RAILWAY TRACK TECHNOLOGY

铁路轨道技术

JUANJUAN REN
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西南交通大学出版社
Http://press.swjtu.edu.cn

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图书在版编目（CIP）数据

铁路轨道技术 = Railway Track Technology：英文 / 任娟娟编著. —成都：西南交通大学出版社，2014.6
ISBN 978-7-5643-2026-3

Ⅰ. ①铁…　Ⅱ. ①任…　Ⅲ. ①轨道（铁路）– 教材 – 英文　Ⅳ. ①U213.2

中国版本图书馆 CIP 数据核字（2012）第 245431 号

铁路轨道技术

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责任编辑	张　波
助理编辑	胡晗欣
封面设计	墨创文化
出版发行	西南交通大学出版社 （成都市金牛区交大路 146 号）
发行部电话	028-87600564　028-87600533
邮政编码	610031
网　　址	http: //press.swjtu.edu.cn
印　　刷	四川森林印务有限责任公司
成品尺寸	170 mm × 230 mm
印　　张	18.75
字　　数	439 千字
版　　次	2014 年 6 月第 1 版
印　　次	2014 年 6 月第 1 次
书　　号	ISBN 978-7-5643-2026-3
定　　价	38.00 元

PREFACE

Beginning from the construction of Qinhuangdao-Shenyang Passenger Dedicated Line in 1999, the Chinese high speed railway develops rapidly and the first Chinese high speed railway (Beijing-Tianjin Passenger Dedicated Line) began its service in 2008. By the end of 2013, the total length of high speed railway line in China had become the longest in the world with more than 11 000 km in operating and another 14 160 km in building.

Started several decades later than that in developed countries, the high speed railway in China develops much faster. During the last 20 years, the Chinese high speed railway has made a series of significant achievements in the aspects of civil engineering, rolling stock, communication, signal, operation management and security monitoring, etc, which leads to the formation of the high speed railway technological system with Chinese characteristics and China's entry of countries with the advanced technologies. From the "late-comer" to the "pursuer" to the "leader", the Chinese high speed railway is moving towards to the internationalization.

As one of the main Chinese high speed railway technology equipments, the track structure has achieved a lot of breakthroughs in design principles, design methods, monitoring and maintenance, etc. In order to adapt to the internationalization of high speed railway and cultivate internationalized talents of high speed railway, I have written this book based on the teaching requirements of railway track technology. This book presents the main components, basic principles, fundamental knowledge and skills of railway track, by which the mature achievements in the world are introduced.

This book is divided into 8 chapters. The first chapter introduces the track structure, including the type and requirements of the main components.

Chapter 2 presents the track geometry. Chapter 3 is dealing with the dynamic response of the track and its component parts (especially their stresses and deformation) under the action of rolling stocks with different operational conditions. Chapter 4 describes the wheel-rail interface, including the wheel-rail guidance, lateral movement of a wheelset on straight track, equivalent conicity, worn wheel profiles, wheel-rail contact stresses and train resistances. Chapter 5 focuses on the design and constitute of different slab tracks. Chapter 6 introduces the switches from its function, structure and dimensions. Chapter 7 presents the Continuously Welded Rail track (CWR track), introducing the principles, stability and design of CWR track. In this part, the CWR track on bridges is extensively discussed. Chapter 8 outlines the track maintenance and repair, including the inspection of track geometry, fundamental principles, regular maintenance, arrangements of curtailed rails on curved tracks, string lining of curves and capital repair of tracks.

Although many contents presented in this book were developed by myself through years of research, teaching, and engineering practice, much information was obtained from the published literature, especially *Track Compendium: Formation, Permanent Way, Maintenance, Economics* by Dr. Bernhard Lichtberger, *Railroad Track* by T.H.TUNG and *Modern Railway Track (Second Edition)* by Coenraad Esveld, my deepest gratitude goes first and foremost to them.

JUANJUAN REN in Chengdu, China

April, 2014

Contents

1 The Track Structure

1.1 General Information

What is track?

Rail transport is the means of conveyance of passengers and goods by the way of wheeled vehicles running on rail tracks. The track supports the loads of vehicles (cars) and locomotives and guides their movements. The excellence of the track determines the permissible wheel loads, speeds, safety and dependability of railroad operation. No modern railroad can hope to survive in a competitive economy if its track is a hindrance to safe, dependable, on-time service.

The track consists of two parallel steel rails, anchored perpendicular to members called ties (sleepers) that made of timber, concrete, steel, or plastic to maintain a consistent distance apart, or gauge. The track guides the conical, flanged wheels, keeping the vehicles on the track without active steering and therefore allow trains to be much longer than road vehicles.

