation of temporary minimum distance between two lines is the same as formula (8.31).

[Fig. 8.41 shows the elevated subgrade cross section, Fig. 8.42 shows the lowered subgrade cross section.](#)

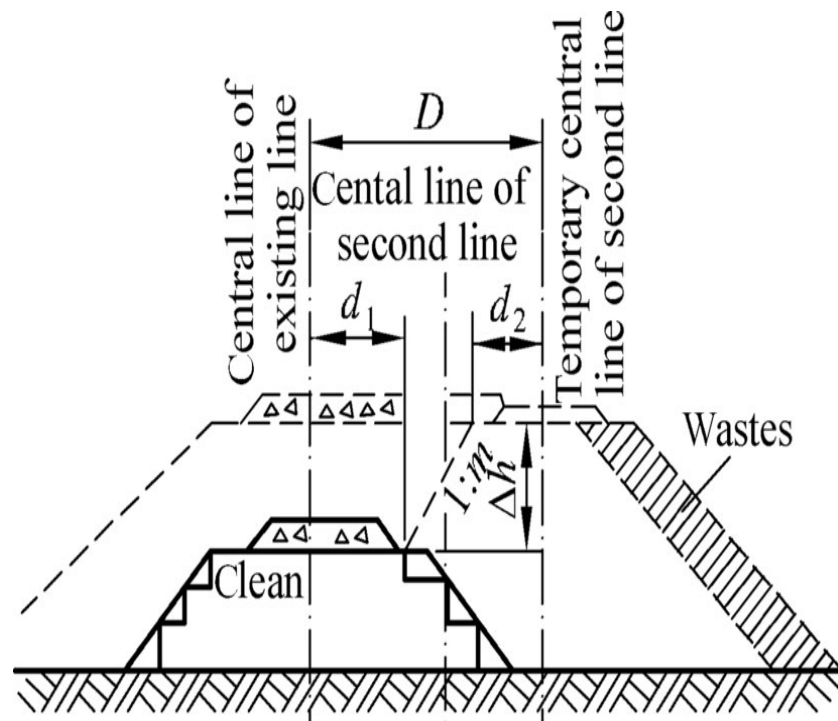


Fig. 8.41 Shifting second line and raising subgrade surface.

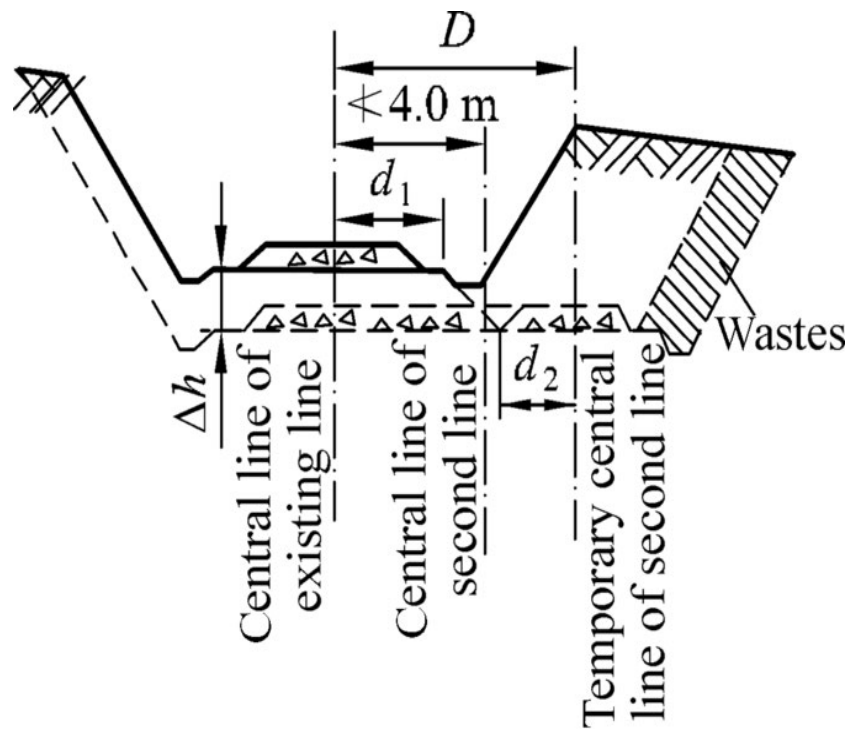


Fig. 8.42 Shifting second line and lowering subgrade surface.

8.2.3.2 Running in Parallel With Different Elevation

When the second line runs in parallel to the existing lines but elevation of subgrade shoulders are different, it is called parallel with different elevation. It is usually used in the segments with different grade in two lines. Fig. 8.43 shows several types of subgrade cross-sections in segments of parallel with different elevation.

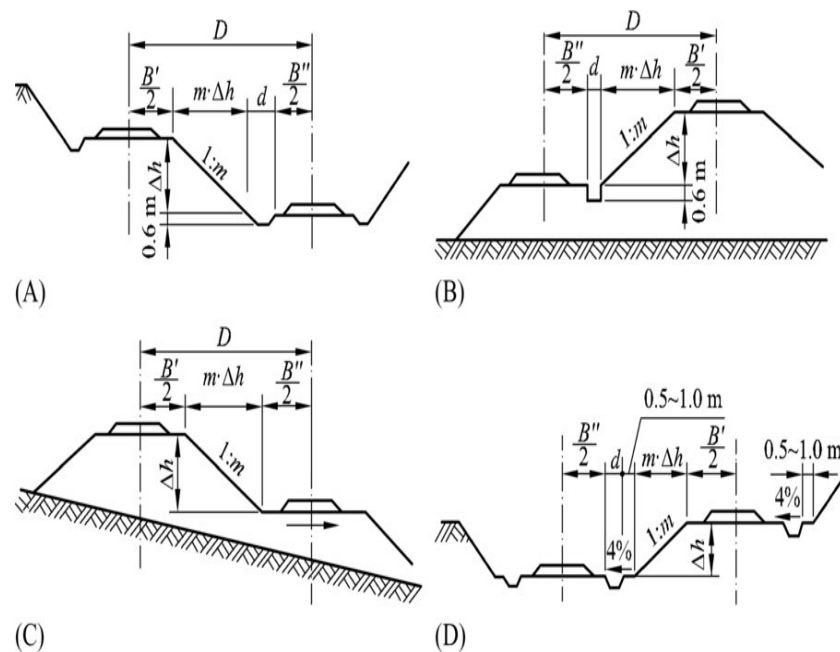


Fig. 8.43 Cross section of parallel and unequally elevated subgrade.

The elevation difference of the subgrade surface makes the drainage between the two lines difficult, which may cause roadbed diseases in the lower line due to accumulated water. In blizzard regions, the lower line is easily buried by snow. For the lower line, it is not convenient to change tie, and cannot be set with any road crossing, for segments of parallel with different elevation, the minimum distance between the two lines is decided both by the difference between the two subgrade surface elevations and by the subgrade slope rate m . In cutting segment, the influence from the train loads of higher line should still be considered and the slope should be smoother. When necessary, the subgrade slope shall be reinforced, or shoulder walls built to minimize the distance between the lines.

Based on the requirement of subgrade structures, the minimum distance between the two lines is

(8.32)

where $B'/2$ is the half subgrade width of higher line, generally is 3.35 m; $B''/2$ is the half subgrade width of lower line, generally is 3.20 m; m is the subgrade slope rate, generally is 1.5; Δh is the elevation difference between subgrade shoulder of two lines (m); and d is the width of ditch, bottom width of ditch for 0.4 m, depth of ditch for 0.6 m or 0.4 m, ditch slope of ditch is designed according to the 1:1, then d is 1.6 m and 1.2 m; If using plasma build by laying bricks or stones flaky channel, the width of ditch can be reduced to 0.4 m + width of the side wall of the ditch.

When the distance between two lines is restricted, the elevation difference between the two subgrade surface is not big, and the route length is shorter, so cannot set the drain (slot) between the two lines, but the subgrade surface of the below line should set the drainage cross slope with gradient of 1%-4%, as shown in Fig. 8.43C.

In coarse sand, medium sand, loess, easily weathered rock and other bad soil cutting, the platform, at the above subgrade side of drainage between the two lines, with 4% gradient to the ditch, should be set up, the platform width depending on the height of slope and soil properties, generally from 0.5 to 1.0 m, as shown in Fig. 8.43D. For this type of subgrade cross section, the drain platform width should be added in calculation equation of minimum spacing between two lines.

8.2.3.3 Subgrade for the Second Line and Newly Built Subgrade for Double-Track Lines

In single line detouring section of second line, bridge and tunnel leads segments and segment that subgrade needs to be constructed due to large distance between two lines, it should be designed according to newly built single-line railway subgrade standard. For double-line detouring, the subgrade cross section should be designed according to the newly built double-line subgrade.

8.2.4 Plane Calculation of the Second Line

In a straight section, plane of the second line is usually parallel to the existing line, the distance between two lines is 4.0 m; In curve segment, concentric circle of the existing line is often applied, the distance between two circular curves lines is $4.0 + \Delta$ (m), Δ is widening value of curve. Distance between the two lines needs to be calculated (plane calculation of the second line) only in the segments with the distance between second line and existing line changing (typically spacing changing at curves). The plane calculation method of second line generally uses triangle analysis method and coordinates analysis method, etc.

8.2.4.1 Methods of Plane Calculation

1. Realignment calculation of the existing line

When designing the plane of the second line, realignment calculation for reconstruction of the existing curve comes first, its principle and method have been introduced in Section 8.2.2.

When rebuilding the existing curve, in order to reduce the work quantity of reconstruction, one should avoid the moving or reconstructing of buildings such as the bridge, tunnel, etc., and try to reduce the shift distance of curve as possible. In order to avoid widening both sides of the existing subgrade, it would be best to shift the existing line to the direction of the second line; under special circumstances, shift to the opposite direction of the second line. However, in order to avoid the insufficient margin between the two lines, which may potentially cause traffic accidents, the existing line must be shifted to the correct design position before the second line being delivered for operation.

The plane of the second line shall be designed according to the realigned existing curve.

2. Calculation of design curve elements

As shown in Fig. 8.44, the existing line lies on the outer side, the second line lies in the inner side, distance of lines in curve is widened from D1 to D2; TS1-SC1-CS1-ST1 represents the realigned existing curve, TS2-SC2-CS2-ST2 represents the design second curve. According to geometric relationship, b_1 and b_2 , the tangential dislocation between starting or ending points of the two circular curves, can be calculated.

The start point TC1 and end point CT1 of the existing circle curve are the points of tangency after the existing tangent line moving inward with inward shifting distance of p_1 . Distance along the tangent direction from point TC1 or point CT1 to the intersection point IP1 is $L_1/2$, distance along tangent direction from point TC1 or point CT1 to point CMP1 of inward tangent is $L_1/2$. When realigning the existing curve, calculated start and end kilometers of the circular curve are kilometers of TC1, CT1 in the figure.

The start point TC2 and end point CT2 of second curve circle are the points of tangency after the tangent of second line moving inward; the inward shifting distance is p_2 . The distance along the tangent direction from point TC2 or point CT2 to the intersection point IP2 is $L_2/2$, distance along tangent direction from point TC2 or point CT2 to point CMP2 of inward tangent is $L_2/2$.

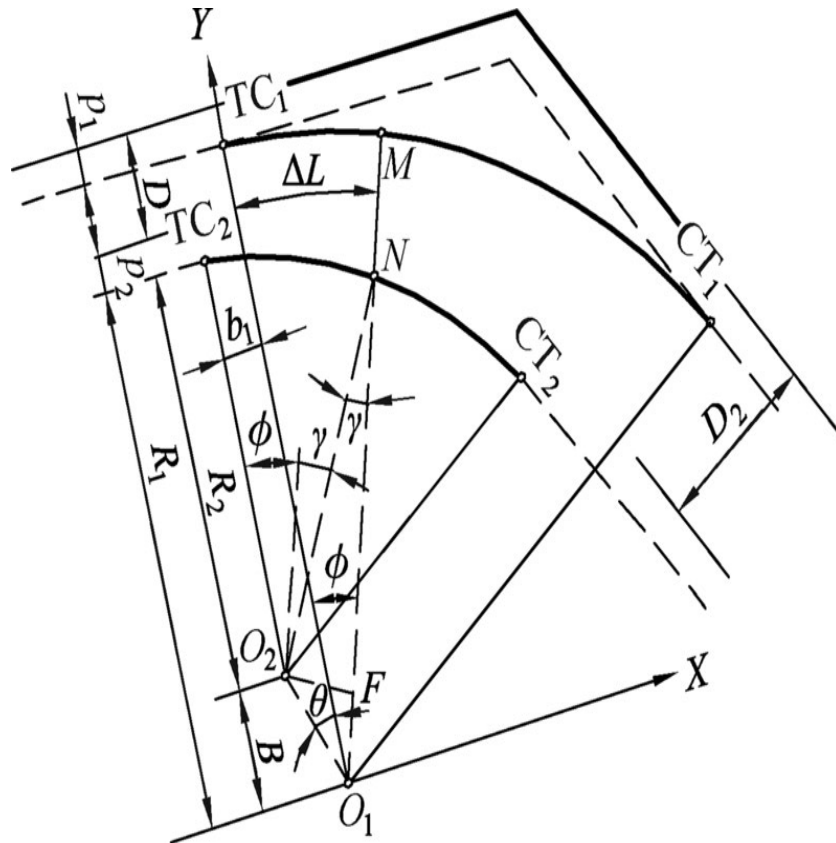


Fig. 8.44 Plane with widened distance between curves.

