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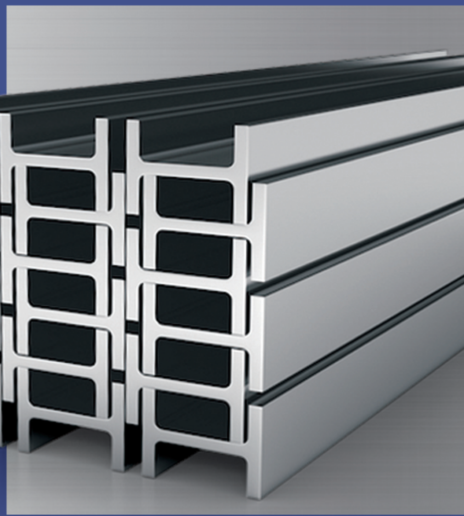

Introduction to Chinese Structural Steel – Production Processes, Materials Specifications and Product Standards

K F Chung, W Feng, Y C Wang, H C Ho

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Foreword

This Technical Guide introduces Chinese steel to construction professionals and provide them information on the production of Chinese steel and the corresponding specifications. This Guide covers different types of steel materials and products that are commonly used in the construction industry in China. Being the largest steel manufacturing country in recent years, both quality and quantity of the steel produced are highly competitive and readily compared to those in many parts of the world.

The technical information provided in this Guide on production processes, materials specifications and equivalence to international standards gives a comprehensive profile of quality, compositions and control of steel production in China. It aims to provide construction professionals an alternative supply source for economical as well as reliable structural steel. With a professional guide entitled "*Selection of Equivalent Steel Materials to European Steel Materials Specifications*" also published by the Chinese National Engineering Research Centre for Steel Construction (Hong Kong Branch), this Guide aims to facilitate construction professionals to select appropriate high quality structural steel produced in China which readily satisfy the steel materials specification and the structural design standards of various parts of the world, including Australia, Europe, Japan, Russia, and U.S.A..

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Section 1

Introduction

1 Introduction

This Guide presents an introduction to current states of the steel construction industry in China together with key information of the iron and steel industry in China. It aims to provide technical information and essential data of the Chinese steel construction to design and construction engineers overseas so that they are confident in adopting Chinese steel products in their projects, whenever appropriate.

This Guide provides an overview on the following aspects of the Chinese steel construction:

i) production processes commonly adopted among Chinese steel producers;
ii) steel usage among different industry in China;
iii) commonly used structural steel for construction, and their typical delivery conditions;
iv) rolling technology and procedures for manufacturing different steel products;
v) materials specifications and products standards; and
vi) key design data of mechanical properties in various design codes on structural steel.

In addition, a comprehensive list on both chemical compositions and mechanical properties of commonly used China steel products for construction are provided in the appendices:

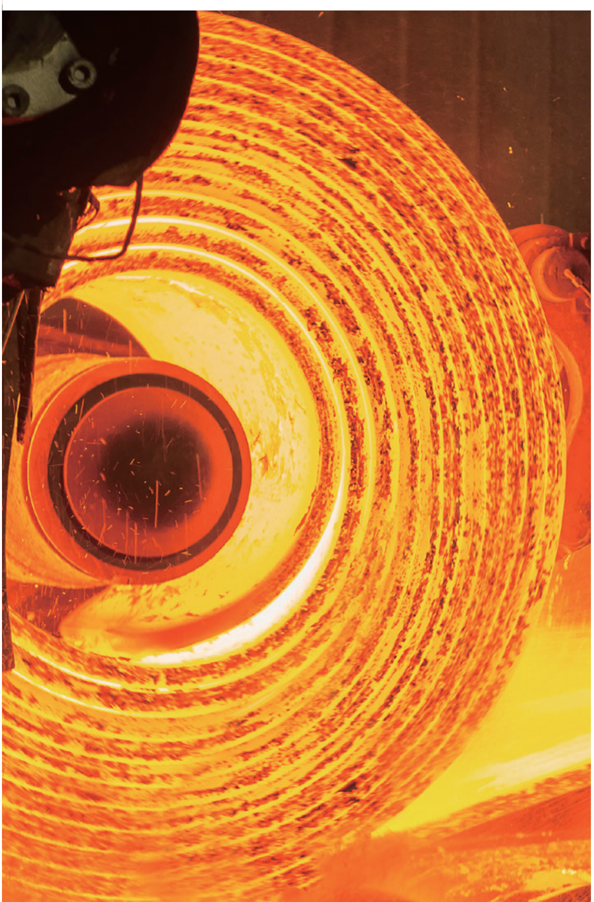
- GB/T 700 *Carbon structural steel*
- GB/T 699 *Quality carbon structural steel*
- GB/T 1591 *High strength low alloy structural steel*
- GB/T 16270 *High strength structural steel plates in quenched and tempered conditions*
- GB/T 4171 *Atmospheric corrosion resisting structural steel*
- GB/T 19879 *Steel plates for building structures*
- GB/T 11253 *Cold rolled sheets and strips of carbon structural steel*
- GB/T 2518 *Continuously hot-dip zinc and zinc alloy coated steel sheets and strip*s
- GB/T 11352 *Carbon steel castings for general engineering purposes*
- GB/T 7659 *Steel casting for welded structures*

Typical sections with cross-sectional dimensions of commonly used steel products are also summarized in the appendices:

- Hot roll steel sheets and strips to GB/T 709
- Cold rolled steel sheets and strips to GB/T 708
- Hot rolled H and split T sections to GB/T 11263
- Welded H sections to GB/T 33814
- Hot rolled sections to GB/T 706
- Cold formed open sections to GB/T 6723
- Cold formed tubes to GB/T 6728
- Hot rolled (seamless) tubes to GB/T 8162
- Longitudinal electric (resistance) weld to GB/T 13793

Section 2

Production Processes of Structural Steel



2 Production Processes of Structural Steel

2.1 Production processes

Steel is one of the most commonly used structural materials in construction. In general, steel production involves control of the carbon content (0.22 ~ 2.11%), and removal of raw material impurities, including Phosphorus (P), Sulphur (S), Oxygen (O), Nitrogen (N), Hydrogen (H) and addition as well as adjustment of some beneficial elements, including Manganese (Mn), Nickel (Ni), Chromium (Cr), Molybdenum (Mo) and Vanadium (V) according to various mechanical and physical performance requirements. The finished products require various rolling and heat treatment processes in order to achieve the desired mechanical properties.

2.1.1 Manufacturing methods

Two manufacturing methods are commonly used in steelmaking, namely: i) Basic Oxygen Steelmaking (BOS) or Converter Steelmaking, and ii) Electric Arc Furnace Steelmaking (EAF). These processes include coking, sintering and pelletizing, then ironmaking, followed by steelmaking in a ladle converter or an electric furnace. Refining, mould casting or continuous casting and steel rolling are important parts of the process which is illustrated in Figure 2.1. Descriptions on functions of each of these processes are as follows:

- **Coking**: The raw material, coal, in air-free conditions is converted into coke as the result of high-temperature distillation. Products such as gas, coal tar and other chemicals are produced during this coal conversion process. Coke is mainly used as fuel for ironmaking.
- **Sintering**: Fine iron ore or ore powders are mixed with fuels and solvents at high temperatures generated by fuel combustion. Through a series of physical and chemical reactions, the sintered ore possesses a stable chemical composition with a suitable range of intensities and sizes for a conversion of iron into steel in subsequent steelmaking processes.
- **Pelletizing**: Since sintering is not applicable for ultrafine mineral powders, the pelletizing process with an addition of ingredients of bentonite or hydrated lime is introduced. After several repeated processes, including mixing, pelleting and sintering, pellets become the final product for a conversion of iron into steel in subsequent steelmaking processes.
- **Blast furnace ironmaking**: Sintered and pelleted iron ore, cokes and limestone are continuously supplied to the upper part of the furnace whilst hot air is blown from the lower layers of the blast furnace. Hence, the heat produced from the burning coke reduces the iron ore, and liquid iron sinks to the bottom of the furnace to produce pig iron.