The track must:

- Guide vehicles without risk of derailment,
- Take up vertical and horizontal/lateral vehicle forces,
- Off-load these forces via the track grid and ballast bed into the subsoil, and
- Ensure high passenger comfort and high availability for train traffic.

In contrast to road transport where vehicles merely run on a prepared surface, rail vehicles are also directionally guided by the tracks they run on. The track usually consists of steel rails installed on sleepers/ties and ballast, on which the rolling stock, usually fitted with metal wheels, moves. However, other variations are also possible, such as slab track where the rails are fastened to a concrete foundation resting on a prepared subsurface.

Figure 1-1 gives an overview of the track structure. It shows that the traditional ballasted track consists not only of rails, fastenings, ties (sleepers), but also of ballast as well as of the subsoil itself.

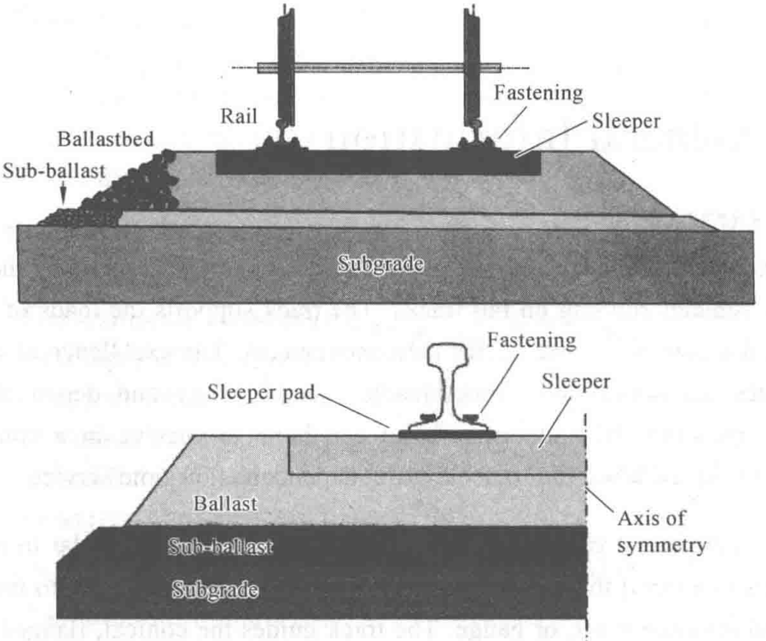


Figure 1-1 Track structure

1.2 Rail

1.2.1 Rail requirements

The rail is running surface, carrier and guiding element at the same time. It is subject to equal static and dynamic stress. In heavy haul traffic, axle loads up to 35 t are applied. Depending on the topography, rails are laid with radii as low as 300 m, therefore, they have to bear very high lateral forces exerted by the wheel flange striking against the gauge corner of the outer rail. To be able to withstand manifold and high forces, the rails must meet the following requirements:

- High resistance to wear,
- High resistance to compression,
- High resistance to fatigue,
- High yield strength, tensile strength and hardness,
- High resistance to brittle fracture,
- Good weldability,
- High degree of purity,
- Good surface quality,
- Evenness and observance of profile , and
- Low residual stress after manufacturing.

1.2.2 Rail types

The weight of a rail per length is an important factor in determining rails strength and hence axle loads and speeds. So rail types are divided by its unit weight in China, such as 75, 60, 50, 43 kg/m. Weights are measured in kilograms-per-meter or pounds-per-yard; the pounds-per-yard figure is almost exactly double the kilograms-per-meter figure. Rails in Canada, the United Kingdom, and United States are described using pounds-per-yard. In China, Australia metric units are now used as in mainland Europe.

Two standard lengths of 12.5 m and 25 m are available for rail types of 60, 50, 43 kg/m, one length of 25 m is available for 75 kg/m rail. Different shortness values are designed for inner rail on curve consisting of 40, 80 and 120 mm (for 12.5-m-long standard rail) or 40, 80 and 160 mm (for 25-m-long standard rail).

With the developing of high speed rails and heavy haul traffic, manufacturing of long rails has become a worldwide tendency. The 36-m-long rails have been lengthened to 72-80 m by French manufacturers whereas the 120-m-long rails have been produced in German. Chinese manufacturers have realized the production of 100-m-long rails, too.