1) Select circular curve radius R_2 and easement curve length of l_0 the second line

First to figure out the hypothetical circular curve radius, start kilometer of curve is the same as the start kilometer of the existing circular curve, according to this choose circular curve radius of the second line. As shown in Fig. 8.45, according to the relationship of the inner and outer circular curve radius, the following two equations are listed

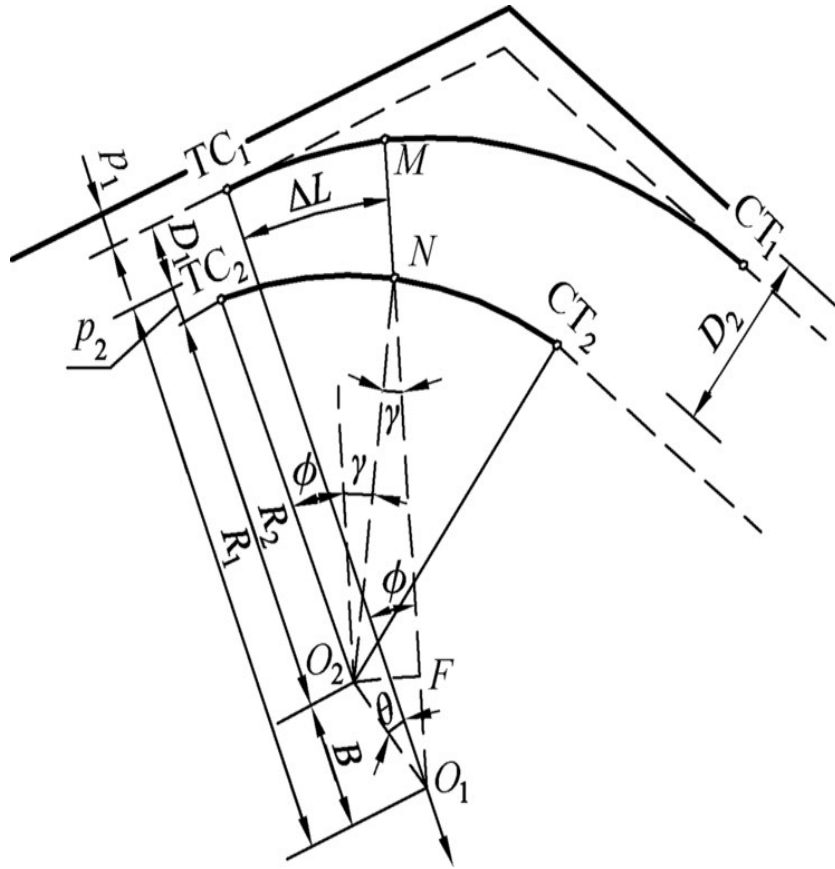


Fig. 8.45 Calculation of displacement.

①

②

(8.33)

Then, calculate $R\phi$

(8.34)

Before picking R_2 and I_2 , assuming , obtain likelihood value of $R\phi'$, $R\phi'$ is rounded to the multiple value of 10, namely the circular curve radius of second line R_2 .

When rounding the value of circular curve radius, the minimum distance between the two lines should be not less than 4.0 m, so when the starting line spacing on the tangent between the two lines is 4.0 m, then:

(1) when the second line at the inside, R_2 should be rounded up into multiple value of 10.

(2) when the second line at the outside, R_2 should be rounded down into multiple value of 10.

Then, in accordance with the constructing standard of new railway lines, the easement curve length L_2 is selected according to R_2 . Accordingly, can be calculated, then the correct value of R_ϕ can be calculated according to Eq. (8.34)

2) Calculate the circle curve elements of second line

α is the same as the existing curve, then

$$T_2 = R_2 \times \tan \frac{\alpha}{2}, \quad L_2 = R_2 \times \alpha, \quad T_\phi = R_\phi \tan \frac{\alpha}{2}$$

3) Calculate tangential dislocation b_1 and b_2 of starting points and ending points between inside and outside circular curve (see Fig. 8.46)

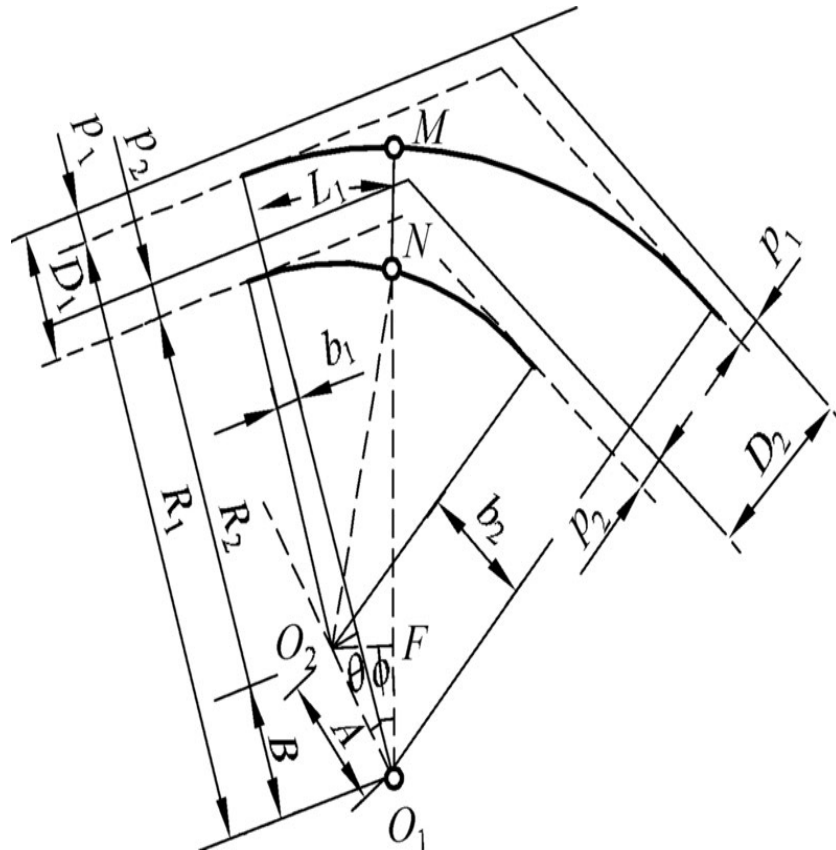


Fig. 8.46 Distance between lines deriving.

$$\left. \begin{aligned} b_1 &= T_2 - T_\phi \\ b_2 &= \alpha - (T_2 - T_\phi) = Z \times \sin \alpha - b_1 \end{aligned} \right\}$$

(8.35)

4) Calculate main point kilometer of design curve of the second line

Calculating the kilometer of the second line according to the projection to the kilometer of the existing lines

$$\begin{aligned} TC_2 \text{ kilometer} &= TC_1 \text{ kilometer} - b_1, & TC_2 \text{ kilometer} &= TC_1 \text{ kilometer} - b_1 \\ TS_2 \text{ kilometer} &= TC_2 \text{ kilometer} - l_2/2, & SC_2 \text{ kilometer} &= TC_2 \text{ kilometer} + l_2/2 \\ CS_2 \text{ kilometer} &= CT_2 \text{ kilometer} - l_2/2, & ST_2 \text{ kilometer} &= CT_2 \text{ kilometer} + l_2/2 \end{aligned}$$

3. Calculation of distance between inside and outside circular curve

Calculation of the distance between the inside and outside circular curve is shown in Fig. 8.46.

(1) The projection length of line connection two circle centers on the normal direction of the starting point of the existing curve is

(8.36)

(2) Distance of two centers

$$A = O_1O_2 = \sqrt{B^2 + b_1^2} \quad \text{or} \quad A = \frac{B}{\cos \theta} = \frac{b_1}{\sin \theta}$$

(8.37)

(3) The angle between the extension of two circles attachment O_1O_2 and the normal direction of the starting point of the existing circle curve is

(8.38)

(4) The central angle of the arc length which is between from any point M on existing circular curve to the starting point on the existing circle curve is

$$\phi = \frac{L_1}{R_1} \times \frac{180}{\pi}$$

(5) The distance MN which is from any point on existing circular curve to the second line is

$$\begin{aligned} Y &= MN = O_1M - O_1N \\ &= O_1M - (O_1F + FN) \\ &= O_1M - O_1F - \sqrt{|O_2N|^2 - |O_2F|^2} \end{aligned}$$

(8.39)

So

$$Y = R_1 - A \cos(\theta + \phi) - \sqrt{R_2^2 - A^2 \sin^2(\theta + \phi)}$$

4. The calculation of distance of two lines within easement curve

After calculating the distance between circular curves, as shown in Fig. 8.47, on both ends of circular curve, the shifting distance of easement curve should also be included. According to the measuring point location, equations listed in Table 8.10 are applied to calculate the distance between lines, Δ .

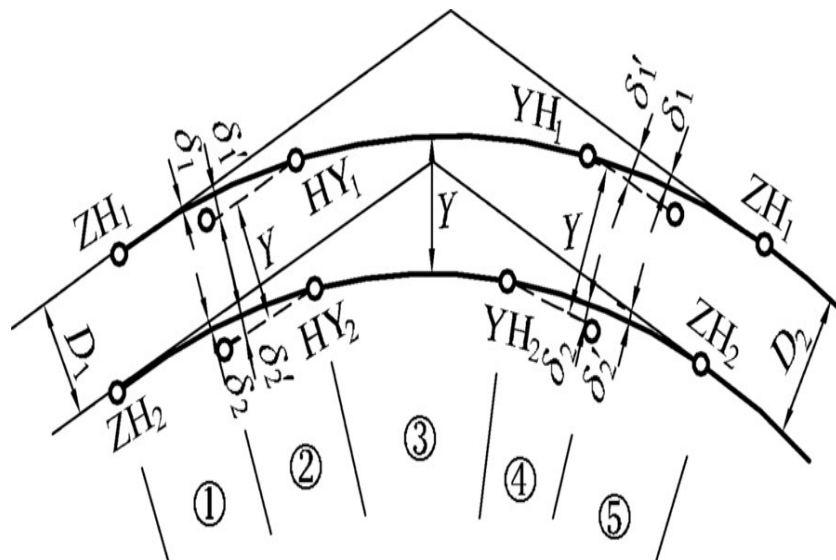


Fig. 8.47 Easement curve shifting.

Table 8.10

Calculation Equation of Distance Between Lines

Measurement Point Range	Distance	61,61'	62,6
Outside ZY, Y value has not been calculated, the measuring point on easement curve			
ZY-HY, Y value has been calculated, measurement point on easement curve			
HY-YH, Y value has been calculated, measurement point on circular curve			
HY-YZ, Y value calculated, measuring point on easement curve			
Outside of YZ, Y value has not been calculated, measurement point on circular curve			

Note: When calculating δ_2 , δ_2' , because l_2 , l_2' is projection length on the existing length, its direction is not the normal direction of the existing lines, there should be error theoretically, the error is very small, which can meet precision requirement.

8.2.4.2 General Calculation Equation of Triangle Analytic Method

1. The basic types of change distance in curve

Changing distance in curve, distance is calculated with triangle method. Varying with the inside and outside of the second line, distance between lines can change from small to large or from large to small, and the value of the R_1 and R_2 can change, thus there are variety of schemata. All kinds of schemata have different calculation equation of the tangential dislocations and the distances between lines, but the theory is the same. Beginners should draw the plane graph, according to the geometric relationship derive. When drawing, should make normal of endpoint curve R_1 and curve R_2 coincidence, so that the reasonable selection of the second line curve radius. Below is a list of three types of schemata calculation type (the derivation is abbreviated).