- **Converter steelmaking / Basic oxygen steelmaking (BOS)**: With molten pig iron obtained from the blast furnace as the main raw material, oxygen is injected into the melting pool of the converter to oxidize various impurities. This oxidation process will release heat into the iron mass, and keeps it molten. This process is very important as fluxes are added to promote impurity removal and to protect the lining of the converter.
- **Electric furnace steelmaking (EAF)**: With scrap iron as the main raw material, the impurities are oxidized and removed by heat which is generated electrically. Being different from BOS, all charged materials are exposed to the electric arc directly whilst the current in the furnace terminals passes through these charged materials. External arc heating permits a good thermal control, which allows improved alloy additions when compared with those in BOS. However, the steel made by EAF normally has higher carbon contents by 0.05% since the process does not involve any oxidation.
- **Ladle refining**: This is a fine-tuning process aiming to refine the molten steel for advanced quality control and chemical composition control during the manufacturing of alloy steel. Ladle refining is achieved by vacuum degassing and feeding methods. The main purposes of refinement are for i) good control of chemical composition; b) impurity reduction for an effective improvement in fatigue characteristics of products; iii) a reduction of gas composition, especially for oxygen and nitrogen control; and iv) for an improvement in both machinability and weldability.
- **Mould casting**: In recent years, mould casting has been increasingly replaced by continuous casting, but moulds are still needed for some types of steel and large steel forgings in various manufacturing industries. Mould casting is good for producing structural elements in complex shapes. However, metallurgical grain refinement and post-heat treatment are required for advanced quality control.
- **Continuous casting**: The molten steel is transferred into a vessel from the ladle through a long vacuum nozzle. It is then poured into crystallizers through preheated submerged nozzles. Billets (blooms or slabs) are formed continuously from the crystallizers. Rapid chilling in the mould ensures a fine and uniform grain structure with improved physical and mechanical properties.
- **Rolling**: The process of changing the shapes of ingots and billets with a series of rollers is called rolling. Three typical methods are commonly applied, including i) hot rolling, ii) cold rolling, and iii) mechanical controlled rolling. For hot rolling and mechanical controlled rolling, the products must be heated to a high temperature, usually to 1200°C and above. In general, the rolling temperature should be carefully controlled throughout the entire process.

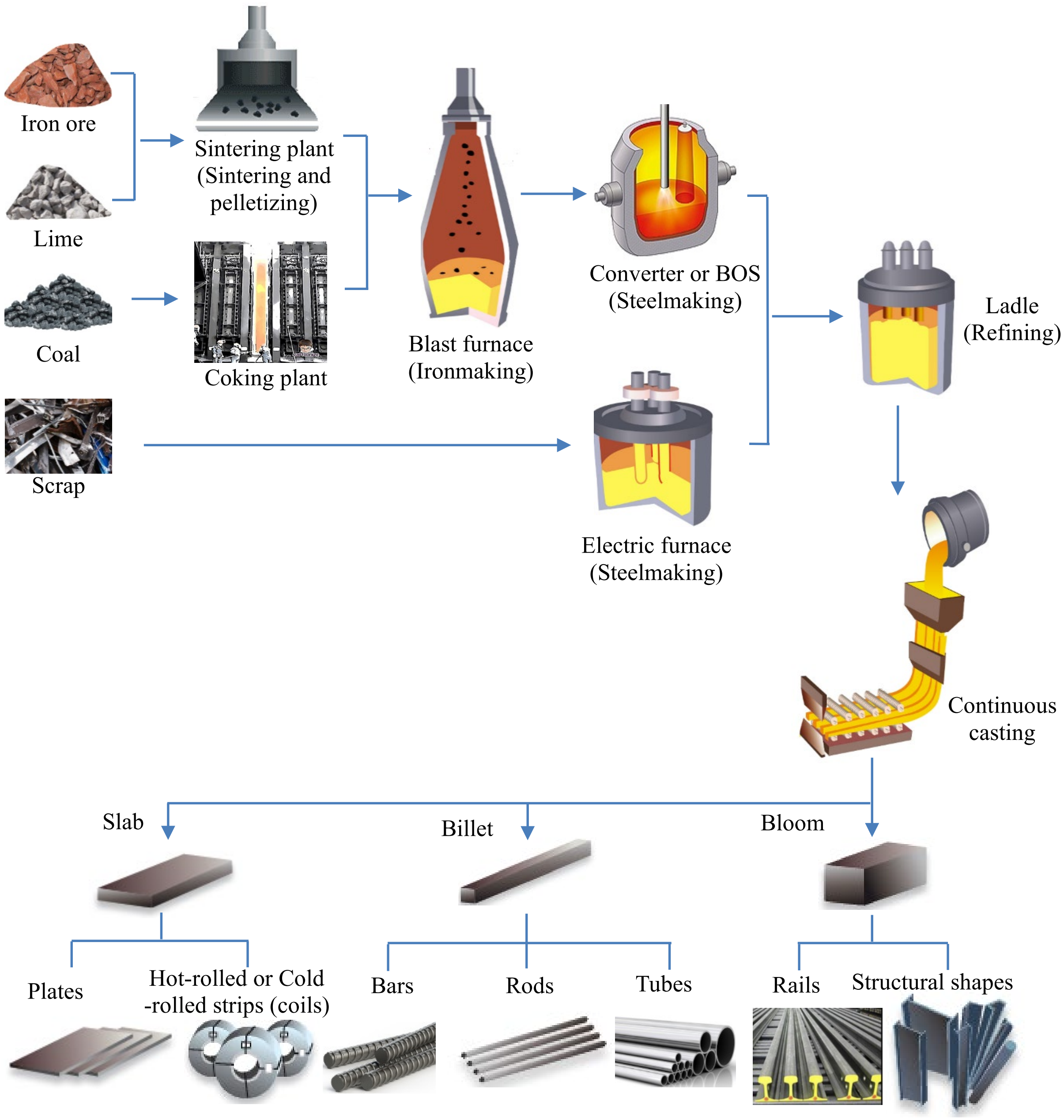


Figure 2.1 Steel production process

2.1.2 Effects of chemical composition on steel properties

In general, the physical as well as the mechanical properties of structural steel result from a combination of chemical composition, heat treatments and manufacturing processes. Structural steel is mainly composed of Iron (Fe) (≥ 95%) with small amounts of Carbon (C) (≤ 0.55%). However, the presence of other chemical elements may be adverse effects on some of the mechanical properties. For example, the amount of Sulphur (S) should be kept low for good ductility. In order to attain certain specific properties and characteristics, certain chemical elements such as Manganese (Mn), Niobium (Nb) and Vanadium (V) should be added during tapping or secondary steelmaking to achieve improved mechanical properties such as ductility, toughness, and weldability. For example, an addition of Nickel (Ni) will improve toughness of the steel though the material cost of the steel is increased accordingly. Consequently, the chemical composition of each steel material must be carefully considered to achieve the required properties. Table 2.1 summarizes common chemical elements in steel and their effects on its mechanical and material properties.

Table 2.1 Typical functions of chemical elements in structural steel

Elements	Typical content (%)	Strength	Ductility	Toughness	Hardness	Weldability	Corrosion resistance	Remarks
Aluminum (Al)	*0~ 0.015*	↑	-	↑	-	-	-	Usually used as a deoxidizer.
Boron (B)	*0~ 0.005*	-	-	-	↑	-	-	Uses only in aluminum-killed steel, and is most effective in low-carbon steel.
Calcium (Ca)	*0~ 0.015*	↑	-	↑	-	↑	-	Minimizes re-heat cracking, and prevents lamellar tearing in large restrained welded structures.
Carbon (C)	*0.05~0.25*	↑	□	□	↑	□	-	-
Chromium (Cr)	*0.10~0.90*	↑	-	-	↑	-	↑	-
Copper (Cu)	*0.20~0.60*	-	-	-	-	-	↑	-
Manganese (Mn)	*0.50~1.70*	↑	□	-	↑	□	-	Controls harmful effects of Sulphur.
Molybdenum (Mo)	*< 0.30*	↑	-	-	-	-	↑	Increases the yield strength at elevated temperatures as well as the creep strength.
Niobium (Nb)	*< 0.05*	↑	-	↑	-	-	-	Columbium (Cb), referred to as Niobium (Nb) in Europe, is one of the key elements in the various HSLA grades.
Nitrogen (N)	*0 ~ 0.004*	↑	□	□	↑	-	-	With other elements, strength can be increased.
Nickel (Ni)	*0.25~1.50*	↑	-	↑	-	-	↑	-
Phosphorus (P)	*< 0.05*	↑	-	-	↑	-	-	-
Sulphur (S)	*< 0.05*	-	-	-	-	-	-	-
Silicon (Si)	*0.10~0.40*	-	-	-	-	-	-	Good deoxidizers of steel.
Titanium (Ti)	-	↑	-	↑	↑	-	-	Increases creep and rupture strength, and refines grains.
Vanadium (V)	*< 0.20*	↑	-	↑	-	-	-	Refines grains and increases strength.