1.2.3 Rail profiles

The rail profile is the cross sectional shape of a railway rail, perpendicular to the length of the rail. A rail is hot rolled steel of a specific cross sectional profile (an asymmetrical I-beam) designed for use as the fundamental component of railway track. Figure 1-2 shows the teil profile in tram ways.

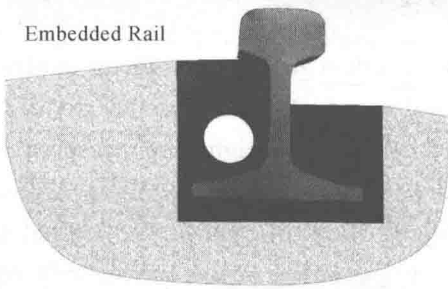


Figure 1-2 Tram ways

The following rail forms are in use at present:

- Vignoles rail (standard railway rail with head, web and foot),
- Double-head rails with head, web and foot (obsolete),
- Grooved rails for tram ways,
- Switch rails, and
- Crane rails etc.

Rail profiles should meet the following requirements:

- The running surface should be broad enough and formed in such a way that the surface pressure due to the contact between wheel and rail is minimized;
- Taking into account a long service life, the head height should allow for a sufficient wear clearance;
- The rail web must be of sufficient thickness to ensure carrying capacity and flexural strength;

- The foot must be of enough width to ensure high stability and to minimize surface pressure exerted on sleepers;
- The section modulus of the rail has to be adapted vertically and horizontally to the expected loads;
- To achieve a favorable stress flow the transition areas should be of sufficient radii;
- Height and foot width have to be chosen in such a way as to ensure enough tilt resistance;
- Due to static reasons the centre of gravity should be at approximately half the rail height.

Some of these requirements contradict each other, therefore, it is difficult to develop rails of optimum form; sometimes this may be achieved only on the basis of many years of practical use. For UIC 60, e.g. (figure 1-3), several railways and steel works carried out photoelastic studies of stresses and measurements with wire strain gauges, before this profile could be chosen as the best of 10 different profiles. Today's FEM calculation methods ensure better design and more exact qualification tests with mathematical methods.

The table 1-1 gives an overview of the several Chinese rail profiles (figure 1-4) and their parameters in contrast to UIC 60 rail.

Table 1-1 Parameters of rail profiles

Rail type/(kg/m)	75	CHN 60	50	43	UIC 60
Weight G/kg	74.414	60.64	51.514	44.653	60.34
Area A/cm^2	95.04	77.45	65.8	57	76.86
Neutral axis y_1/mm	88	81	71	69	80.95
Moment of inertia I_x/cm^4	4489	3217	2037	1489	3055
Moment of inertia I_y/cm^4	665	524	377	260	512.9
Section modulus downwards W_1/cm^3	509	396	287	217	377
Section modulus upwards W_2/cm^3	432	339	251	208	336
Horizontal deflection section modulus of foot W_y/cm^3	89	70	57	46	68.4
Proportion of head area A_h/%	37.42	37.47	38.68	42.83	—
Proportion of web area A_w/%	26.54	25.29	23.77	21.31	—
Proportion of foot area A_b/%	36.04	37.24	37.55	35.86	—

Table 1-1

Rail type/(kg/m)	75	CHN 60	50	43	UIC 60
Rail height *H*/mm	192	176	152	140	172
Base width *B*/mm	150	150	132	114	150
Head height *h*/mm	55.3	48.5	42	42	51
Head width *b*/mm	75	73	70	70	74.3
Web *w*/mm	20	16.5	15.5	14.5	16.5