(1) When the second line is inside, (see Fig. 8.48),

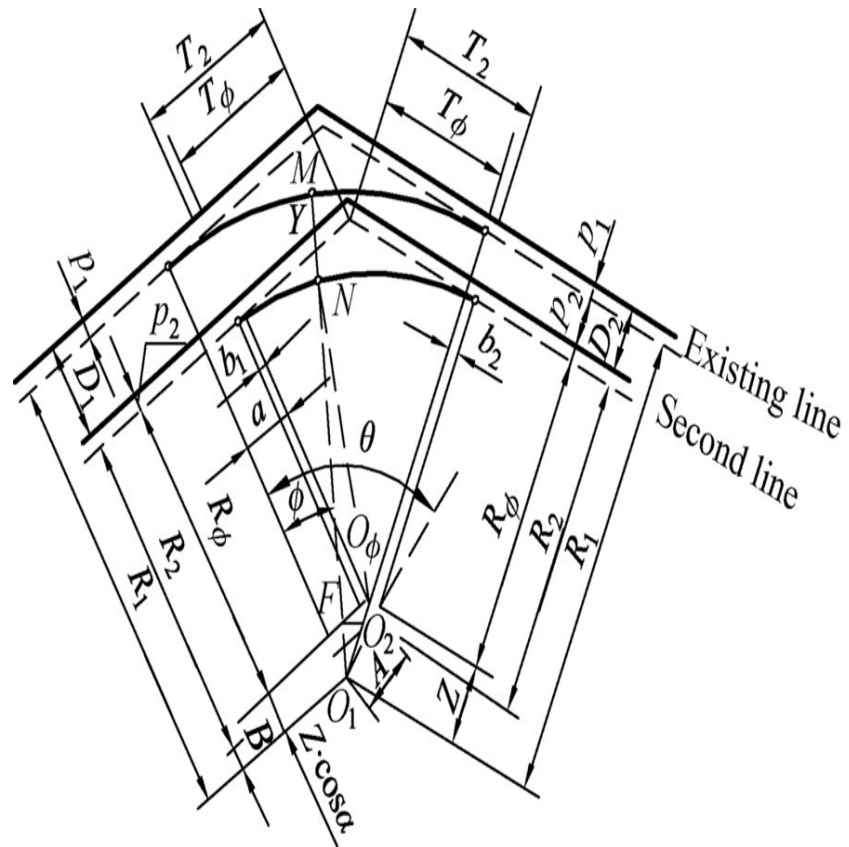


Fig. 8.48 Plane of line distance calculation.

$$Y = R_1 - A \cos(\theta - \phi) - \sqrt{R_2^2 - A^2 \sin^2(\theta - \phi)}$$

(2) When the second line is outside, $D_1 < D_2$ (see Fig. 8.49),

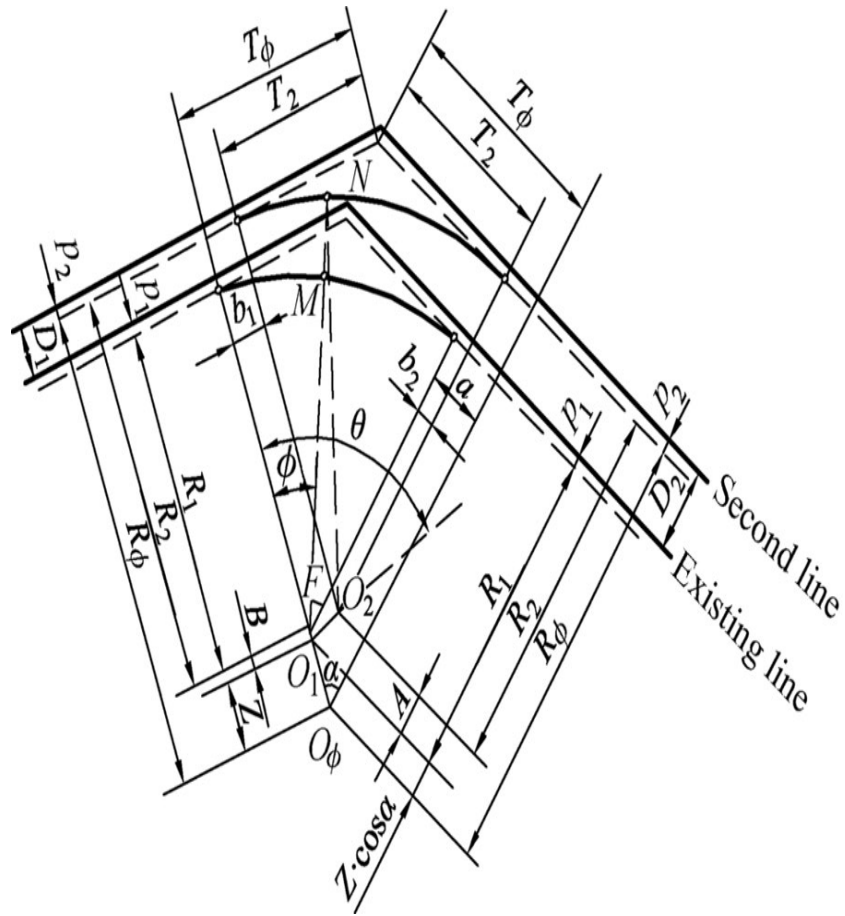


Fig. 8.49 Plane for distance between lines calculation.

$$Y = -R_1 + A \cos(\theta - \phi) + \sqrt{R_2^2 - A^2 \sin^2(\theta - \phi)}$$

(3) When the second line is outside, (see Fig. 8.50),

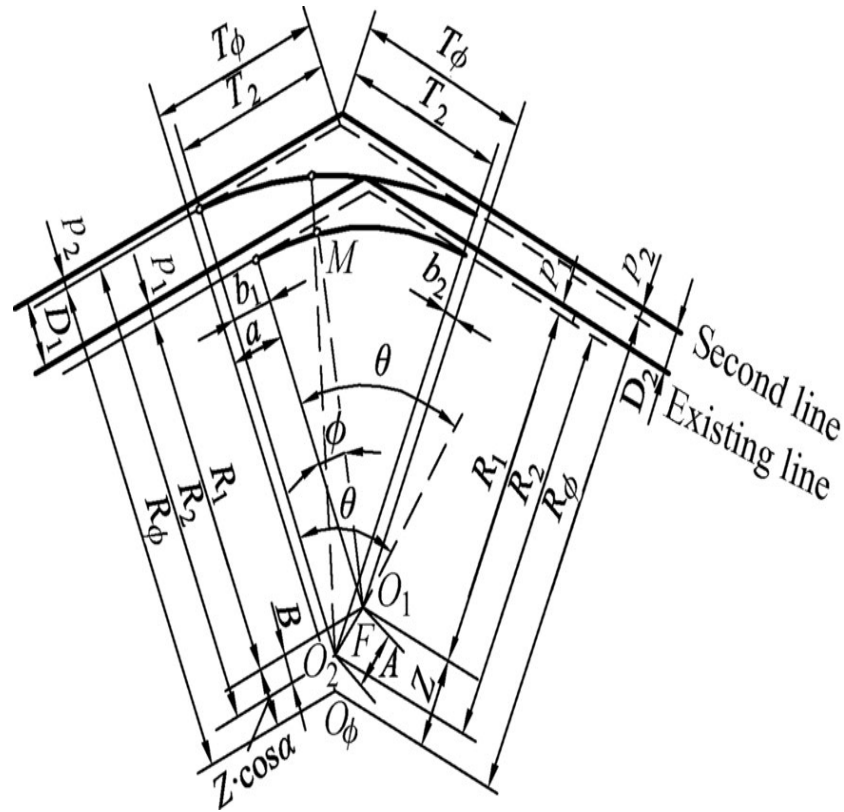


Fig. 8.50 Plane for distance between lines calculation.

$$Y = -R_1 - A \cos(\theta - \phi) + \sqrt{R_2^2 - A^2 \sin^2(\theta - \phi)}$$

2. General calculation equation of distance between the inside and outside circular curve

When calculating the distance between lines, plus or minus are introduced according to the following rules, then various calculation equations can be incorporated into a general equation. The method is as follows:

- (1) Under the condition that the second line inside, select a positive value for start spacing distance D_1 , D_2 ; for the second outside, pick a negative value for D_1 , D_2 .
- (2) The plus or minus sign is introduced to the calculated value of the following equation:

$$Z = \frac{D_1 - D_2}{1 - \cos \alpha}$$

$$a = Z \sin \alpha$$

When

$$|D_1| < |D_2|, R_\phi = R_1 + p_1 - D_1 - p_2 + Z, \quad b_1 = T_\phi - T_2$$

When

$$|D_1| > |D_2|, R_\phi = R_1 + p_1 - D_2 - p_2 - Z, \quad b_1 = a + T_\phi - T_2$$

$$B = (R_1 + p_1) - D_1 - (R_2 + p_2)$$

$$\theta = \arctan \frac{b_1}{B} \quad (\text{if } b_1 = 0, \text{ then } \theta = 0)$$

If $B=0$, when b_1 is positive, $\theta=90^\circ$; when b_1 is negative, $\theta=-90^\circ$

$$A = \frac{B}{\cos \theta}; \quad \text{if } B = 0, \text{ then } A = \frac{b_1}{\sin \theta}$$

$$\phi = \frac{L_1}{R} \times \frac{180}{\pi} (\text{positive})$$

(3) Calculation equation of the normal length

$$Y = R_1 - A \cos(\theta - \phi) - \sqrt{R_2^2 - A^2 \sin^2(\theta - \phi)}$$

Positive value of Y means the second line is inside; negative value of Y , means the second line is in the outside.

(4) The distance between the lines according to formulas listed in Table 8.10 calculate.

8.2.4.3 Distance Between Lines Calculated with Coordinates Method

Because of different thinking and coordinate system, methods for calculating the distance between the lines are different. Based on schema of the triangle method, two easy methods will be introduced.

1. Method using center of the existing curve O1 as the origin of coordinates

As shown in Fig. 8.51, the second line is inside, . Center of the existing curve O1 is the origin of coordinates, O1 (TC1) is the Y axis, and the straight that perpendicular to the Y axis and direction point to the curve is the X axis, measuring points are located in the first quadrant, MO1 is the normal direction of the existing curve. The calculation equation of normal length MN is as follows:

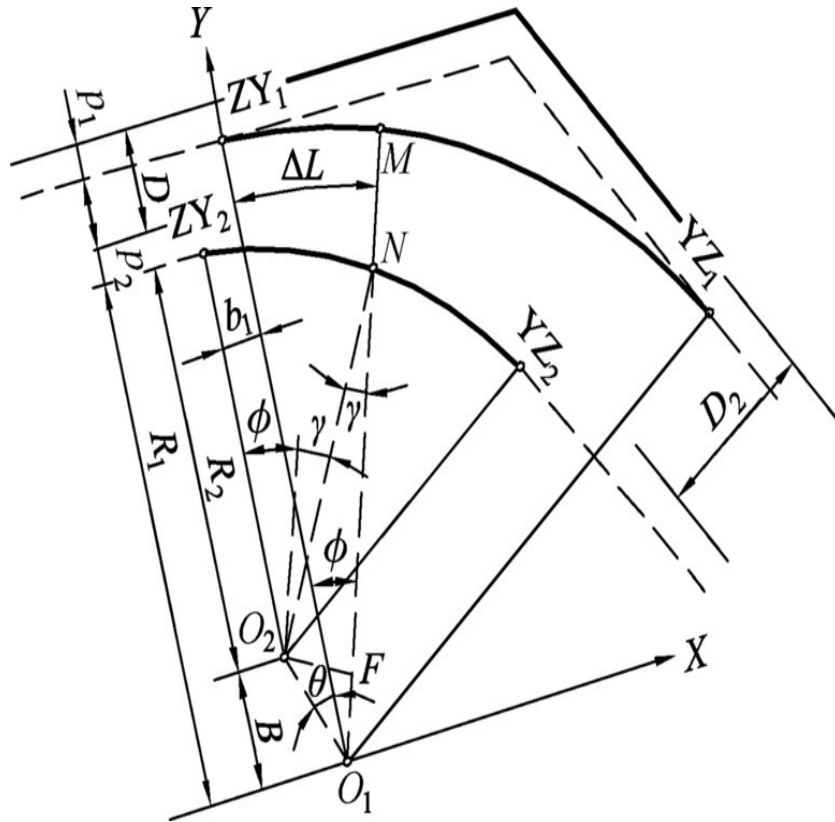


Fig. 8.51 Spacing distance calculation with the coordinates method.

(1)

(2)

(3)

(4)

$$b_1 = T_2 - T_\phi, \text{ or, } b_1 = R_2 \tan \frac{\alpha}{2} + \frac{D_2 - p_1 + p_2}{\sin \alpha} - R_1 \quad \tan \frac{\alpha}{2} - \frac{D_1 - p_1 + p_2}{\tan \alpha}$$

(5)

(6)

$$\phi = \frac{\Delta l}{R} \times \frac{180}{\pi} (^{\circ}), \quad \Delta L = \text{measurement point kilometer} - \quad \text{TC}_1 \text{ kilometer}$$

(7)

(8)

$$O_2 F = O_1 O_2 \times \sin(\theta + \phi) = \frac{b_1}{\sin \theta} \times \sin(\theta + \phi)$$

(9)

An indicative diagram and corresponding equations can also be figured out for other kinds of schema of changing distance in curve segment. Positive or negative values about symbols can also be determined, and a general calculation equation can be deduced.

2. Method using TC1 of the existing curve as the origin of coordinates

As shown in Fig. 8.52, the second line is inside, . TC1 of the existing curve is the origin of coordinates, tangent direction is X axis, normal direction is the Y axis. For the calculation of normal length MN, in addition to formulas (1)–(3), formulas (4)–(9) is the same as above method.