2.2 Production Technology

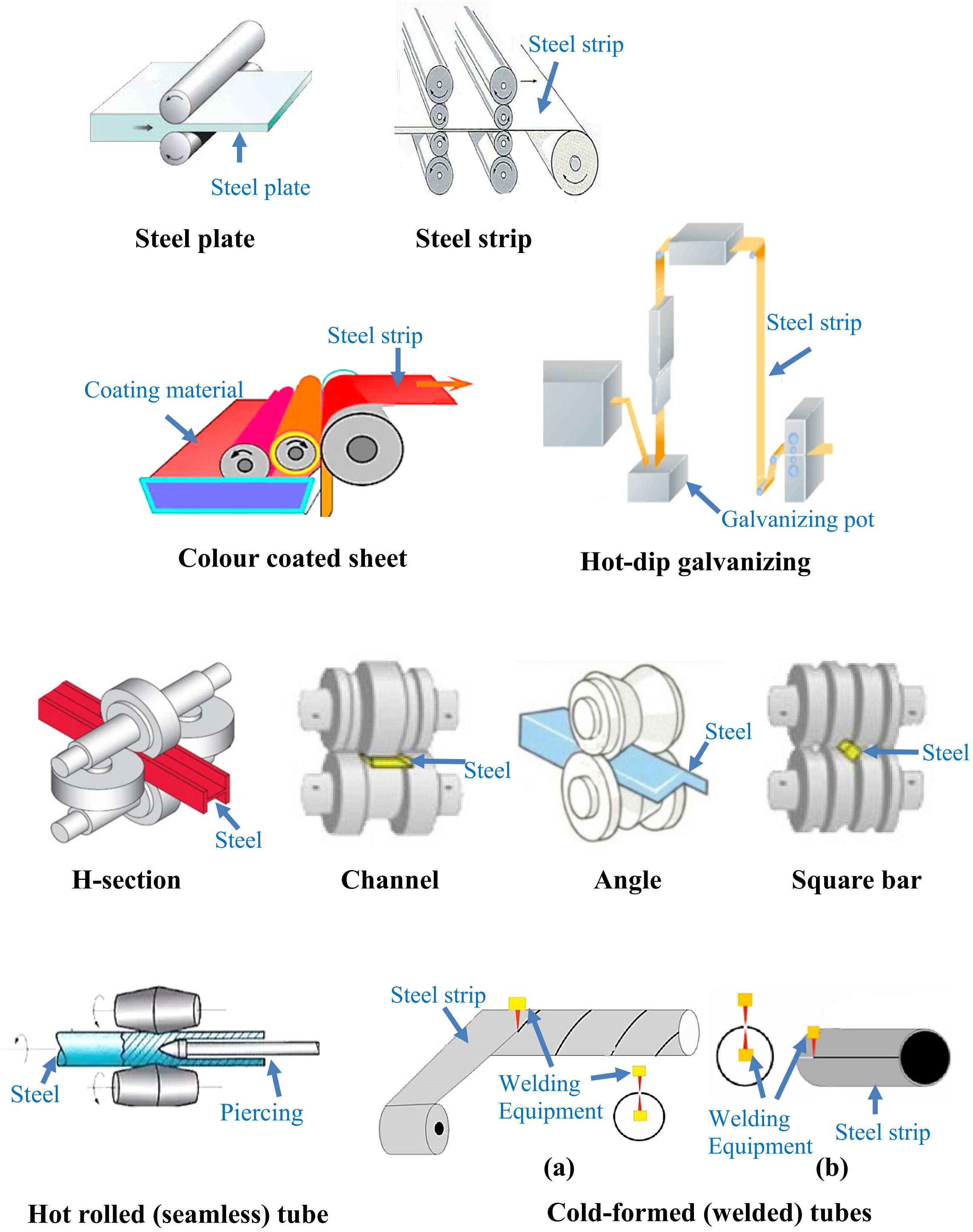


Figure 2.2 Rolling processes of common steel products

Structural steel products of different forms can be divided into steel plates, steel strips, H-sections, joists, channels, angles, tubes and bars. Depending on section shapes, the production technology, and thus the rolling processes, differ. The basic rolling process includes preparation, heating and rolling.

Technical requirements of chemical composition, mechanical properties and surface conditions must be considered in the selection of raw materials. In production of various steel products, ingots, billets, and continuous-casting billets are commonly used.

(1) Hot rolled steel plates

Plates with thicknesses larger than 3 mm are considered as hot rolled plates. Currently, the Chinese product specifications define clearly that the plate thickness should be between 4 mm and 250 mm, and they are mainly used in machinery and equipment, vehicles, pipelines, structural steelwork, buildings, bridges and ships.

(2) Hot rolled steel strips

In general, hot rolled steel strips are plate products with thicknesses between 0.8 and 25.4 mm and a width between 600 mm and 2200 mm. Hot rolled strips can either be used as hot rolled steel plates directly, or used for cold rolling. Rolling temperatures should be maintained between 900 and 950°C. After that, the strip temperature should be cooled down rapidly to a range between 600°C and 650°C in a few seconds for roll forming. To ensure good product performance, coiling speed should be well controlled under a temperature ranging from 500°C to 650°C.

(3) Cold rolled steel strips

It is important to note that the hot rolled coils and strips are raw materials for producing cold rolled strips. Annealing is a key process which is divided into intermediate annealing and final annealing. In general, intermediate annealing eliminates process hardening whilst final annealing is performed to obtain required microstructures and mechanical properties.

(4) Galvanized steel strips

Among various hot-dip galvanized steel production technology, Chinese galvanizers commonly adopt an improved Sendzimir process for hot-dip galvanization. Pre-treatment before hot-dip galvanizing is performed to remove grease and scales. The galvanization temperature is controlled within a small range between 450°C and 465 °C. Post-treatment includes annealing, spangle-control, cooling, etc.

(5) Colour coated steel strips

Colour coated steel strips are steel strips with versatile organic coating, and they have high strengths, good corrosion resistances and excellent formability.

(6) Hot rolled steel tubes

Hot rolled steel tubes are commonly known as seamless tubes, and they have strict requirements on chemical composition, dimensional tolerances, surface quality and technical delivery conditions. Centering process is a key manufacturing procedure for determination of the centre of the tubes for piercing whilst radius setting reduces deviations in diameters of the finished products.

(7) Welded steel tubes

Cold formed steel tubes with longitudinal welding are commonly known as welded tubes. Welding methods include oven soldering, resistance welding, and arc welding.

2.3 Delivery Conditions of Structural Steel

The delivery condition of steel products is defined as the state of the final products on delivery in terms of various mechanical requirements. Symbols and descriptions are shown in Table 2.2, and the corresponding rolling and heat treatment processes are illustrated in Figure 2.3. For a detailed introduction to metallurgy, please refer to Appendix A - An introduction to the metallurgy of Iron-Carbon alloys.

Table 2.2 Common delivery conditions and symbols

Symbol	Delivery Condition
AR	As-Rolled or Hot Rolling
CR	Controlled Rolling
TMCP	Thermal Mechanical Controlled Process
N	Normalizing
T	Tempering
QT	Quenching & Tempering
NT	Normalizing & Tempering
A	Annealing

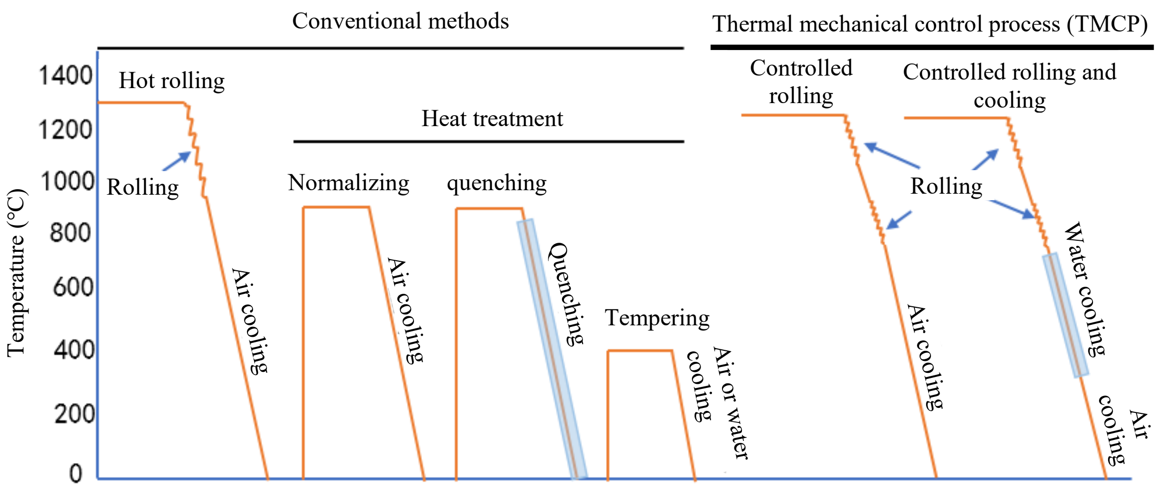


Figure 2.3 The rolling and heat treatment processes

Typical delivery conditions include:

(1) Hot rolling

After hot rolling or forging, the steel products are delivered directly after cooling, without any other heat treatment. Generally, cooling occurs naturally in the air, rather like normalizing, but without a strict control of a normalizing temperature. Both microstructure and mechanical properties are inferior to those of normalized products.