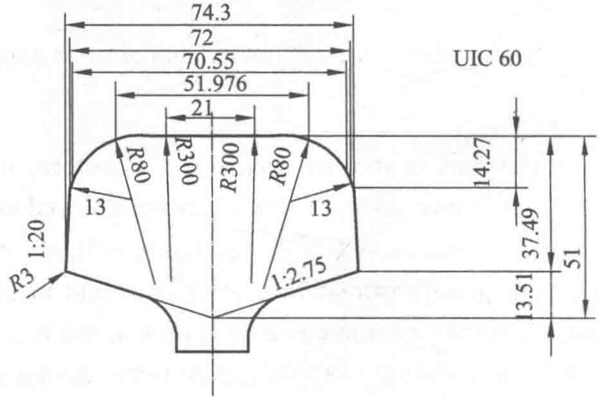
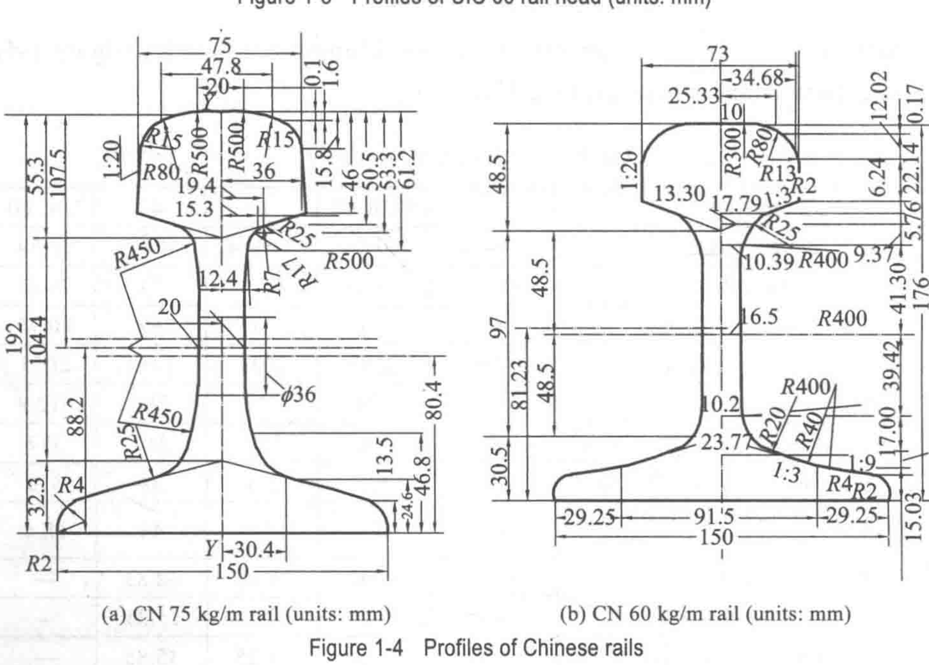


Figure 1-3 Profiles of UIC 60 rail head (units: mm)



(a) CN 75 kg/m rail (units: mm)

(b) CN 60 kg/m rail (units: mm)

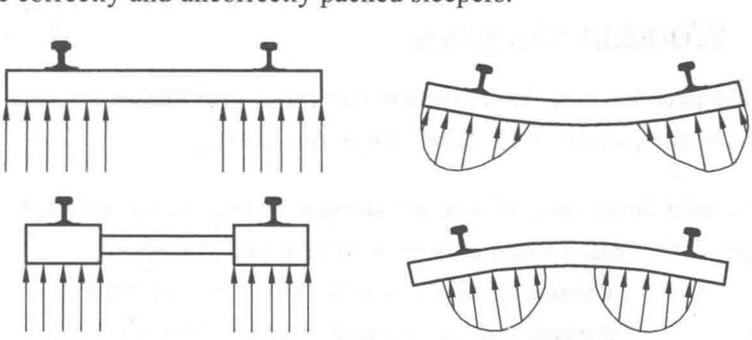
Figure 1-4 Profiles of Chinese rails

1.2.4 Composition

Unlike some other uses of iron and steel, railway rails are subject to very high stresses and have to be made of very high quality steel. It took many decades to improve the quality of the materials, including the change from iron to steel. Minor flaws in the steel that pose no problems in reinforcing rods for buildings, can, however, lead to broken rails and dangerous derailments when used on railway tracks.

1.3 Sleepers/ties

At the beginning of railway technology the preferred sleeper (figure 1-5) material was wood and it continued to be so for the next 50 years. Wood is susceptible to weathering and other external influences. This and the intense steel production in the last quarter of the 19th century finally led to the changeover to steel sleepers. They were used for more than 50 years in many parts of the world including Europe. However, increased axle loads and train speeds soon required heavier sleepers. The first concrete sleepers were introduced at the end of the 19th century. The introduction of heavy prestressed concrete sleepers was essential to enable the use of long welded tracks. High-speed traffic with speeds of 200-350 km/h led to the development of different types of ballastless track. At the same time new systems of concrete sleepers, such as the broad sleeper, the frame sleeper and the ladder sleeper were developed and presented. The figure 1-5 shows the correctly and uncorrectly packed sleepers.



(a) Correctly packed sleepers (b) Uncorrectly packed sleepers

Figure 1-5 Sleeper packing

1.3.1 The purpose of sleepers

The purpose of sleepers is:

1. To establish and maintain track gauge;
2. To distribute and transmit forces to the ballast bed, such as:
   - the perpendicular axle loads,
   - the horizontal centrifugal forces,
   - the longitudinal forces within the rails.
3. To hold the rails,
   - in height (in the case of arching or settlement),
   - to the sides, against centrifugal and transversal forces,
   - in the longitudinal direction against rail creeping, brake, acceleration and temperature forces.
4. To secure the track,
   - under construction,
   - in the case of a rail breakage,
   - after derailment (in such cases the measures prescribed by the railway authorities, such as temporary rail connection, have to be taken).
5. To dampen rail vibration.