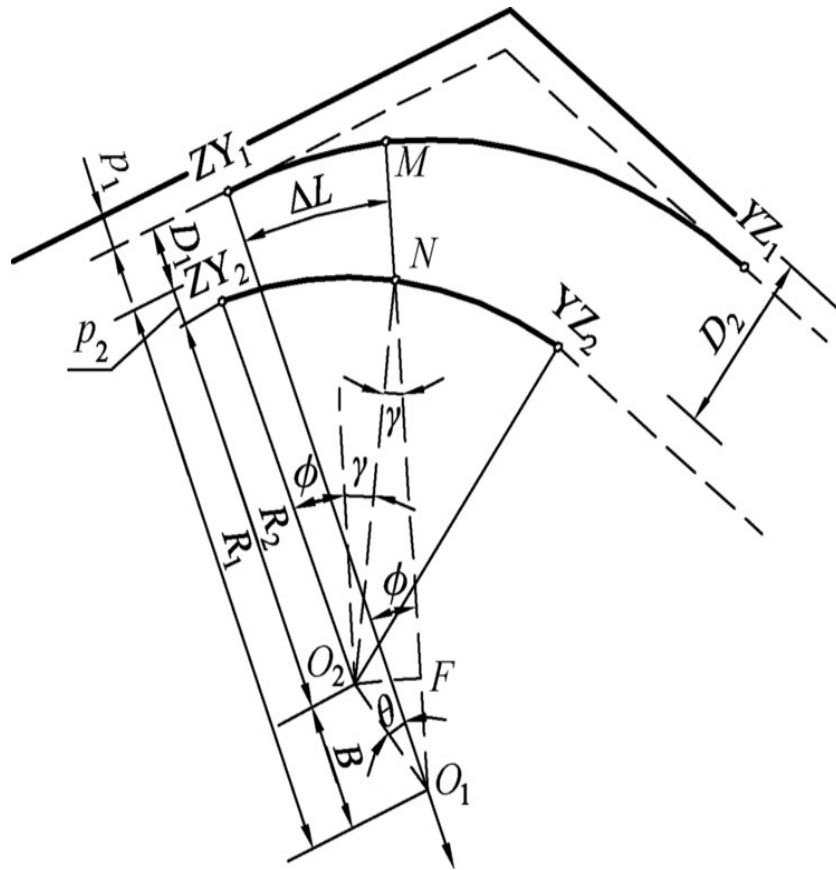


Fig. 8.52 Spacing distance calculation with the coordinates method.

3. Calculation of distance between two lines

The calculation equation of the distance between two lines still can use the method which described in triangle analysis method, such as listed in Table 8.10.

(1)

$$Y = MN = \sqrt{(x_N - x_M)^2 + (y_N - y_M)^2}$$

(2)

(3)

$$y_N = R_1 - B - R_2 \cos(\phi + \gamma)$$

8.2.4.4 Application of Calculation Method for Plane Distance Between Lines

1. Example for widening distance between lines in curve segment

According to the example to calculate the throw of curve in the third section (see Fig. 8.53), the calculated data of throw of the existing curve are shown in Table 8.4. The calculation results of distance between two lines are shown in Table 8.11.

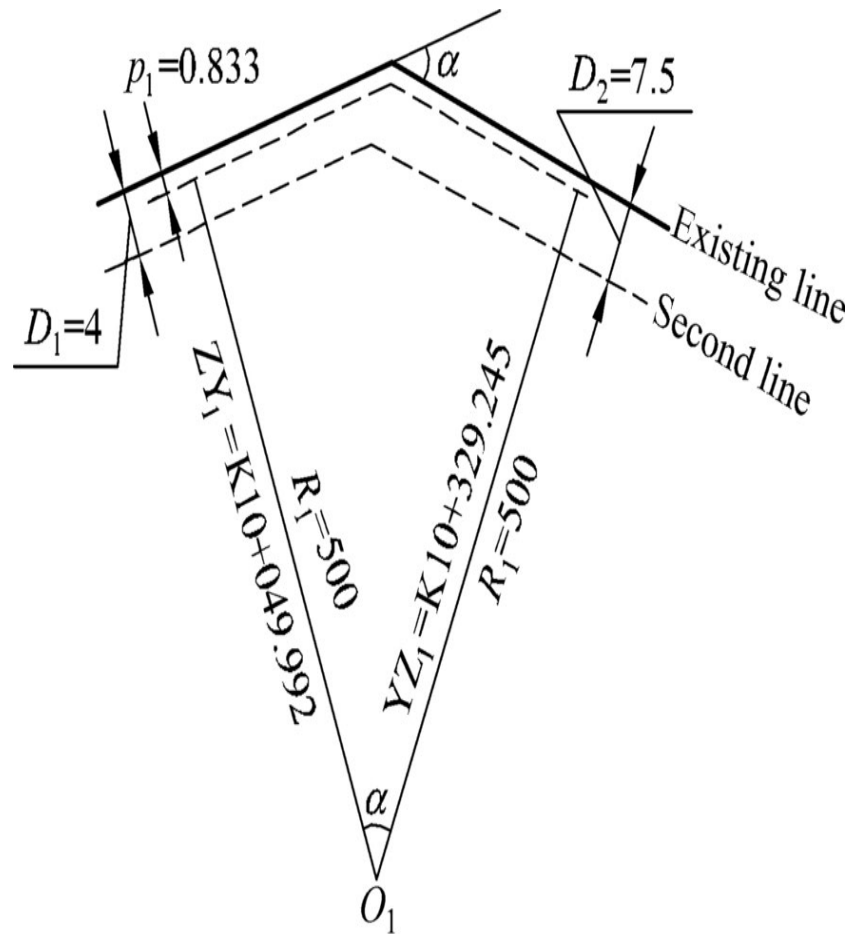


Fig. 8.53 Plane of widening of curve distance.

Table 8.11

Calculation of Distance Between Two Lines

Measurement Point Mileage	Calculation of Normal Length	Normal Length
Start spacing distance D1D2	Data and Equation	Shifting Distance of Easem
R1	$\theta + \phi$	$A \cdot \cos(\theta + \phi)$

$\theta = 8^{\circ}08'39''$ $\phi 1 = 1^{\circ}08'49''$ $\phi 20 = 2^{\circ}17'30.6''$ **A = 15.523**

1	2	3
K9+960	4.000	
+980	4.000	
K10+000	4.000	
+020	4.000	
+040	4.000	
+060		500
+080		500
+100		500
+120		500
+140		500
+160		500
+180		500
+200		500
+220		500
+240		500
+260		500
+280		500
+300		500
+320	7.500	
+340	7.500	
+360	7.500	
+380	7.500	
K10+400	7.500	
Note		

2. Exchange sides at curve segment

Two lines changing sides at the curve segment, actually refers to two schemes to widen distance between centers of curves. As shown in Fig. 8.54, for existing lines, on the left side of design line the distance is changed from D_1 to 0; on the right side of the design line the distance is from 0 to D_2 . Calculation method is the same as widening the distance of the curve.

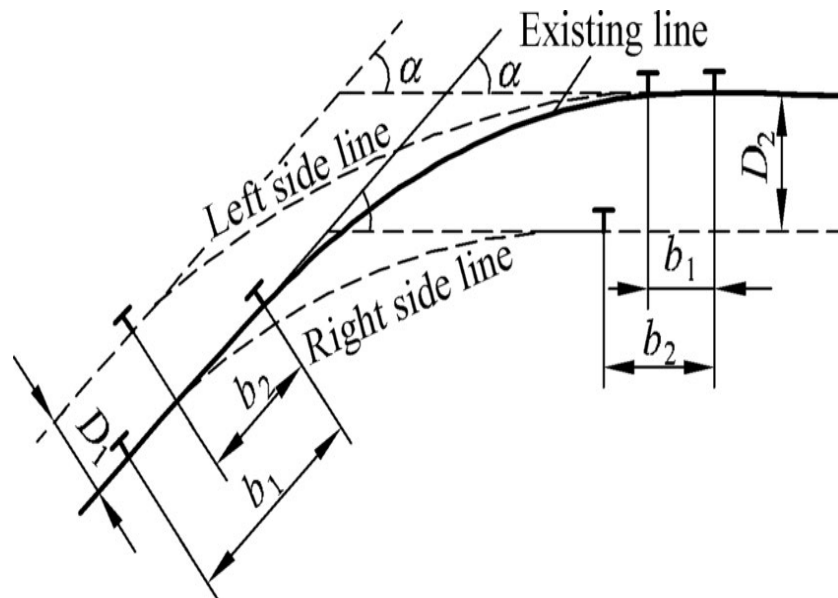


Fig. 8.54 Exchange sides at curve segment.

3. Enlarger radius of the existing curve

When the existing curve angle is large, the easement curve and curve radius are small, and the curve radius needs to be enlarged and the length of easement curve needs to be lengthened, as shown in Fig. 8.55, due to the curve length changing after shifting, the traditional calculation method cannot be applied to calculate throw value for this case. Throws need to be calculated with method for calculating distance between lines; there are mainly three steps:

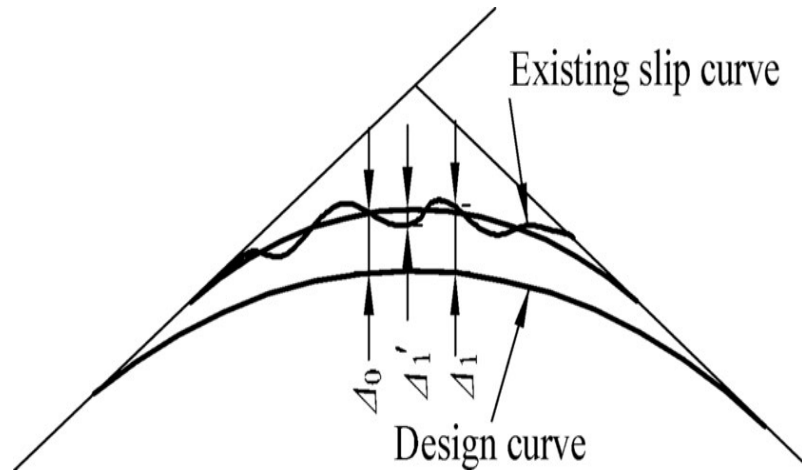


Fig. 8.55 Enlarger curve radius.

(1) First using the traditional throw calculation method to realign the misaligned existing curve to regular curve, calculating the throw of track Δ_1' ;

(2) Calculating distance Δ_0 between realigned existing curve and design curve by using distance calculation method, at this time .

(3) Throw to shift the misaligned existing curve to design curve is .

4. Exchange sides at straight segment

Exchanging sides on straight line actually refers to problem of widened line spacing on two straight lines. As shown in Fig. 8.56, for existing lines, spacing distance of left side changes from D_1 to 0, spacing distance of right side changes from 0 to D_2 . The calculation method is the same as above.

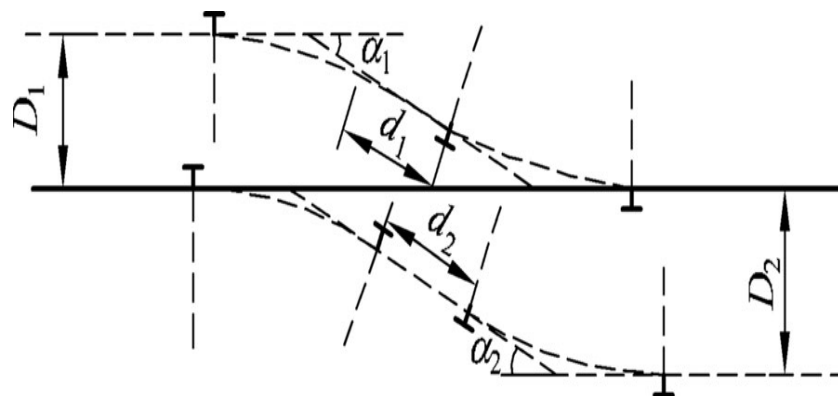


Fig. 8.56 Exchange sides at straight segment.

5. Change spacing distance at straight segment

Distance between lines at straight segment can be changed by adding a set of reverse curve, as shown in Fig. 8.57. The curve radius of reverse curve, generally 4000 m is adopted; 3000 m under difficult circumstances. Under normal circumstances, the easement curve should be set, if limited by the minimum curve length requirements, the easement curve can also not be set, and the length of intermediate straight line between two curves generally is not less than 80 m.

When changing distance between lines at straight segment, distance D_1 and D_2 , curve radius R_1 and R_2 , length of intermediate straight line are generally known. The calculation steps of the main parts of plane and the distance between two lines are as follows:

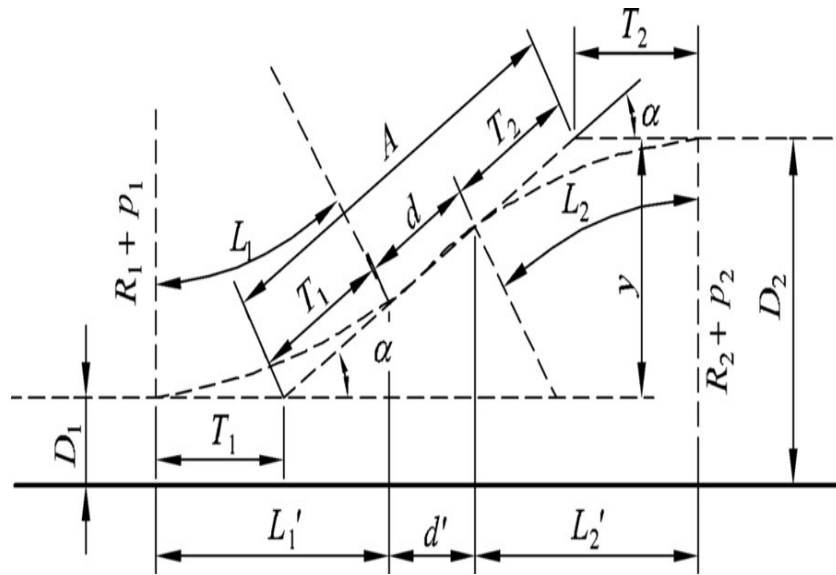


Fig. 8.57 Widening space at straight section.