(2) Controlled rolling

The heating temperature, the rolling temperature and various deformation process parameters, etc., are controlled to manage phase transformation, recrystallization and grain growth, and hence, to improve their strengths and toughness.

(3) Normalizing

The process is widely adopted by the iron and steel industry in which as-rolled steel is heated up to approximately 900 ºC, and held at that temperature for a specific time before a natural cooling process takes place. This process refines the grain size, and improves the mechanical properties of the steel, especially toughness. It also improves consistency of the mechanical properties of the steel, and removes residual rolling strains effectively.

(4) Annealing

This is another process of post-heat treatment. In general, the steel is re-heated to a pre-determined temperature, and then held at that temperature for a specific time, and then, cooled down slowly. Annealing is usually performed to release induced residual stresses.

(5) Quenching

This is another process of post-heat treatment, and the steel is re-heated above its critical temperature, A_3 (refer to Appendix A) to transform its microstructure into full austenite. It is then cooled rapidly by soaking with a quenching medium, such as water or oil, to make sure that transformation occurs only in the martensitic temperature range.

(6) Tempering

This is another process of post heat treatment, and the steel is re-heated to a temperature below its critical temperature, A_3, and then, held at that temperature for a period, followed by cooling in air, water, oil, or other media, to increase ductility and toughness of the steel.

(7) Thermal mechanical controlled rolling

Thermomechanical rolling involves various combinations of controlled heat treatments and mechanical rolling processes to obtain cost-effective steel products with high strengths and toughness.

2.4 Influencing Factors of Structural Steel

2.4.1 Chemical composition

For structural steel, its chemical composition during the smelting process should be controlled to vary only within certain limits. The most important elements are Carbon (C), Sulphur (S) and Phosphorus (P). Carbon plays a leading role in improving the strength of steel, but increasing its content significantly reduces the weldability. Consequently, its content is generally controlled to be 0.22% or below. Both Sulphur (S) and Phosphorus (P) are harmful elements, and their contents should be controlled strictly. The effects of chemical composition on the properties of steel are given in Section 2.1.2.

Unless otherwise specified, the chemical composition of each grade of structural steel should comply with the limits for chemical contents in each corresponding standard.

Test standards:

a) GB/T 222 *Permissible tolerances for chemical composition of steel products*

b) GB/T 223 *Methods for chemical analysis of iron, steel and alloy*

Chemical indicators:

a) The chemical composition of steel include such as C, S, P, Mn, Si, Ni, Cr, Mo, V, W, Al, Cu, Ti, B, Co, Pb, Nb, etc.

b) Chemical composition limits.

c) Upper and lower deviations allowable on the chemical composition proportions.

2.4.2 Deoxygenation

During the cooling process of rimming steel, the core of steel may undergo insufficient de-oxidation, leading to a possible impurity segregation. Hence, the steel may not be highly uniform. In order to ensure a complete de-oxidation taken place in the steelmaking process, a de-oxidizer is added so that a "killed" steel is obtained. Once de-oxidation is completed, the steel becomes completely uniform, the grain is refined, and their overall performance is enhanced.

According to the extent of de-oxygenation, the killed steel is divided into three categories, namely i) semi-killed steel (code b), ii) killed steel (code Z), and iii) special killed steel (code TZ). In general, structural steel should be killed steel.

(1) Delivery condition

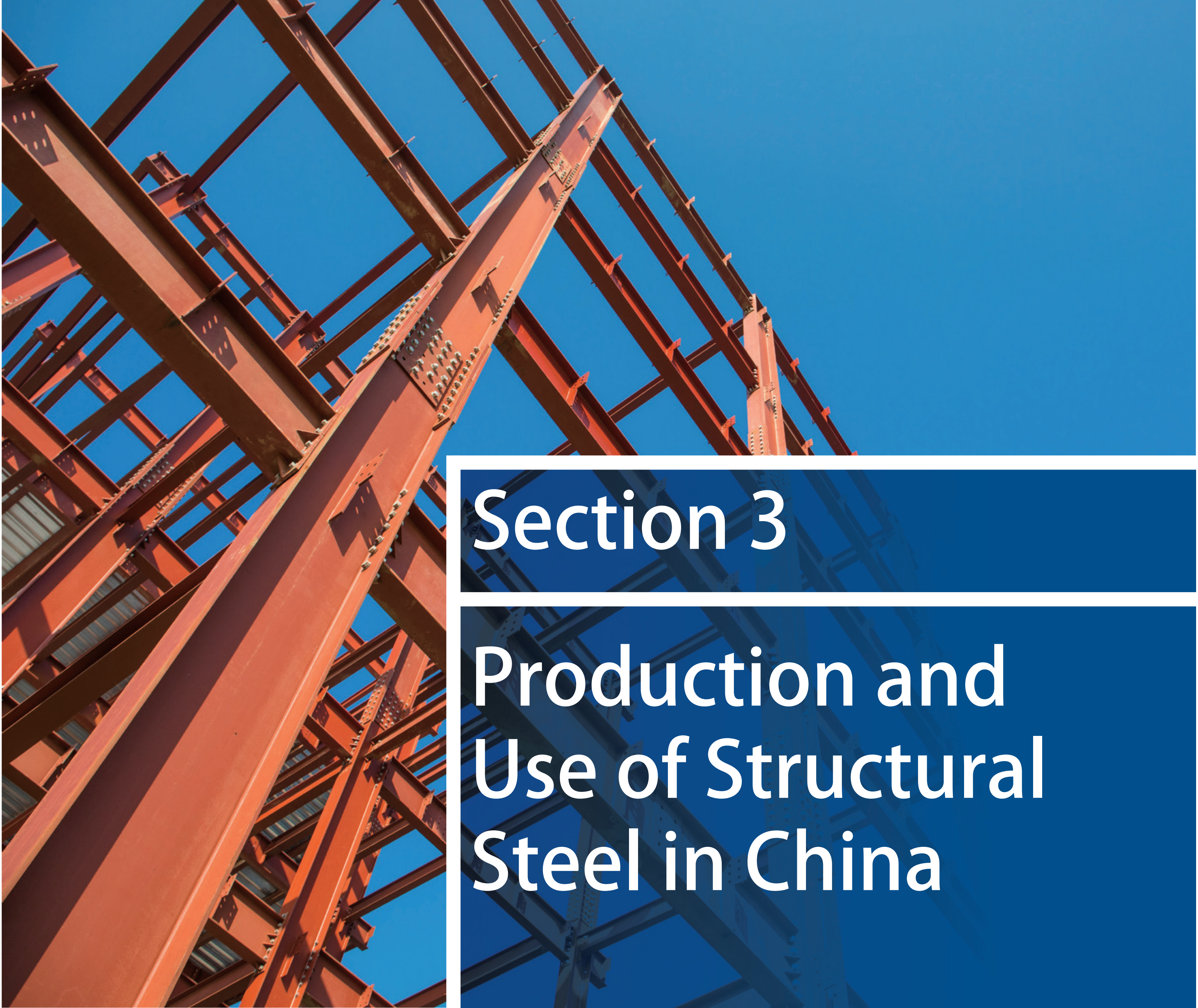
The delivery condition of the steel refers to the rolling and heat treatment method adopted during its production. It should be noted that the rolling of steel is a process in which the steel is subjected to pressure exerted by rollers, typically at high temperatures, to obtain desired shapes and to improve internal quality. Heat treatment consists of different durations of i) heating up, ii) heat preservation, and iii) cooling down in solid state to modify physical properties. A detailed explanation of the delivery condition may be found in Section 2.3.

Examples of delivery conditions for typical steel are:

- In GB/T700, Q235 to Q390 are common carbon structural steel and low alloy structural steel which are delivered in i) hot rolled condition, ii) controlled rolled condition, or iii) normalized condition.
- For high strength steel, Q420 to Q460 steel in GB/T 1591 are delivered in i) normalized condition, ii) normalized and tempered condition, and iii) thermo-mechanically rolled or thermo-mechanically rolled and tempered condition.
- In GB/T 1591 and GB/T 16270, high strength Q500 to Q690 steel are delivered in i) thermo-mechanically rolled condition, ii) thermo-mechanically rolled and tempered, or quenched and tempered condition.

(2) Quality level

Quality levels mainly reflect differences in impact which depend heavily on chemical composition of steel. As there is a significant increase in cost, the quality level should be selected properly according to specific applications. In general, the quality level for all structural steel should be at least Level B. For those structural members which are required to possess fatigue resistance, structural steel of Levels B, C, D, and E should be adopted according to various working temperature conditions.