These manifold tasks can be fulfilled by:

1. Transversal wooden, steel or reinforced concrete sleepers,
2. Longitudinal reinforced concrete sleepers, and
3. Reinforced concrete sleeper plates.

1.3.2 Wooden sleepers

Wooden sleepers have to have rectangular cross sections, their side surfaces being beveled at an angle of 45° as shown in figure 1-6.

Typical standard dimensions of wooden sleepers in heavily loaded track:

Europe	Hard wood 16 × 26 × 260 cm (oak, beech),
USA	Various species of wood 18 × 23 × (240-270) cm,
China	Various species of wood 16 × 22 × 250 cm.

Many railways reduce the height of the sleeper in the middle, because bending moments and stresses are lower here (centre-bound sleepers have to be avoided). The life cycle of wooden sleepers is 25-45 years—depending on the quality and sort of wood used, as well as on the methods of impregnation. They are not suitable for high-speed lines with speeds of more than 160 km/h, as their resistance to lateral displacement is 15% lower.

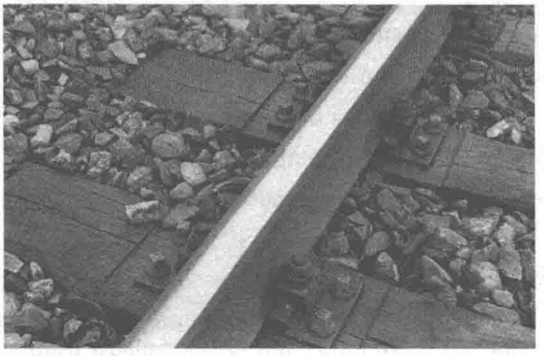


Figure 1-6 Wooden sleeper + base plate

The wood used must be free from the following faults:

• Grey and purple heart wood,

• The red heart (beech) must be free of fungi and must not exceed certain given dimensions,

• Seasoning checks,

• Frost cracks,

• Rotten knots,

• Torsion,

• Transverse warping,

• Decay, and

• Inclusions of sap.

The wooden sleepers may bend or twist due to the drying and impregnation process of the wood. The reason for warped sleepers is usually the growth of the tree, whereas bent sleepers are the consequence of tension or shrinkage of the wood. The shrinkage of the wood in the longitudinal direction is negligible as opposed to its radial and tangential shrinkage. Bent sleepers usually cause narrowing of the track gauge; therefore the vertical twist of wooden sleepers should not exceed 5 mm of version.

The third of the sleeper projecting from the ballast is subject to the full influence of climatic changes. A sleeper usually contains approximately 30%-50% of water. Newly impregnated sleeper show a retarded water absorption. Therefore, it takes about 1-3 years, before a wooden sleeper has adapted to the prevailing humidity of the ballast bed.

During long dry periods in summer the upper parts of the wood dry up significantly, which can lead to the development of cracks. The sleeper may even bend additionally. Large differences in humidity within the sleeper inevitably lead to the occurrence of tensile stress on the sleeper surface. The consequence is a narrowing of the track gauge due to the sleeper ends pulling up.

Defects of wooden sleepers occur due to:

- Base plates pressed into the sleeper,
- Widening of the fastening holes and occurrence of longitudinal cracks, and
- Decay and defects due to rusty water coming from the fastenings.

1.3.3 Reinforced concrete sleepers

The operational stress of concrete sleepers is characterized by frequent changes in temperature and by the permanent traffic load. This stress requires high tensile strength of the sleeper concrete and favorable deformation properties.

1.3.3.1 Requirements to be met by concrete

It is advisable to use only type I Portland cement. Its minimum strength should meet the requirements of class 42.5, and its compressive strength — depending on the client's requirements — C45/55 MPa or C50/60 MPa class. The water — cement ratio must be below 0.45. The minimum content of cement should be 300 kg/m^3. The weight of the individual components of concrete must not deviate by more than 3% from the calculated weight. Cement with an alkali content of less than 0.6% should be used. The total mass of reactive alkalis should never exceed 3.5 kg/m^3.

The following characteristics must be indicated on every concrete sleeper:

- Year of production,
- Boarding number,