1) Calculation of deflection angle α

Set

For

$$\begin{aligned} A = T_1 + T_2 + d &= (R_1 + p_1) \tan \frac{\alpha}{2} + (R_2 + p_2) \tan \frac{\alpha}{2} + d \\ &= (R_1 + R_2 + p_1 + p_2) \tan \frac{\alpha}{2} + d \end{aligned}$$

And because

So

$$y = \left[(R_1 + R_2 + p_1 + p_2) \tan \frac{\alpha}{2} + d \right] \frac{2 \tan \frac{\alpha}{2}}{1 + \tan^2 \frac{\alpha}{2}}$$

After transportation of the term,

$$\tan \frac{\alpha}{2} = \frac{-d \pm \sqrt{d^2 + [2(R_1 + R_2 + p_1 + p_2) - y]y}}{2(R_1 + R_2 + p_1 + p_2) - y}$$

(8.40)

where d is the length of intermediate straight line+ half length of the adjacent easement curve on both ends, if 80 m is adopted for the intermediate straight line length, d is 80 m under no easement curve condition.

The obtained value of α should be rounded down to “minutes,” which is applied to the following calculation.

2) Calculate curve elements and kilometer difference of two lines

$$\begin{aligned} A &= \frac{y}{\sin \alpha} \\ T_1 &= (R_1 + p_1) \tan \frac{\alpha}{2}, \quad L_1 = (R_1 + p_1) \times \alpha \\ T_2 &= (R_2 + p_2) \tan \frac{\alpha}{2}, \quad L_2 = (R_2 + p_2) \times \alpha \\ d &= A - T_1 - T_2 \end{aligned}$$

Actual length of design line

Projection length of design line on existing line is

$$L'_1 + d' + L'_2 = (1 + \cos \alpha)T_1 + d \times \cos \alpha + (1 + \cos \alpha)T_2$$

Kilometer difference of two lines

The projection kilometer which are the start and ending points of second circle curve has on the existing line

$$\begin{aligned} CT_1 \text{ projection kilometers} &= TC_1 \text{ kilometers} + (1 + \cos \alpha)T_1 \\ TC_2 \text{ projection kilometers} &= TC_1 \text{ kilometers} + T_1 + (T_1 + d) \cos \alpha \\ CT_2 \text{ projection kilometers} &= TC_1 \text{ kilometers} + T_1 + A \cos \alpha + T_2 \end{aligned}$$

3) Calculation of normal length

The normal length between second center line and existing center line can use the tangent offset equation to calculate, as shown in Fig. 8.58.

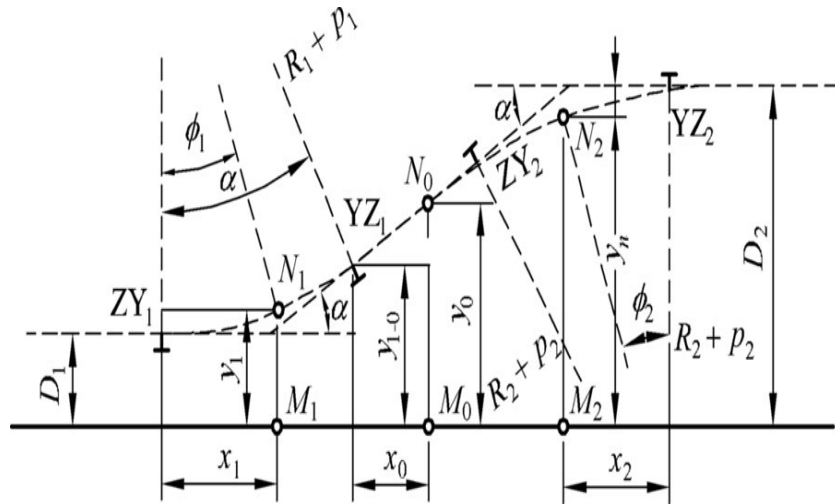


Fig. 8.58 Changing distance between lines in a straight line segment.

① Between TC1 and CT1:

Normal length

$$y_1 = M_1N_1 = D_1 + (R_1 + p_1)(1 - \cos \phi_1)$$

(8.41)

where

x1 is the kilometer of measurement point M1 on existing line—projection kilometer of TC1

Normal length of point CT1

(8.42)

② Between CT1 and TC2:

Normal length

$$y_0 = M_0N_0 = Y_{1-0} + x_0 \tan \alpha$$

$$= D_1 + (R_1 + p_1)(1 - \cos \alpha) + x_0 \tan \alpha$$

(8.43)

where x_0 =kilometer of measurement point M0 on existing line-projection kilometer CT1

③ Between TC2 and CT2

Normal length

$$y_2 = M_2N_2 = D_2 - (R_2 + p_2)(1 - \cos \phi_2)$$

(8.44)

where

x_2 is the projection kilometer CT2 —kilometer of measurement point M2 on existing line.

4) Calculation of distance between lines

The distance between the TS1-ST1 is

The distance between the ST1-TS2 is

The distance between the TS2-ST2 is

where Y is the normal length of corresponding sections; δ_1 , δ_2 are the internal shifting distance of measure point after adding the easement curve, δ_1 , δ_2 is zero if no easement curve being set.

8.3 Building the Third, Fourth, and Branching Lines

On a busy line which is located in a developed urbanization zone and national important economic regions with dense population, concentrated industry, and developed economy, passenger and freight traffic volume grows very fast. In order to meet the requirements of the quick development of traffic in these regions, for busy double-track railways, after its technical load reaches a certain level, the third, fourth, and branching line as a further capacity expansion measures need to be constructed.

8.3.1 Building the Third, Fourth, or Loop Line in the Busy Section of a Hub Area

Building the third, fourth or branching line on the basis of double-track automatic block line, the first is to meet the actual transportation requirement of the suburb area adjacent to the big city, or sections in big hub with heavy transportation load, such as Harbin - Bingjiang - TaiPingQiao - Three trees, Shenyang - HunHe - Su Gutun, Fengtai—MajiaBao - Yongdingmen, North Tianjin—Wanxin, east Nanjing—Xingweicun—Nanjing, and Yuhu line of Shenyang hub, the Southeast loop line of Beijing hub, North loop of Tianjin hub, etc. The construction of the third, fourth or loop line has played an important role to improve through capacity in hub, to reduce interference at the plane cross, to reduce the burden of primary throat area, and to promote flexibility of hub.

To build the third, fourth or branching line at busy hub area range, its construction scheme must be according to the characteristics such as the nature of hub, traffic structure, transfer mode, main marshaling station, station layout, etc. to study, According to in favor of reducing cross interference, improving through capacity, and reasonable using of the existing technical equipment requirements, adjust measures to local conditions to study the construction and use scheme of the third, fourth or loop line, And the construction duly to achieve the desired effect.

- 1) Main line goes around outside the marshaling station

When the main line goes around outside the marshaling station, the third line should be built between two main lines, and be close to the yard side of the tense capacity, and in the section it should be close to the side with operation requirement so that passenger train and freight train can operate separately, to ensure the proper track time between passenger train and freight train after merging, reduce the deducting coefficient of passenger train, and use the third line as parked line for commuter car, to reduce the occupation time of trunk line.

2) The marshaling station located at one side of two main lines

When a marshaling station is located at one side of two main lines, the third line should be built at one side near the arrival-departure yard and the freight flow direction, in order to reduce the cutting interference on the main line and station throat, and can delay the building of the interchange facilities of cross line.

For a loop line within junction terminals, its main role is to divert flows. Practically, loop line provides service for the through train flows, while existing line mainly provides operations for passenger train, pick-up and drop train, and transfer train, this arrangement can therefore both reduce the train running kilometer, and ease the load of junction terminals where carrying capacity has been stressed.

The build loop line is one of the important measures to strengthen the carrying capacity of large railway hub and mobility; it should be developed in stages according to the overall hub development plan. At the same time, a series of problems such as the locomotive servicing, train vehicle maintenance, steward apartment building, locomotive routing adjustment, etc. should be solved so as to realize the division scheme cannot achieve because of containing a

certain factors, and to avoid bringing certain difficulties and inconvenient for operations.

8.3.2 Build the Third, Fourth or Branching Line in All Sections or the Entire Railway Line

On the electrified automatic block double-track railway lines, the third and fourth line should be constructed if other measurements cannot meet the requirement of rapid increase of transportation density. The construction schemes of building the third and fourth line are usually compared with a building diverting line. That is to say, to build the third and fourth line is reasonable only under the circumstances that build branching line is the unfavorable. Generally, double line are expanded to four lines only at suburb sections with large traffic volume, in other cases, it should first be expanded to three lines.

8.3.2.1 Build the Third Line

The construction scheme of the third line is related to many factors such as construction methods, traffic organization, carrying capacity, etc.

1. Detouring scheme

According to the traffic volume and goods composition, if possible, the third line can be adopted to detouring the existing two lines. For the detouring scheme, the third line is separated from existing lines, each line became a separate system, the dispatching command is more convenient, the work quantity is small, it can be compatible with urban planning, the new line cannot interfere the old line operation. The disadvantages are: more occupation of land area, extra facilities should be built, the investment is very big. Due to the system works alone, more labor and investment are involved. Newly built third line is mainly used for release section and through freight train. If possible, a set of trains can be organized.

2. Parallel scheme

The third line is built at one side of the existing double track subgrade, compared with detouring scheme, its advantage is less land occupation, land occupation per kilometer is just 6000 m³ (30% of the detouring line) with 5.5 m distance between lines, and most of the land have been expropriated by railways, earthwork quantity is small, about 70% of the detouring scheme. With full use of the existing station equipment, or with upgraded old equipment, the project investment can largely be saved. Operating labor becomes less, and the operation adjustment becomes more flexible. Its disadvantage is that the interference of construction and operation is great, it needs to set aside the construction "skylight," which can affect carrying capacity of the existing line. Demolition quantity is larger, with more contradiction of town planning; Scheduling command work is relatively complicated, the labor intensity of shunting personnel driving is bigger. If existing technology standard is low, it is not good for the modernization of technological transformation.

According to the different volume and nature of passenger and traffic flow, three parallel lines can undertake the tasks in three different ways:

(1) The existing double-track lines operate as usual, the newly built third line can be organized as single-track line. Trains with large coefficient of removal will run on the third line, such as passenger train, pick-up and drop train, transfer train, and some of the freight train. For this, the third line should be built at the left or the right side of the existing main line according to the factors or principle such as: the characteristics of facilities in most intermediate station and distribution of urban road towards the station, the convenience of passengers and less interference for main line train operation, and reducing influence of pick-up and drop train disturbance to the operation of the main track, etc. This design scheme has the advantage of convenience for passenger taking bus at intermediate station, reducing the operation interference and overload of attendants, without changing the original position of main track, without producing uneven subsidence problems of new and old roadbed, having advantageous for the railway maintenance.

The scheme is suitable for double-track section with much operation of slow passenger train, suburb and pick-up and drop train.

(2) Double lines are separated on both sides, which together with main equipment of the bidirectional automatic block form three-line system. In this case, the whole section still can operate in the normal way with double-line operation with any one of the main line under construction. But the turnout, track spacing, signal interlocking conditions of the original solution should be modified with complex project, which has serious operation interference for existing line, especially not suitable for the section with large passenger

and freight traffic volume. At this point, basically two modes can be applied for the operation of three parallel lines, depending on the passenger and freight flow.

① Freight and passenger train basically can run according to parallel train work diagram on double line, the third line is applied to release express passenger train and express freight train.

② The third line allow two direction trains overtaking without stopping, and thus it needs to lay the necessary cross line between main lines, with the whole automatic operation-command equipment, as shown in Fig. 8.59.

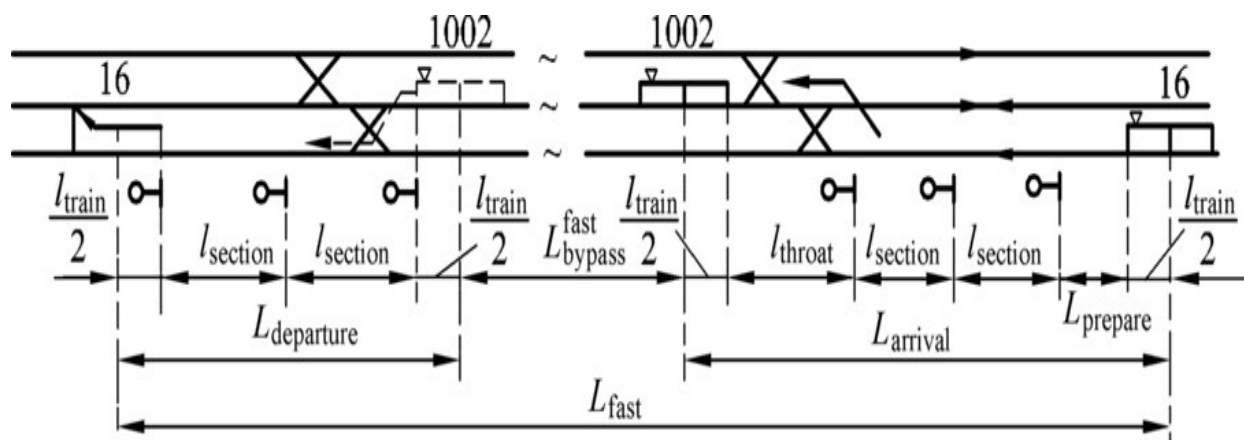


Fig. 8.59 Indicative diagram of train overtaking without stopping.