Section 3

Production and Use of Structural Steel in China

3 Production and Use of Structural Steel in China

3.1 Overview of World Supply of Steel Materials

According to the statistics on world crude steel production in 2021 provided by the World Steel Association (www.worldsteel.org) as shown in Table 3.1 and Figure 3.1, the annual steel production of China has reached 1,032.8 million metric tonnes (mmt), accounting for 52.9% of world production. Hence, it is important to engage design and construction engineers worldwide to use Chinese steel effectively, taking advantage of the economical and reliable supply of the Chinese steel.

Table 3.1 Top 10 steel production countries in 2021

<table>
<tr><th>Rank</th><th>Countries</th><th>Crude steel production(mmt)</th><th colspan="2">Proportion</th></tr>
<tr><td>1</td><td>China</td><td>1032.8</td><td>52.9 %</td><td rowspan="10">83.2 %</td></tr>
<tr><td>2</td><td>India</td><td>118.2</td><td>6.1 %</td></tr>
<tr><td>3</td><td>Japan</td><td>96.3</td><td>4.9 %</td></tr>
<tr><td>4</td><td>U.S.A.</td><td>85.8</td><td>4.4 %</td></tr>
<tr><td>5</td><td>Russia</td><td>75.6</td><td>3.9 %</td></tr>
<tr><td>6</td><td>South Korea</td><td>70.4</td><td>3.6 %</td></tr>
<tr><td>7</td><td>Turkey</td><td>40.4</td><td>2.1 %</td></tr>
<tr><td>8</td><td>German</td><td>40.1</td><td>2.1 %</td></tr>
<tr><td>9</td><td>Brazil</td><td>36.2</td><td>1.9 %</td></tr>
<tr><td>10</td><td>Iran</td><td>28.5</td><td>1.5 %</td></tr>
<tr><td colspan="2">Total</td><td>1953.3</td><td colspan="2">100 %</td></tr>
</table>

Note: All data are available from the World Steel Association.

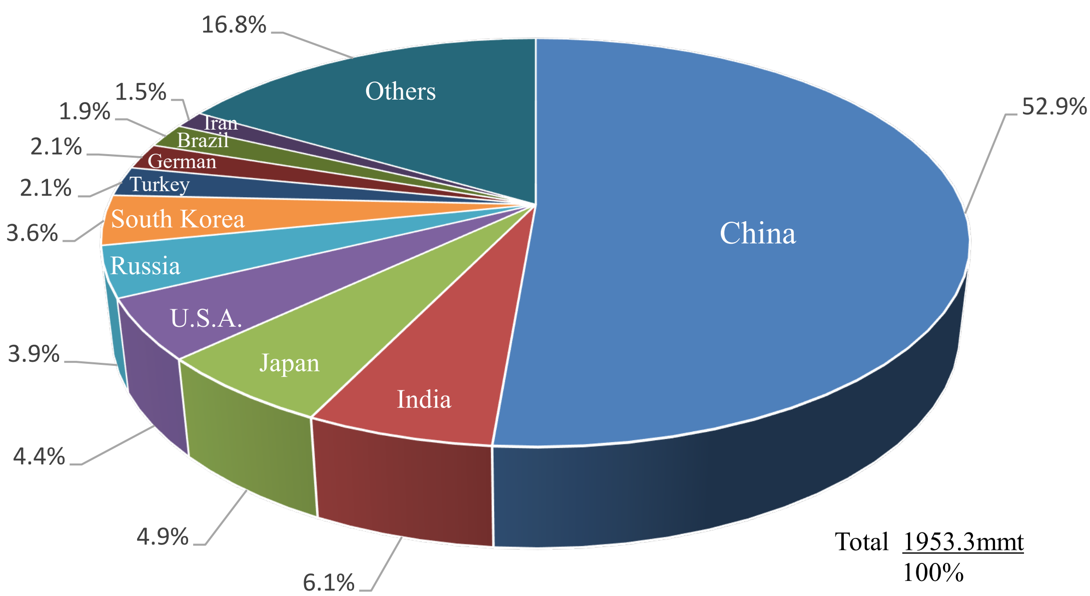


Figure 3.1 Distribution of crude steel production in 2021

Figure 3.2 illustrates top 10 steel production countries in 2021.

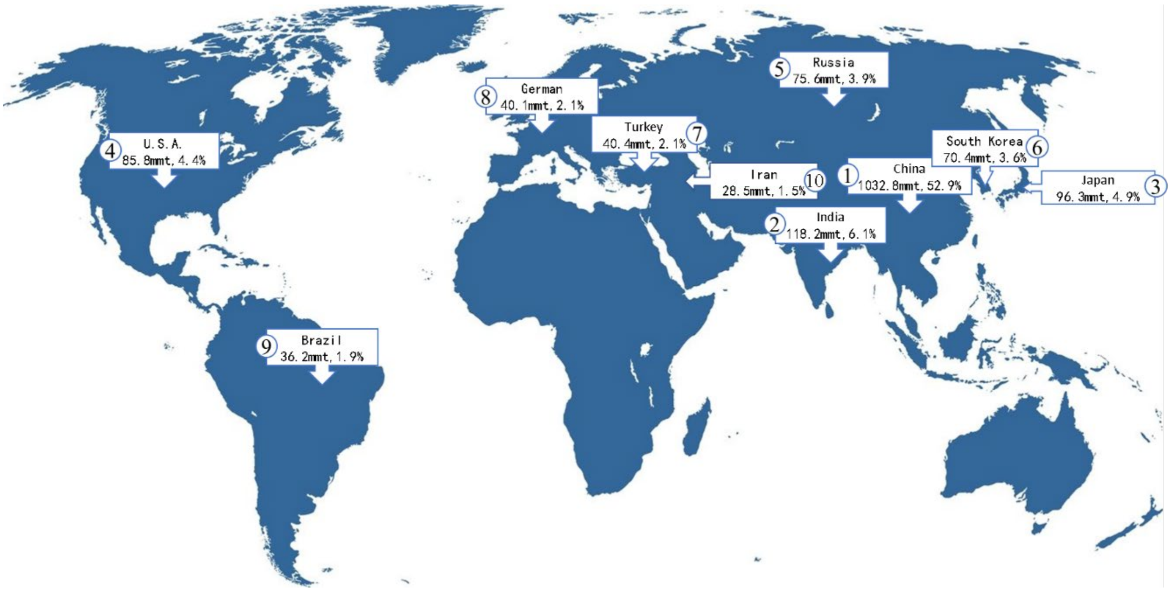


Figure 3.2 Distribution of top 10 steel production countries in 2021

There are many steel enterprises all over China, especially in Hebei, Shandong, Jiangsu. Detailed information is given in Appendix B, and locations of these steel enterprises in various parts of China are illustrated. Since 2009, the crude steel production in China has accounted for about 50% of the world total production. In 2014, it exceeded 800 mmt. In 2021, the annual production of Baowu Group, Ansteel Group, Shagang Group, HBIS group, Jianlong Group and Shougang Group all exceeded 30 mmt, as shown in Table 3.2 and Figure 3.3.

Table 3.2 Steel production of Chinese steel enterprises in 2021

Rank	Enterprise	Production（mmt）
1	China Baowu Group	119.95
2	Ansteel Group	55.65
3	Shagang Group	44.23
4	HBIS Group	41.64
5	Jianlong Group	36.71
6	Shougang Group	35.43
7	Shandong Steel Group	28.25
8	Delong Steel Group	27.82
9	Valin Group	26.21
10	Fangda Steel	19.98

Note: All data are available from the World Steel Association.

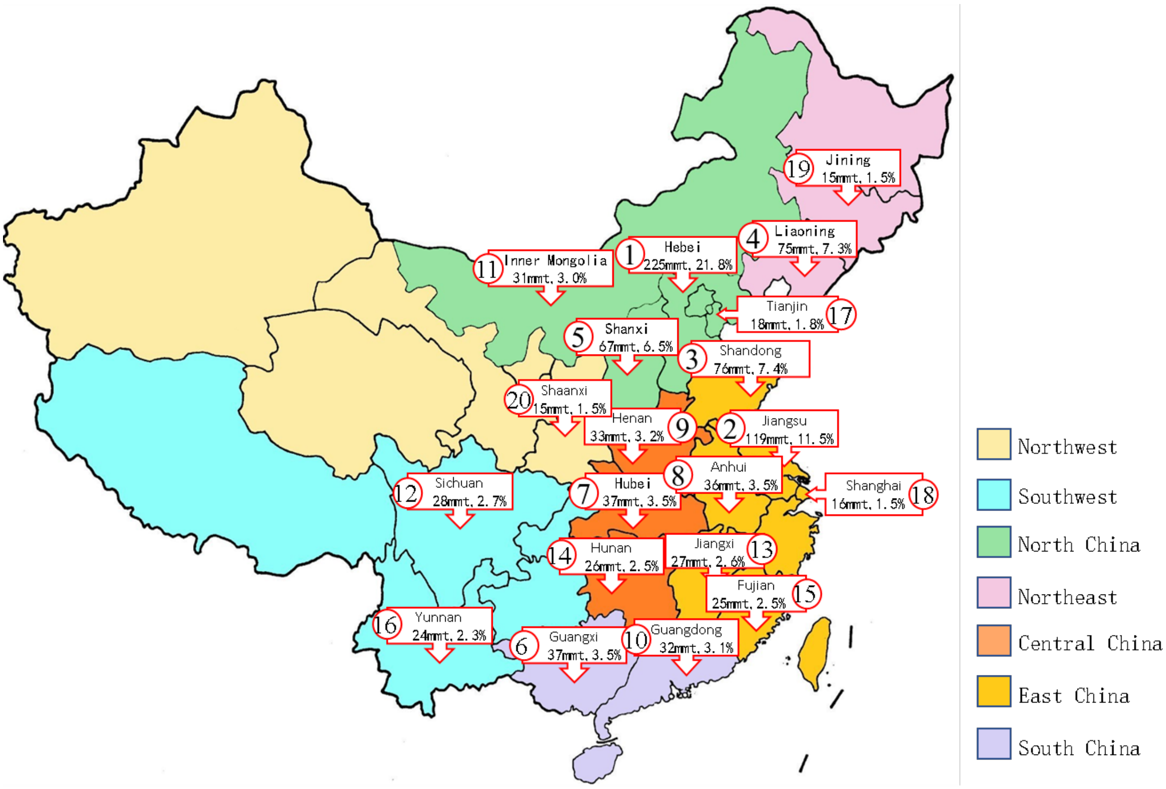


Figure 3.3 Top 20 provinces of steel production in China in 2021

Note: All data are available from the Chinese Bureau of Statistics

3.2 Steel Production in China

Over the past 30 years in China, the national economy has grown rapidly while demand for steel in the domestic market has increased dramatically. Hence, China has developed into the largest steel producer, exporter and consumer in the world. The market size of the Chinese steel industry has grown from 1,034 mmt in 2015 to 1,325 mmt in 2020, representing a compound annual growth rate of 4%. Driven by new infrastructure investment and the "One Belt & One Road" initiative, the market size of the Chinese steel industry is expected to maintain a growth rate of 2.5% in the coming few years. At present, the leading enterprises operate with a wide range of activity including mining, processing and application. Structural steel is widely used in construction, machinery, automotive, and energy sectors. Among them, the construction sector is the main consumption sector of structural steel, accounting for about 35%.

According to statistics in 2021, steel production with electric furnaces only accounted for about 10.7% of the crude steel production in China while the global average over the same period was about 26.3%. After deducing China, the proportion of steel production with electric furnaces in the rest of the world was about 42%, among which the corresponding proportions were about 70% in the U.S.A., 31% in South Korea and 25% in Japan. According to the material source, scrap steel are divided into three categories: self-produced scrap steel, processed scrap steel and depreciated scrap steel. In general, the theoretical accumulation of scrap steel was found to be in the range of 250 to 280 mmt in 2021 and 2022 respectively, and they are anticipated to increase to over 300 and 350 mmt in 2025 and 2030 respectively.

3.3 Classification of Steel Products

Chinese structural steel include primarily structural steel, steel reinforcements, steel strands, steel wires, etc. Structural steel mainly cover a large range of product forms, such as structural steel sections and plates, seamless and welded steel tubes, cold rolled plates, and colour-coated steel strips etc..

The usage of structural steel products depends mainly on the structural forms applied in construction and various performance requirements. For high-rise buildings and long-span structures, hot rolled or welded steel sections are adopted as primary structural members, such as beams and columns, to achieve structural adequacy and rigidities. For low-rise, light weight steel structures, cold-formed C-sections or Z-sections are adopted as purlins and side rails while colour-coated steel strips are widely used as building envelopes.

Typical distributions of Chinese steel products in recent years are shown in Figure 3.4.

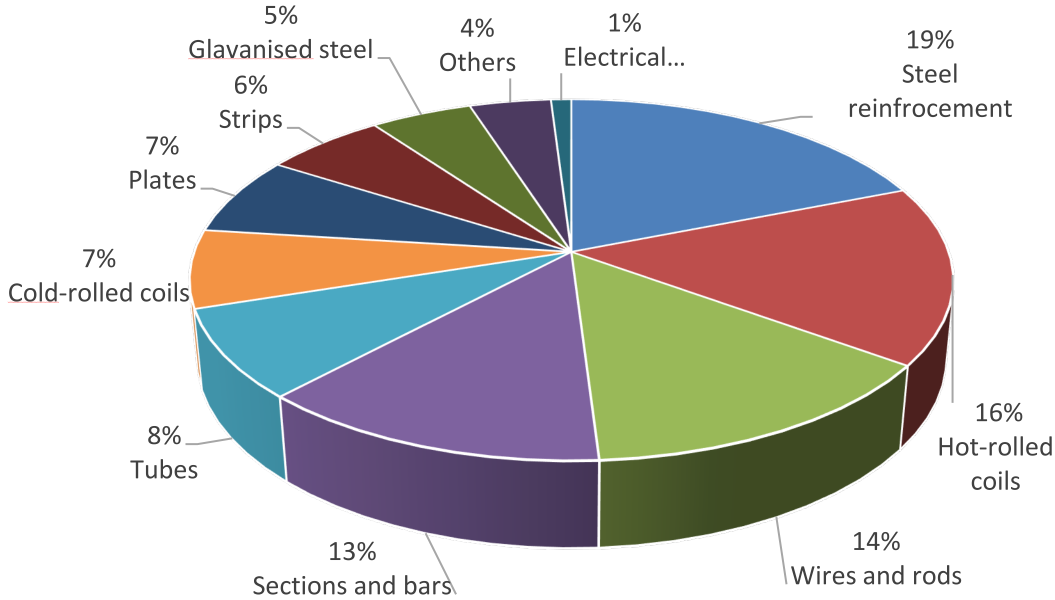


Figure 3.4 Typical distributions of Chinese steel products in recent years

3.4 Steel Usage in China and the World

Conventionally, over 50% of the steel produced in China is used in construction while the remaining amount is used in machinery, shipbuilding, automobiles, home appliances and other related industries. It should be noted that reinforced concrete construction is commonly adopted in China over the past decades, and hence, reinforcement bars are the main steel products in the construction industry for many years. As a result, the proportion of steel as structural steelwork remains to be small, and it amounts to be about 5% only in 2021 according to official statistics in China. It should be noted that the consumption of structural steel in the U.S.A. exceeds 50% for many years.

In the recent years, many iconic structures were built with structural steel in China, and demand for construction is anticipated to continue to grow in the coming years. Steel construction is widely regarded as an environmentally friendly construction method in terms of effective energy saving, good recyclability, lightness, high land utilization rate, large spaces, reliable quality production and short construction period. Hence, the steel usage in China is expected to increase significantly in the coming years.

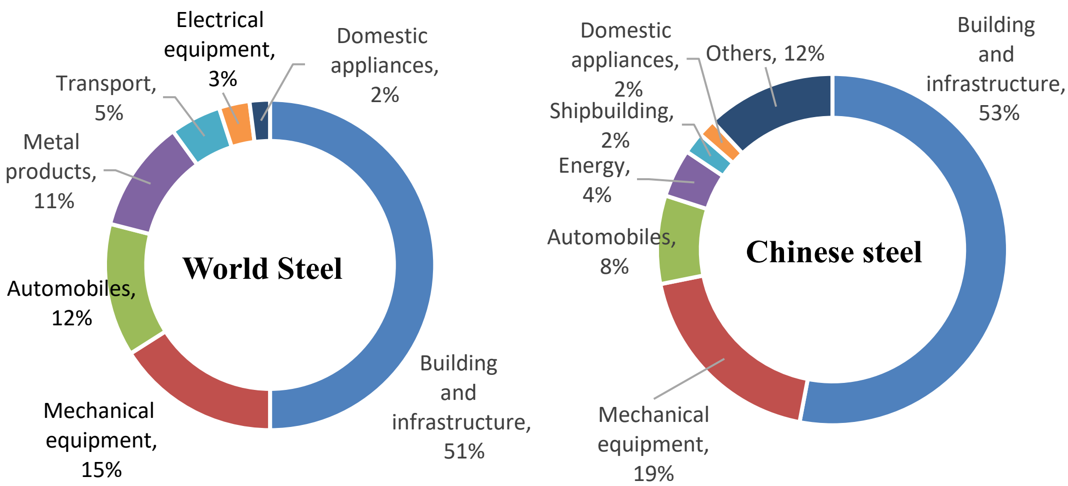


Figure 3.5 Typical distributions of steel products in recent years

3.5 Introduction to Chinese Associations in Steel Industry

3.5.1 China Iron and Steel Industry Association

The China Iron and Steel Association (CISA) is a nationwide industrial organization of the Chinese steel industry. It is dedicated to function as a bridge between the government and enterprises as well as improve competitiveness of the Chinese steel industry in both the domestic and the international market.