8.3.2.2 Build Four-Line Railway

When the railway traffic volume grows continuously to 180 pairs per day and night, the four-line railway should be built. Four-line railway can realize the separate operation of passenger and freight train, or suburb and main-line trains, carrying capacity can reach more than 300 pairs. It has been widely used in the US, UK, Germany, France, Netherlands and Japan. In the UK, multi-line railways have accounted for 12% of railway mileage. Most multi-line railway is built at the import and export points of railway hub in big city. Such as in Paris railway hub, most routes of 16 railway lines are multiple track railways. The former Soviet Union not only construct suburb four-line railway, but also construct main four-line railway to strengthen railway capacity of a double or three-line railway.

The main configuration and scheme of four-line railway mainly have four modes, as shown in Fig. 8.60.

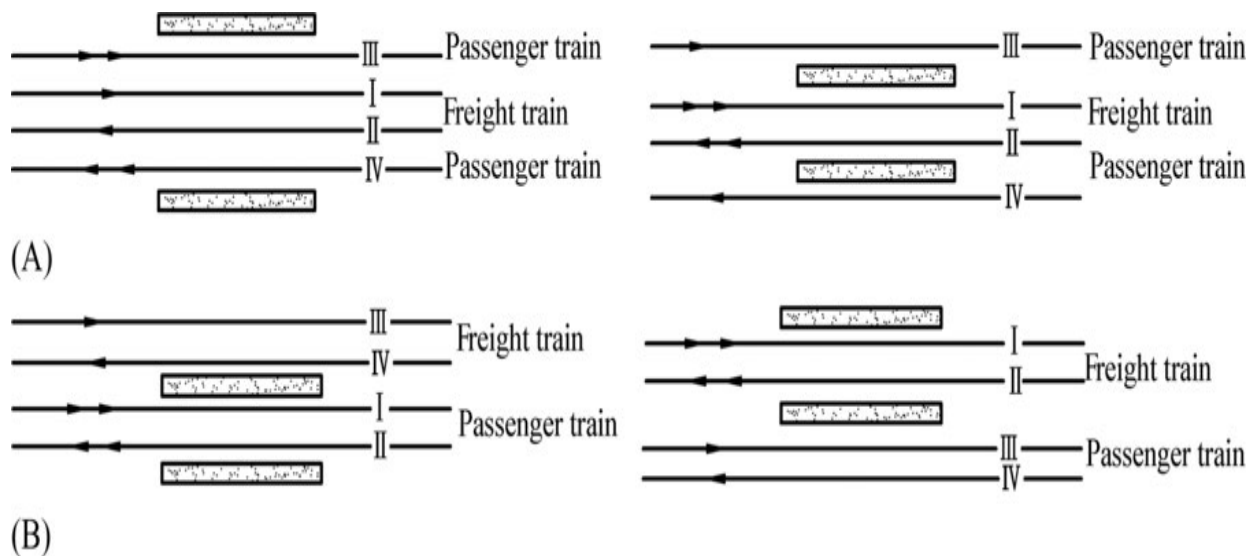


Fig. 8.60 Main configuration and using scheme of four-line railway.

(1) Four lines parallel arrangement, two down direction lines I, III at the left side, the two up direction line II, IV at the right side, as shown in Figs. 8.60A and B. Its line operation program: (A) two main lines for freight train, two side main lines for passenger train (B) in the middle of the two main tracks for passenger trains or high-speed trains use, two side lines for freight train or slow train. Due to the different line scheme, the configuration of the passenger platform is different, the former one lays at both sides of four parallel lines, the latter lays between the main lines in same direction. The characteristics of line layout are: when a route is under construction, it still can organize trains as double-line operation, which is more convenient. Due to separate transportation of freights and passengers, high-speed passenger train overtaking freight can be avoided. In scheme (B), overtaking low speed passenger trains is avoided, but passengers taking a low-speed passenger train and suburb passenger train need to cross track when passenger in and out of the main station, thereby investments to build tunnels are increased.

(2) Two double-track railways in parallel, one (III, IV) for freight train operation, another (I, II) for passenger trains operation, as shown in Figs. 8.60C and D. The advantage of this railway layout scheme are: construction with minimum interference for existing line, new double track scheme can use detouring, which is convenient for improving or raising technical standards of new line. The disadvantage is that, when one track of the double line is under construction, another line can only be used as single line, operation is less flexible.

Each of the four-line railway construction scheme has advantages and disadvantages, and should be selected according to local specific conditions. The main factors that should be taken into account are: the composition of traffic

flow and total traffic volume, the configuration of a marshaling station and passenger station in hub, running speed of all kinds of train and the ratio of speed of rapid train and slow train, the weight and weave of the train, the train running diagram types, kinds of traction and performance of locomotive, modernization of railway technology and equipment, necessary routes number for relieving train flow within junction terminal, and the convenience degree of traffic management, etc. In the specific conditions, choosing the optimal route layout and use scheme should be able to provide the complete safety of the train operation and passenger, achieving maximum carrying capacity and maximum travel speed, and the lowest conversion engineering and operating costs.

A four-line railway should generally be constructed based on three-track line for the transition. Therefore, when building the third line, the technical condition and operation requirements of the fourth line should be taken into account, lest produce a large number of abandoned projects, or have to reduce some technical standards and cannot give full play to the advantages of railway line.

8.3.2.3 Build Branching Line

Both reconstruction of the existing line and construction of new line are important parts of railway network construction, which aim to enhance the capacity of railway transport with different functions and features. Transformation for busy railway line, basically to increase the number of main line without expanding attraction scope, which can be constructed stage by stage, renovation and production, as

soon as possible to performance the investment benefit, effect is obvious. But construction inevitably interference with the operation, affect the current transport capacity. If the project is too large, the cost is even higher than construct a new line, it should consider be compared with the construction of diverting line and connecting line. To build new branching line or connecting line, in addition to increase capacity, it may also have other effects. Generally, when transportation of the existing main line is too nervous and the potential is very small, under this condition, parallel line can be built as branching line to enlarge capacity, which can share part of through traffic flow volume from existing line, can ease the burden of carrying capacity, at the same time it can promote the development of certain region or industrial and mining enterprises, so as to increase the attracting scope in the entire network. Connection line is mainly used to connect two main lines with short line, in order to increase the pathways, shorten haul distance for reasonable transportation. In addition, the construction of new line can also play the role of optimizing the structure of railway network and consolidating national defense. A common problem to build a new line is the large investment, long construction period, the capacity is formed and the benefits is obtained after completed all project. Therefore, existing line and new line must be arranged as a whole.

Constructing branching line is actually a type of new line construction, when selecting scheme by comparison, the composition of passenger and freight traffic volume and its development trend must be investigate exactly, after comprehensively considering the following issues in all aspects, a right decision shall be made:

- (1) The department economic benefits and social economic benefits can be provided by the scheme;

- (2) The funds required for the unit transportation capacity;
- (3) The rationality and reliability of operation;
- (4) The realizability of scheme, mainly about the requirement for technical equipment, funding sources, energy supply, and the relevant supporting facilities, etc.; and
- (5) The significance of politics, national defense, etc.

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Index

Note: Page numbers followed by f indicate figures, and t indicate tables.

A

Additional resistance

curve resistance

average unit train resistance 117

equivalent grades of 116-117

sources of 108, 108f

total conversion grade 117

unit curve resistance 111-113

wheel-rail positioning 108-111, 109-111f

grade resistance 106-107, 107f

tunnel resistance 113-116, 114t

wind/cold climate conditions 117

Adhesive tractive effort 76-77, 77t

Air braking pressure 123-128

conversion pressure of brake shoe 128

generation and restriction 124-125, 124f

train braking force 125–127, 127t

working principle of 123–124, 123f

Arrival-departure track, effective length of 487–488

Attracting scope 10–13, 11–12f

Automatic blocks, trains 26, 26f

Auxiliary engineering 375

Average deflection angle method 561, 561f

B

Beijing-Shanghai High-speed Railway 285, 286f, 291–292f

Benefit-cost analysis 392–393

Bidirectional transversal marshaling station 452

Braking force

air braking pressure

conversion pressure of brake shoe 128

generation and restriction 124-125, 124f

train braking force 125-127, 127t

working principle of 123-124, 123f

dynamic braking 121, 128-132

electromagnetic brake 122-123

friction braking 120-121

Branching railway line

construction of new line 624

hub area 618-619

Bridge and culvert engineering 375

Bridge and culvert zones

plane design 250-251, 250t

profile design 251-252, 251f

Bridge testing and reinforcement 515

Budget reserve 376-377

Build out/shut down crossing stations 485-486

Bulb-shaped curve 305–306, 306f

C

CAD model 359

Carload (CL) freight train 19

Carrying capacity diagram 499, 500f

Carrying capacity strengthening

principal measures 473–499

reconstruction engineering facilities 485–494

temporary measures 477–478

traction power 482–485

Centralized dispatching system (CTC) 135

Chengdu-Kunming Railway 283f, 284

China's electric power and diesel locomotives 50, 51t

China's high-speed railway network, construction of 524–526

Chinese electric locomotives 77t, 86

Chinese Railway Train Control System (CTCS) 59

Chinese traction calculation procedures (TCP) 85

Circular curve

elements of 160–162, 167–169, 168f

engineering work and operation, radius influence on 181-183

field work 183-184, 184-185f

minimum radius 176-177, 178t

superelevation

actual superelevation, calculation of 180

allowable superelevation, range of 178-179, 179f

average speed 171-172

centrifugal force 171

China experience 174

deficient superelevation 173–174

deficient/surplus superelevation 175–176

European and Japan experience 174

lateral offset vs. resultant 170f

maximum radius 180–181, 183t

maximum speed 172, 173f

superelevation-pie case 170f

unbalanced centrifugal acceleration 175–176

Combined heavy load trains 527–529

Communication and signal engineering 376

Computer aided location and alignment design

automatic generation, initial profile 360

CAD model 359

chain-like profile modification 361

DTD 349–353

DTM See (Digital Terrain Model (DTM))

object model 357–359

profile diagram drawing 362

profile optimization 361

route plane See (Route plane, computer aided design)

Continuous welded rail (CWR) 78–79

Cross-section design, second railway line

double-track lines 602

parallel with different elevation

cross section of parallel and unequally elevated
subgrade 601f, 602

parallel with equal-elevation

cutting subgrade 599, 600f

lifting subgrade 599, 599f

lifting track with ballast 599f

roadbed widening 597–598, 598f

shifting second line and lowering subgrade surface 600, 601f

shifting second line and raising subgrade surface 600, 600f

CTCS system See Chinese Railway Train Control System (CTCS)

4-cycle engine locomotive 87-89

D

Datong-Qinhuangdao Heavy Haul Special Line for Coal Transportation 527, 529

Demolition engineering 375

Density of freight traffic (DFT) 17

Density of passenger traffic (DPT) 17

Detouring scheme 620

DF4B diesel-electric locomotive 93f, 94

DF8 Diesel-electric locomotive 87, 88f

Diesel locomotive 86–96

diesel engine

4-cycle engine 87–89

DF8 Diesel-electric locomotive 87, 88f

electric coupling 89

external starting torque 91

fuel-injector unit 89

generators 90, 90–91f

HXN3Diesel-electric locomotive 87, 88f

internal-combustion engine 87

motors 91, 93f

2-stroke cycle 87–89

transmission devices 87–92

tractive characteristics

acceleration 95

altitude correction coefficient 95, 96t

correction coefficient of ambient air temperature 95, 96t

electric drive 93f, 94

high-speed EMU 96–97, 97f, 98t

traction effort 94–95

tractive effort 92, 93f

Diesel locomotive passenger transportation 510

Diesel multiple unit (DMU) 50

trains 511

Diesel traction 47

Digital Terrain Data (DTD) 349–353

aerial photographs 350–351, 352f

aerial reconnaissance 350

field ground survey 350

oblique photographs 351, 351f

photogrammetry 350

stereovision 352–353

strip photographs 352f

topographic map digitization 350

Digital Terrain Model (DTM) 349–357

Fishbone Digital Terrain Model 353–357

Square Grid Digital Terrain Model 354, 354f

Triangulation Network Digital Terrain Model 355, 356t, 356f

Disc brake 120–121

Discrete Digital Terrain Model 349

Distance widening

conditions 206

method 204–206, 205f

reasons

car body, deviation of 204

geometry deviation 202, 203f

District station

characteristics 445

distribution and position selection 294-295, 294f

longitudinal type district station in double-track railway 445-446, 446f

major facilities layout

arrival-departure yard, freight train 446-447

car maintenance facility 449

freights yard 448

locomotive depots 448-449

locomotive running track 448-449

passenger traffic facilities 446

shunting yard and lead track 447-448

operations 444-445

throat zone layout 450, 451f

transversal type district station

in double-track railway 445-446, 445f

in single-track railway 445-446, 445f

DMU See Diesel multiple unit (DMU)

Double-track intermediate station 407-408, 408f

Double-track railway construction 494

DPT See Density of passenger traffic (DPT)