3.5.2 China Construction Metal Structure Association

The China Construction Metal Structure Association (CCMSA) is a non-profit organization throughout China with members from academia (such as universities, scientific research, design units, etc.) and enterprises that are engaged in construction (such as fabricators, suppliers of steel products and related building products). It advocates innovation and sustainable development, and promotes a healthy development of the industry.

3.5.3 China Steel Construction Society

The China Steel Construction Society (CSCS) is a national association with a legal entity status composed of enterprises, research institutes, universities and technical experts. The professional scope covers metallurgy, construction, chemical and petroleum industry, machinery, shipbuilding, electric power, railways, transportation and aviation sectors. It is a link between enterprises and authorities, and it provides services for the entire industry in improving management of the industry, expanding international exchanges and cooperation, and promoting a healthy development of the industry.

3.6 Awards for Structural Steel Products and Steel Structures in China

3.6.1 Golden Cup Awards

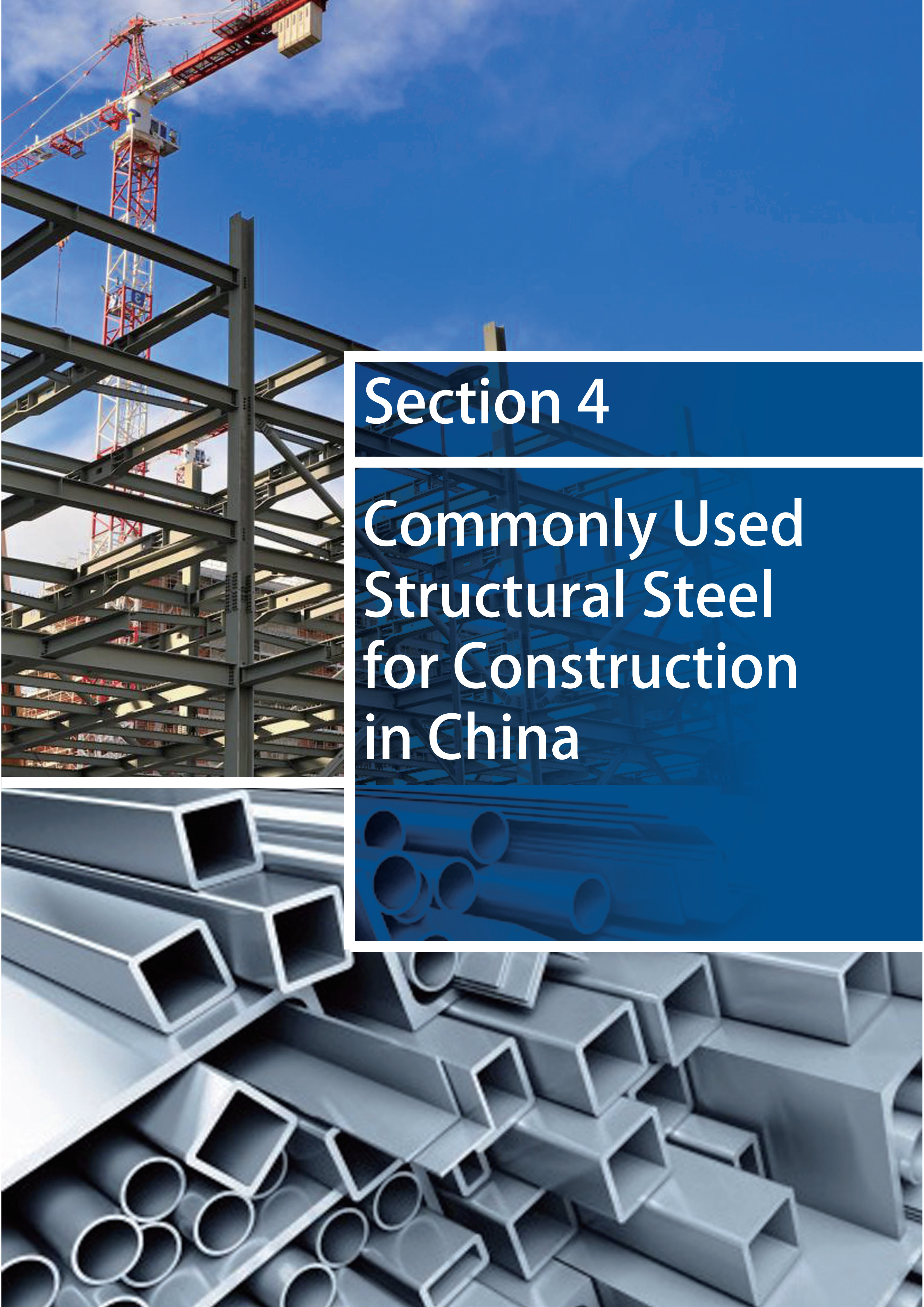
The China Iron and Steel Association conducts objective assessments on metallurgical products, including structural steel, hot rolled plates, hot rolled strips, cold rolled strips, coated strips, hot rolled tubes etc. on an annual basis. In order to enhance technological advancement and product innovation, CISA presents the “Golden Cup Awards" to steel products with advanced quality, and these products serve as ‘benchmarks’ for similar products. In addition, steel products with exemplary quality and performance are honoured with the “Special Quality Awards”. It should be noted that both Awards are valid for three years only.

Figure 3.6 Golden Cup Awards and Special Quality Awards

3.6.2 Gold Awards for Quality Steel Structures

The “Gold Awards for Quality Steel Structures” are the highest awards for quality steel construction projects in China. The Awards are presented annually by the China Construction Metal Structure Association to promote quality of steel construction.

Figure 3.7 Gold Awards for Quality Steel Structures



Section 4

Commonly Used Structural Steel for Construction in China

4 Commonly Used Structural Steel for Construction in China

4.1 Materials Specifications and Products Standards for Steel Structures

Various types of materials specifications are available in China, including national, industrial and corporate specifications and standards. All requirements in national specifications and standards must be complied with, i.e. mandatory. Good practice recommendations provided in various industrial and corporate specifications and standards are encouraged to be complied with. All of these documents are subjected to continual reviews, and they are basically on par with international standards (ISO).

The relationship between steel materials specifications, such as carbon steel, alloy steel, etc. and those of steel products standards such as plates, sections, tubes, etc. is illustrated in Figure 4.1.

Figure 4.1 Steel Materials Specifications and Steel Products Standards

Common Chinese specifications and standards providing detailed requirements on steel materials and steel products are summarized in Table 4.1.

Table 4.1 Common Specifications and Standards for Structural Steel in China

First group: General structural steel

Classifica-tion	Standard	Title	Version	Material	Product
Basic standard	GB/T 700	Carbon structural steel	2006	√	
	GB/T 699	Quality carbon structural steel	2015	√	
	GB/T 1591	High strength low alloy structural steel	2018	√	
Plates and strips (include medium or heavy plates and strips)	GB/T 16270	High strength structural steel plates in quenched and tempered condition	2009	√	
	GB/T 11253	Cold-rolled sheets and strips of carbon structural steel	2019	√	
	GB/T 2518	Continuously hot-dip zinc and zinc alloy coated steel sheets and strips	2019	√	
	GB/T 709	Dimensions, shapes, weights and tolerances for hot rolled steel plates and sheets	2019		√
	GB/T 3274	Carbon structural and low alloy steel rolled plates and strips	2017		√
	GB/T 708	Dimension, shape, weight and tolerances for cold rolled steel plates and sheets	2019		√
	GB/T 12754	Coloured paint coat steel plates and strips	2019		√
	GB/T 33162	Continuously hot-rolled steel sheets and strips for cold formed steel sections	2016		√
Sections	GB/T 706	Hot rolled steel sections	2016		√
	GB/T 11263	Hot rolled H and split T sections	2017		√
	GB/T 33814	Welded H sections	2017		√
	YB/T 3301	Welded steel H sections	2005		√
	GB/T 6725	Technical requirements of cold formed steel sections	2017		√
	GB/T 6723	Cold formed open steel sections for general structures	2017		√
	GB/T 6728	Cold formed hollow steel sections for general structures	2017		√
Piles	GB/T 17395	Dimensions, shapes, weights and tolerances of seamless steel tubes	2008		√
	GB/T 21835	Dimensions and weights of welded steel tubes	2008		√
	GB/T 8162	Seamless steel tubes for structural purposes	2018		√
	GB/T 13793	Steel pipes with a longitudinal electric (resistance) weld	2016		√
Cast steel	GB/T 11352	Carbon steel castings for general engineering purposes	2009	√	
	GB/T 7659	Steel casting suitable for welded structures	2010	√	