DTD See Digital Terrain Data (DTD)

DTM See Digital Terrain Model (DTM)

Dynamic braking pressure

CRH2 EMU regenerative brake characteristics 129–131, 131f

determination of 131

diesel locomotive 129, 130f

electric locomotive 129, 130f

principle of electric braking 129, 129f

E

Ecological environment recovering 345

Economic internal rate of return (EIRR) index 371

Economic net present as value (ENPV) index 371

Economic speed, high-speed trains 517

Eddy current brake 122-123

EIRR index See Economic internal rate of return (EIRR)
index

Electric locomotive

electric locomotive ratings 83f, 84-86

electric tractive effort 82-84, 83f

locating engineer 86

motor-generator systems 80–81

motor types 79–80

poly phase and split phase 81–82

Electric locomotive passenger transportation 511

Electric multiple unit (EMU) 50–52, 52t, 62

trains 511

Electric traction 47

Electromagnetic brake 122–123

Electromotive force (EMF) 92

EMU See Electric multiple unit (EMU)

ENPV index See Economic net present as value (ENPV) index

Equipment-to-traffic-capacity diagram 497–499, 498f

Existing line enhancement, overall planning for

carrying capacity diagram 499

equipment-to-traffic-capacity diagram 497–499

rules 496–497

work contents 494–496

F

Fast freight train (FFT) 19

Financial internal rate of return (FIRR) indicator 371

Financial net present as value (FNPV) indicator 371

FIRR indicator See Financial internal rate of return (FIRR) indicator

Fishbone Digital Terrain Model 353–357

Fixed equipment standards 69

Flange resistance 101–102

FNPV indicator See Financial net present as value (FNPV) indicator

Fourth railway line See also Branching railway line; Second railway line; Third railway line

busy hub area 618–619

freight train operation 622f, 623

main configuration and using scheme 622f

main factors 623

passenger trains operation 622f, 623

three-track line 623

Freight traffic volume 14–15, 15f

Freight train (FT) 19

length of 143

net loading capacity 143

number of vehicles 143

Freight turnover (FT) 16

Friction braking 120-121

G

Goods flow heavy direction (GFHD) 17-18

Goods flow light direction (GFLD) 17-18

Grade resistance 106-107, 107f

Grade section length

maximum length

freight traffic and passenger traffic 235

passenger traffic 235–236

minimum length

adjacent gradient change points 233

coupler strength 231, 231t

high-speed railway line 233

intermediate straight grade section 233, 233t

minimum allowable length 234f, 234t

200m length 234–235, 235f

smooth and steady of train running 232, 232t

Green location 340–341

Guangzhou-Shenzhen quasi-high-speed railway 38

Guiyang-Guangzhou Railway 281–282, 282f

H

Helper grades

definition 217

design of 219

economics of 219–220

maximum value of 218, 219t

modern alternatives 220

operation of 218, 481

High-speed EMU 96-97, 97f, 98t

High-speed railway construction

advantages 520-521

construction mode

Chinese railway network 524-526

Europe and Japan 523-524

power mode 519-520

targeted speed 517-518

timing and preconditions

city layout 522

economic effect and construction years 522

main technical standards 522

transportation demands 521

High-speed railway transport capacity

carrying capacity of

different speed levels 31, 32t

in non-parallel train diagram 30-31

in parallel train diagram 30

removal coefficient method 29

utilization of 33

traffic capacity of 32–33

High-speed station

catch siding 456–457

classification 456

curve section 457, 458t

depot-managed siding 456

distribution

average distances between stations 298

comprehensive factors 300

comprehensive maintenance area 300

general intermediate stations 299

large intermediate stations 299

position selection 300

section crossovers 300

track-connection 300

flyover bridge 458-459

location selection 455

MU depot and workshop depot 457-459

operations 460-461

passenger transportation, equipment for 470-472

pattern

departure station 466, 467f

for intermediate station 463–465, 464–465f

for overtaking station 463

rules, station layout 461–463

private siding 456

quantity 455

station name requirements 459–460

straight line section 457, 458t

track plane and profile 467–470

Hilly regions 273

Hump decomposition process 452–453

HXN3Diesel-electric locomotive 87, 88f

Hydraulic brake 121

I

Indirect fees 376

Intermediate stations 296–298, 296t

commercial operations 407

freight traffic equipment

freight platform 412–413, 413f

freight warehouse 413

freight yard 412, 412f

layout diagram 407–409, 408f

passenger traffic facilities

level passageway 411

overpass and underground tunnels 411

passenger platforms 410–411, 410f

passenger station building 409–410, 410f

selection

combination between station position selection and section
main line 303

combine station position and urban planning 303

combine urban and rural layout 301–302

design of railway terminal 304

engineering conditions 302–303

existing railway facilities 303

station plan calculation

connection between turnout and connecting curve 430,
430f, 430t

coordinates calculation 437–444

distances between tracks inside station 421-427, 422-423t, 423f, 426t

fouling post and signal layout 432-437

layout in throat zone 427-429, 428-429t

station tracks length 431-432, 431f, 437-444

tracks numbering 420, 421f

turnouts numbering 421, 421f

station sidings

arrival-departure tracks 413-414

catch siding (safety siding) 416-417, 417f

freights track (goods track) 415-416

industrial line linking 413-420, 420f

lead track 414-415

refuge siding 417-419, 418-419f

technical operations 407-409

Intermediate straight line 164-167, 164f

International annual meeting of heavy haul traffic 526

Investment payback period method 387

Involute method

average deflection angle method 561, 561f

calculating adjusting distance 558

calculation equation of involute length 554, 554t

circular curve and cubic parabolic curve 554

curve correction 566f

estimated curve radius 563

general calculation equation 557

geometric significance 552f

instrument position 556–557f

involute length of standard curve 552

kilometer CMP 564

length of easement curve 564

length of involute, existing curve 555

practical calculation equation 554, 555t

second-order difference 562

three-point method 562, 562f

throw calculation 558, 559t

J

Japanese Shinkansen railway construction 519–520

Ji'nan junction terminal plan 454, 454f

Junction terminal 453–455, 454f

K

Karst zones

Chongqing-Lichuan Railway 322

Qiyao Mountain, anticline groundwater flow 322, 322f

route selection 325

route selection scheme 321

Yichang-Wanzhou Railway 321–322

Yuli Railway Qiyao Mountain area 323, 323f

L

Land-saving principles 344

Leading line 307, 308-309f

Less-than carload (LTL) freight trains 19, 27-28

Level crossing 514

Line planes

mixed passenger and freight line 257, 257t

PDL 257-258, 258t

plane standard 256-258

setting in reverse curve 258

station throat 258

Line plans 267

center lines 267

chainage of curve origin and destination 267-269

classification and scale 266-267

curve elements 267-269

definition 265

main buildings 269

preliminary traverse 268f, 269

Line profile

design of 260-261

grade of 258-262

grade segment 262

passenger stopping point 262

restrictions of 258-260, 259t

starting grade 261-262

Line strike selection

development of route 279f

economic agglomeration points 278-279

general rules

economic controlling points 281

geological conditions 292

large and complicated bridge sites 290, 291-292f

locational industrial and mining enterprises 285

location of intermediate stations 288, 289f

mountain railway 291

selection of major cities and towns 282

selection of traffic corridor 287, 288f

governing factors 279-280

major control points 278-279

minor control points 279

traffic center points 278-279

Local passenger traffic volume 15

Locomotive routing 62, 63f, 64

Locomotive traction motor 74

Longitudinal type district station 445–446, 446f

Longitudinal type passing station 404–405, 404f

LTL freight trains See Less-than-carload (LTL) freight trains

M

Magnetic rail brake 122

Main Railway Technological Policy 511

Marshaling station 451–453, 452–453f

Maximum grade

balanced profile 215f

design of 216

ratio of goods flow 216–217

compensation

compensation design 239–241

compensation for curvature 236–241, 238f

curvature compensation methods 239–241

easy gradient for acceleration 244–245, 244f

gradient in tunnel 241–243

range compensation 243–244

theory of compensation 237–238

tunnel compensation method 242–243, 243t

tunnel resistance 242

helper grades

definition 217

design of 219

economics of 219–220

maximum value of 218, 219t

modern alternatives 220

operation of 218

passenger traffic

adaptability analysis, speed and gradient 209–210, 210t

maximum calculated gradient 208–209

selection of 210–211

ruling grade

calculation of 212

choice of 212–214

definition 211

fixed and variable costs 214–215

optimizing grade selection 215

prime effect 211

train mile costs 214

Maximum static friction force 75–76

Minimum attractive rate of return (MARR) 391

Momentum utilization 479–481

Mountain terrain 274

MU operation mode 63

N

Natural vegetation protection 345

Non-parallel train diagram 21f, 22

O

Object model 357–359

Optimization models

constraining factors

curvature standard 399

railway capacity 397

ruling grade 398

tractive force 398

implementing railway project optimization 401–402

objective function 394–397

technical and economic index 394, 395t

tractive power and grade standard 399–401, 400f

Overlapping curve 305, 306f

Overtaking station

distribution of 551t, 567–580

layout diagram 406–407, 406f

operation and facilities 405–406

P

Parallel scheme 620

Parallel train diagram 22, 22f

double-track line 25–26, 26f

in pairs on single-track line 24–25, 24f, 25t

period in 23–24, 24f

Partial second track construction 490, 490–491f

Partitioning Discrete Digital Terrain Model 349

Passenger dedicated line (PDL) 255–256, 255f, 256t

Passenger traffic

adaptability analysis, speed and gradient 209–210, 210t

maximum calculated gradient 208–209

selection of 210–211

Passenger traffic volume 15–16

Passenger trains 19, 30–31

removal coefficient of 478

Passenger transport

freight transport 516–517

automatic block sections 516

non-automatic block sections 516

signal devices 515–516

step-by-step implementation scheme 504–505

targeted speed 502–504

technical conditions

railway lines 512–515

speedup 505–512

Passenger turnover (PT) 17

Passing station

distribution of 296t

layout diagram 404–405, 404f

operation and equipment 403–404

Payback period method 390

Pick-up and drop train (PUDT) 19

Plain region 273

Plane design

basic alignment 162–163, 163f

bridge and culvert zones 250–251, 250t

circular curve See (Circular curve)

composition of 162–163, 163f

contour map 159, 161f

cross-section of sub-grade 159, 160f

distance between centers of lines

centers of line widening See (Distance widening)

first line and second line 198-202

minimum radius 207, 207t

railway clearance 197-198, 198-200f

second line and third line 202

easement curve/transition spiral

cubic spiral 188-190, 189f

high order spirals 190–193

length of 193–196, 194f

minimum circular arc 196–197, 197t

track geometry requirements 185–188, 186–187f, 187t

horizontal alignment 159

reconstruction of existing railway line

annotation of route 545

compound curve 549

curve radius 548

curve reconstruction 547–548, 548f

curve survey 546, 546f

easement curve and intermediate straight line 551

kilometer measurement 544

setting offset stake 545

space curve 160–162

station site See (Station site)

straight line

general regulations 163–164

length of intermediate line 164–167, 167f

three-dimensional center line 159

tunnel zones

line plane 252

line profile 252–253

subgrade of bridge approach 253

Plan for Railway Development in Medium and Distant Future 525

Poly-phase induction motor 81–82

Power-concentrated multiple units trains 519

Power-dispersed multiple unit trains 519

Present worth method 390–391

Profile design

bridge and culvert zones 251-252, 251f

grade section, connection of

adjacent gradients, algebraic difference 220-222, 222t

radius vertical curves See (Vertical curves, radius of)

grade section, length of See (Grade section length)

length and gradient 207-208, 208f

maximum grade, compensation of See (Maximum grade, compensation)

maximum gradient of grade See (Maximum grade)

operating expenses

different composition of grade section 246

lifting height 248–249, 249f

relation between grade 246, 246f

severe grade segment 247–248, 248f

reconstruction of existing railway line

algebraic vs. adjacent gradients 537

bridge and culvert 543

drawing with enlarging scale 539–542, 540f

elevation of rail top requirement 539

length of grade section 537

maximum gradient 537

profile altitude data 538

reasons of reconstruction 536–537

restrictions of construction method 538

station site 543

subgrade 544

tunnel 543

vertical curve 538

station site See (Station site)

tunnel zones

line plane 252

line profile 252–253

subgrade of bridge approach 253

Profile details

contents of 269–271, 270f

profile column 271–272

profile drawings 272

Purchase cost 378

R

Railway carrying capacity

parallel train diagram 22, 22f

double-track line 25-26, 26f

in pairs on single-track line 24-25, 24f, 25t

period in 23-24, 24f

speed 22-23

train diagram 21-22, 21-22f

Railway classification

annual volume of passenger and freight traffic 36

axle load of rolling stock 34

in China 38

freight railway 41

mixed service for passenger and freight traffic 40

passenger dedicated lines 39

French railways 38

German railways 38

International Union of Railways 38

in Japan 38

maximum running speed 35

railway lines 36

significance of 34

U.S.A., railways 38

Railway crossing strengthening 493

Railway environment location

environmental problem

atmospheric pollution 342

ecologically sensitivity zone 341

electric traction 342

gallery effect 341

geological disaster triggering 341

impact on other infrastructures 343

land and cultivated land occupation 341

noise, vibration and electromagnetic radiation 342

protection of landscape resource 343

soil and water loss 341

travel obstruction 343

general principles

attention paid to ecological environmental protection 344

attention paid to resources protection 344

avoid damage natural landscape 343

coordinate new railway and urban construction plan 343

natural environment protection 347-348

Railway heavy haul traffic development

organization modes 527-532

standards 526-527

technical facilities

braking system 533

depot reconstruction 534

railway engineering and electric facilities 532

railway locomotive equipment 532

wagons 533

Railway location

basic methods

cross-section location 311–312, 312f

leading line 307, 308–309f

maximum gradient 304

plane and profile improvement 312–315, 313–314f

route development mode 305

section of easy grade 309–311, 310–311f

basic principles of 275–276

natural conditions affecting 273–274

steps and methods 276-278

bridge and culvert section

bridge and culvert distribution 332

bridge site selection 332-333

design requirements 334-335, 335f

deviation degree 333

favorable hydrological and landform conditions 333-334

geological conditions 334

high and long-span bridge 334

subgrade condition 335-336

complicated geological conditions

desert regions 326-327

gully regions 320-321, 321f

high-intensity earthquake regions 327-329

karst See (Karst zones)

landslide zones 316-317, 317f

marsh zones 325-326

mudslide-stricken regions 319-320

permafrost regions 326

reservoir construction 331

reservoir region 329–331

talus zones 318–319, 319f

computer aided location and alignment design

automatic generation, initial profile 360

CAD model 359

chain-like profile modification 361

DTD 349–353

DTM See (Digital Terrain Model (DTM))

object model 357–359

profile diagram drawing 362

profile optimization 361

route plane See (Route plane, computer aided design)

crossing, setting condition of 339–340, 340t

distribution and position selection, stations

basic principle of 293–294, 293f

of district station 294–295, 294f

high-speed railway See (High-speed station, distribution)

intermediate stations See (Intermediate stations, selection)

multiple unit train depot workshop 295

overtaking station 296–298, 296t

passing station 296-298, 296t

environment See (Railway environment location)

line strike, selection of See (Line strike selection)

railway and road intersect 338-339

tunnel section

tunnel portal position 337-338

tunnel position selection 337

valley portal location comparison 336f

Railway main technical standards

arrival-departure lines 45

block sections

automatic block 58, 58f

double-track railway line 56

manual block 57

semi-automatic block 57

single-track railway line 56

designed speed 43

items of 42-43

locomotive routing or EMU routing 62, 63f

maximum gradient 44

maximum slope 67

minimum curve radius 44

minimum headway 61

mutual coordination 65

number of main lines 43

optimization method selection 71

point-line coordination 66

railway network 66–67

science and technology 67

synthetic optimization method

characteristics of 68–69

principles of 69–71

tonnage ratings

freight flow 54

length of arrival and departure track 54

locomotive hauling capacity 54

rolling stock 55

ruling grade 55

strength of track structure 55

traction type 47

traffic volume 65–66

train operation control mode 59

transportation scheduling 60

type of locomotives/multiple units 50, 51–52t

Railway traffic capacity (RTC) 26–28, 28t, 32t

Reconstruction engineering facilities

arrival-departure track, effective length of 487–488

build out/shut down crossing stations 485–486

double-track railway construction 494

railway crossing strengthening 493

ruling grade reduction 488-489

second line construction 489-493

track structure strengthening 494

Reconstruction of existing railway line

collect economic and technical information 535

conduct engineering geological investigation 536

construction detail design 535-536

construction organization and budget data investigation 536

cross-section reconstruction 580f

integrated design 585

keep one slope side of subgrade 583, 583-584f

non-shifting central line 581-583, 581-583f

raising and cutting subgrade 583-584f, 584

design and survey method

involute method See (Involute method)

existing individual engineering structures investigation 536

existing line survey and investigation 536

plane design

annotation of route 545

compound curve 549

curve radius 548

curve reconstruction 547–548, 548f

curve survey 546, 546f

easement curve and intermediate straight line 551

kilometer measurement 544

setting offset stake 545

preliminary design 535–536

profile design

algebraic vs. adjacent gradients 537

bridge and culvert 543

drawing with enlarging scale 539–542, 540f

elevation of rail top requirement 539

length of grade section 537

maximum gradient 537

profile altitude data 538

reasons of reconstruction 536–537

restrictions of construction method 538

station site 543

subgrade 544

tunnel 543

vertical curve 538

string lining of curves

calculation of throw 573

circular curves 568

correction factor 572

measured mid-ordinate 567

method and procedure 577, 579t

mid-ordinate f 570

projected mid-ordinates 568–580

restrained conditions 575

stations ahead and behind 574

transition spirals 569, 573

Regenerative brake 121

Regional attracting scope 11, 12f

Regulations on Railway Technical Management 515

Regulations on Railway Train Traction Calculation (RRTTC) of China 74–75

Reserve fee 377

Reservoir region 329–331

Retaining wall 375

Rheostatic brake 121

Route plane, computer aided design

design elevation 365

Digital Model of Land Price 366

drawing of 367

operating expenses 366

optimization and initial horizontal alignment 362–365

principal railway standards 365–366

project operating costs 367

RTC See Railway traffic capacity (RTC)

Ruling grade

calculation of 212

choice of 212-214

definition 211

fixed and variable costs 214-215

optimizing grade selection 215

prime effect 211

train mile costs 214

Ruling grade reduction 488-489

S

Scheduling train working diagram 474-475

Second line construction 489-493

Second railway line See also Branching railway line; Fourth railway line; Third railway line

cross-section design See (Cross-section design, second railway line)

plane calculation

coordinates method 610-612, 611-612f

curve elements and kilometer difference calculation 616, 617f

deflection angle 616

displacement calculation 605f

easement curve shifting 607, 607f, 608t

enlarger curve radius 615f

exchange sides 615f

exchange sides, curve segment 612, 615f

normal length 617f

realignment calculation 603

tangential dislocation 605, 606f

triangle analytic method 607-610, 608-609f

widened distance between curves 604f

widening distance between lines and curve segment 612, 613f, 614t

widening space 615f

plane design

adjacent single-line tunnels 594t, 595f

centers distance 593–596, 593f

changing side 591–593, 592f

parallel and detouring segments 588–589

side selection 589–591, 589–590f

profile design

method 586–588

selecting ruling grade 585–586

Semi-automatic blocks, trains 25, 26f

Shanghai-Hangzhou traffic corridor 287, 288f

Shoe brake 120

Signal devices, of passenger trains 515–516

Single-phase series-wound AC motors 80

Single-phase series-wound DC motor 80

Single-track automatic block district working diagram 476–477

Single-track intermediate station 407–408, 408f

Spiral curve 306, 307f

Split-phase induction motor 82

Square Grid Digital Terrain Model 354, 354f

SS3 electric locomotive 83, 83f

SS4 modern electric locomotive 81, 81f

Station site

design standards 263

inbound easy grade 264–265

length of station site

mixed passenger and freight line 254–255, 254t, 254f

PDL 255–256, 255f, 256t

line plane

mixed passenger and freight line 257, 257t

PDL 257–258, 258t

plane standard 256–258

setting in reverse curve 258

station throat 258

line profile

design of 260–261

grade of 258–262

grade segment 262

passenger stopping point 262

restrictions of 258–260, 259t

starting grade 261–262

outbound accelerating easy grade 265

and section profiles 265

vertical curve and transition curve 263–264, 263f

Steam traction 48

Subgrade engineering 375

Subgrade works 515

Superelevation

actual superelevation, calculation of 180

allowable superelevation, range of 178–179, 179f

average speed 171–172

centrifugal force 171

China experience 174

deficient superelevation 173–174

deficient/surplus superelevation 175–176

European and Japan experience 174

lateral offset vs. resultant 170f

maximum radius 180–181, 183t

maximum speed 172, 173f

superelevation-pie case 170f

unbalanced centrifugal acceleration 175–176

T

Target speed, of high-speed trains

basis for selection 517

economic speed 517

Technical and economic comparison schemes

annual operating expense 385

comprehensive criterion

optimization models See (Optimization models)

traditional comparing methods 394

economic comparison 373

economic criterion method

conversion annual costs method 387

evaluation indexes 385–386

government-operated engineering projects 392–393

investment internal rate of return method 389

minimum conversion cost method 388

payback of investment balance 386

private railway and other projects 389-392, 391t

time factor 385

economic indexes 370

investment

civil engineering investment 374-377

classification of investments 374

purchase expense 377-379

network scheme 371

operating expenses calculation

energy consumption calculation 380

maintenance of permanent way 384-385

number of train 381

resistance mechanical work 381

traction mechanical work 381

traffic amount 379-380

train-kilometer method 382

overall scheme/principle scheme 372

partial scheme 372

purchase expense 377-379

role of 369–370

scheme comparison 372–373

synthetic optimization 373

technical indexes 370

Tests of China Academy of Railway Sciences (TRAINS) 259

Third railway line See also Branching railway line; Fourth railway line; Second railway line

busy hub area 619

detouring scheme 618–620

existing double-track lines 621

parallel scheme 620

separate double lines 621

train overtaking 622f

Through attracting scope 11, 11f

Tilting car body trains 519

Topography 273–274

TQFR-3000 generator external characteristics 90, 91f

TQFR-3000 generator load characteristics 90, 90f

Track engineering 375

Track structure strengthening 494

Traction calculation

braking force

air braking pressure See (Air braking pressure)

dynamic braking 121, 128-132

electromagnetic brake 122-123

friction braking 120-121

tractive effort See (Tractive force/effort)

tractive tonnage

arrival and departure track checking 141

coupling strength checking 142

factors 137

rating 143

ruling condition 137–138

starting section 140–141

straight tonnage rating 143

tangent level track 138–139

train parameters 142–143

train movement equation

approximate integral formulas 135–136

Newton's second law of motion 133

status 132-133

train running resistance

additional resistance See (Additional resistance)

gross resistance 98-99

starting resistance 118-119

train basic resistance See (Train basic resistance)

train running speed and time See (Train running speed and time)

Traction mass 217

Traction power 482-485

Tractive force/effort 73-97

adhesive tractive effort 76-77, 77t

characteristic curves

diesel locomotive See (Diesel locomotive)

electric locomotive 79-82

computational adhesion coefficient 77-79

formation of 74-75

wheel and rail, adhesion 75-76

Traffic flow lines 12

Traffic volume

design period 20

economic investigates and traffic forecasts

attracting scope 10-13, 11-12f

freight traffic 14-15, 15f

passenger traffic 15-16

traffic surveys 13-14

freight traffic

DFT 17

fluctuation coefficient 18

freight turnover 16

ratio of goods flow 17-18

VFT 16

passenger traffic

DPT 17

fluctuation coefficient 18

passenger turnover 17

VPT 16

significance of 9-10

type of railway traffic 19

Train basic resistance

air resistance 102

average unit basic resistance 105

flange resistance 101-102

journal resistance

journal friction proper 100

roller bearings 101

rolling resistance 100-101

track resistance 100

temperature 102-103

total train basic resistance 105

unit basic vehicle resistance 104

unit locomotive resistance 103

Train-kilometer method 382

Train running speed and time 478

calculating running speed and time

equilibrium speed method 156-157, 157f

simplifying gradient route profile 153-154

speed-distance curve and speed-time curve 154-156, 155f

unit resultant force curve 146f

brake speed limiting 148, 148t

characteristics of 150-153

force graph 145–150

SS3 electric locomotive single traction freight train 146–148, 147t

Train working diagram not in pairs 475–476, 475f

Transport capacity strengthening

existing capacity measures 473–499

heavy haul traffic development 526–534

high-speed railway construction 517–526

national economy 473

passenger transport speed up 499–517

reconstruction engineering facilities 485–494

signaling, interlocking, and block facilities 484–485

traction power 482–484

Transport organization measurement

combined trains, running of 481–482

heavy haul traffic development 481–482

helper grade operation 481

momentum utilization 479–481

passenger trains, removal coefficient of 478

scheduling train working diagram 474–475

single-track automatic block district working diagram 476–477

train's running speed 478

train working diagram not in pairs 475–476, 475f

Transversal type district station

in double-track railway 445–446, 445f

in single-track railway 445–446, 445f

Transversal type passing station 404–405, 404f

Tread brake 120

Triangulation Network Digital Terrain Model 355, 356t, 356f

Tunnel engineering 375

Tunnel resistance 113-116, 114t

Tunnel zones

line plane 252

line profile 252-253

subgrade of bridge approach 253

Turnouts 514

U

Unidirectional transversal marshaling station 452, 452f

Unit-heavy load train 529-530

V

Vertical curves, radius of 223f

designing conditions 228–229, 230t

ensure no coupler separation 224–225, 225f

ensure no derailment 223–224, 224t

ensure ride comfort 222–223

geometry elements of 226–227, 226f

minimum allowable curve radius 230t

minimum vertical radius 225, 226t

parabola arc 228

plane circular curve 230f

point of gradient change 229t, 230f

requirement of track maintenance 225

Volume of freight traffic (VFT) 16

Volume of passenger traffic (VPT) 16

W

Wheel slipping 76

Whole-heavy load train 530-532

Widening method 204-206

Wind filling remission 123

Z

Zhenjiang High-speed Station 289f, 290