Second group: Structural steel for building structures

Classifica-tion	Standard	Title	Version	Material	Product
Sections	JG/T 137	High frequency welded light gauge steel H sections for construction	2007		√
Plates	GB/T 19879	Steel plates for building structures	2015	√	
	GB/T 12755	Profiled steel sheets for building structures	2008		√
Pipes	JG/T 178	Cold-formed steel hollow sections for building structures	2005		√
	JG/T 381	Cold-formed and welded circular tubes for building structures	2012		√

Third group: Special steel for building structures

Classifica-tion	Standard	Title	Version	Material	Product
—	GB/T 4171	Atmospheric corrosion resisting structural steel	2008	√	
	GB/T 5313	Steel plates with through-thickness characteristics	2010		√
	YB/T 4112	Welded steel tubes with atmospheric corrosion resistance for structural purposes	2013		√

Note: the latest version of the standard as of December 2021

4.2 Steel Grades

GB/T 13304.1 *Steel Classification Part I - Classification by Chemical Composition* divides steel into three categories according to their chemical composition, and they are classified as i) non-alloy steel (i.e. carbon steel), ii) low alloy steel and iii) alloy steel.

The most commonly used steel standards in China are GB/T 700 *Carbon Structural Steel* and GB/T 1591 *Low Alloy High-Strength Structural Steel*. The corresponding standards and areas of application are given in Table 4.1. In addition to buildings, they are also widely used in vehicles, containers, machinery, etc.

With continuous improvements in steel production technology, high-performance steel with high strength and other properties are available in the market, for example, atmospheric corrosion-resisting structural steel under GB/T 4171, steel plates for high-rise buildings under GB/T 19879, steel plates with through-thickness characteristics under GB/T 5313, etc. The corresponding standards and area of applications are presented in Table 4.2.

Table 4.2 Standards of Commonly Used Structural Steel

No.	Standard	Steel Grades	Application Areas
1	**GB/T 700** Carbon structural steel	Q235	Hot-rolled plates, strips, sections and bars for welding, riveting and bolting structures.
	GB/T 699 Quality carbon structural steel		Prestressed concrete steel wires, steel strands, anchors, high-strength bolts and cast steels for important structures, etc.
2	**GB/T 1591** High strength low alloy structural steel	Q355, Q390, Q420, Q460	High strength low alloy structural steel plates, strips, sections and steel bars for general structures.
	GB/T 16270 High strength structural steel plates in quenched and tempered condition	Q460	High strength low alloy structural steel plates, strips, sections and steel bars for general structures.
3	**GB/T 4171** Atmospheric corrosion resisting structural steel	High weather resistance: Q265GNH, Q295GNH, Q310GNH, Q355GNH Welded weather resistance: Q235NH, Q295NH, Q355NH, Q415NH, Q460N	Construction of bridges, buildings, towers and other structures, hot-rolled and cold-rolled plates, strips, sections, bolted, riveted and welded structural parts with atmospheric corrosion resistance.
4	**GB/T19879** Steel plates for building structures	Q235GJ, Q345GJ, Q390GJ, Q420GJ, Q460GJ	Hot-rolled steel plates (strips) for high-rise building structures, large-span structures, and other important building structures.
	GB/T 5313 Steel plate with through-thickness characteristics	Through thickness property: Z15, Z25, Z35	Z-direction steels are used to prevent lamellar tearing, and their thicknesses are 15 to 400 mm.

Table 4.2 Standards of Commonly Used Structural Steel (continued)

No.	Standard	Steel Grades	Application Areas
5	**GB/T 11253** Cold-rolled sheets and strips of carbon structural steels	Q235	Cold-rolled sheets and strips of carbon structural steels with a thickness not more than 4mm and width not less than 600mm.
	GB/T 2518 Continuously hot-dip zinc and zinc alloy coated steel sheets and strips	S220GD, S250GD, S280GD, S300GD, S320GD, S350GD, S390GD, S420GD, S450GD, S550GD	Steel plates and strips delivered in the hot dip or hot dip and flatting (or smoothing) conditions.
6	**GB/T 11352** Carbon steel casting for general engineering purposes	ZG230-450, ZG270-500, ZG310-570	Cast carbon steel for general engineering purposes for non-welded structures.
	GB/T 7659 Steel casting suitable for welded structures	ZG230-450H, ZG270-480H, ZG300-500H, ZG340-550H	Steel castings with good weldability for general engineering purposes for welded structures.

The standards for various steel grades are on par with international standards. Chemical composition and mechanical properties of various grades of structural steel are given in Appendix C.

4.2.1 Carbon structural steel and high-quality carbon structural steel

Carbon structural steel with less than 0.24% Carbon is generally classified as low carbon steel. It is the most commonly used structural steel in China.

GB/T 700 *Carbon structural steel* covers hot rolled steel sheets, strips, sections and rods in construction, and they are provided with i) hot rolling condition, ii) controlled rolling conditions, or iii) normalized condition.

High-quality carbon structural steel has low sulphur and phosphorus contents [w(S,P) <0.035%]. Its quality and performance of steel are better than those of ordinary carbon steel to meet different processing requirements. As their prices are relatively high, only specific grades are used for steel construction.

GB/T 699 *Quality carbon structural steel* covers hot rolled and forged high-quality carbon structural steel bars with nominal diameters or thicknesses not more than 250 mm. A total of 4 grades (15, 20, 15Mn, 20Mn) of structural steel are available for construction, and they are used to produce pre-stressing wires, strands, anchors, bolts and cast steel.

4.2.2 High strength low alloy structural steel in quenched and tempered condition

Low-alloy structural steel is a carbon steel containing more than 1% but less than 5% of total alloying elements. Their yield strengths are 275 N/mm^2 or more, and all of them have good weldability, corrosion resistance, wear resistance and formability.

GB/T 1591 *High-strength low-alloy structural steel* is one of the most commonly used standards in steel construction. It covers high-strength low-alloy structural steel plates, strips, sections, bars, etc. for general structural and engineering purposes. Products are delivered in: i) hot rolling condition, ii) normalized rolling condition, and iii) thermomechanical rolling (TMCP) condition.

4.2.3 Atmospheric corrosion resisting structural steel

Ordinary carbon steel under unprotected conditions is affected by atmospheric dry and wet cycling, which can lead to occurrence and development of corrosion. During the steel smelting process, small amounts of specific alloying elements (Cu, P, Cr, Ni, etc.) may be added to form a dense protective layer on the steel surface to improve their atmospheric corrosion resistance. These steel are collectively referred as atmospheric corrosion resistant steel or weathering steel.

Weathering steel have moderate strengths, and good performance in ductility, toughness and welding. They are suitable for steel structures in exposed or moderately aggressive conditions.

GB/T 4171 *Atmospheric corrosion resisting structural steel*, GB/T 4172 *Atmospheric corrosion resisting steel for welded structures* and GB/T 18982 *Corrosion resistant steel plates and strips for container*.

GB/T 4171 covers hot-rolled and cold-rolled steel plates, strips and sections with good atmospheric corrosion resistance for bridges, buildings, towers and other large structures. Hot rolled steel are generally delivered in hot-rolled, controlled-rolled or normalized conditions. Q460NH, Q500NH, and Q550NH can be quenched and tempered. Q295GNH and Q355GNH are cold-rolled steel, and they are usually delivered in an annealed condition.

4.2.4 Steel plates for building structures

Special requirements for steel plates in high-rise buildings are low yield ratios, good toughness and ductility, small variations in yield strengths, small thickness effects, high resistance to laminar tearing (through-thickness characteristics), good weldability (i.e. large heat input energy can be employed during welding without a need of pre-heating and subsequent heat treatment), and good fire resistance.

GB/T 19879 *Steel plates for building structures* covers hot-rolled steel plates (or strips) for high-rise buildings, large-span structures and other large-scale structures. Their delivery conditions include hot rolling, normalizing, normalizing and tempering, thermal mechanical control processing (TMCP), and with various combinations of quenching and tempering.

4.2.5 Steel plates and strips

GB/T 11253 *Cold-rolled sheets and strips of carbon structural steel* covers cold-rolled sheets and strips of carbon structural steel with a thickness not more than 4 mm and a width not less than 600 mm.

GB/T 2518 *Continuously hot-dip zinc and zinc alloy coated steel sheets and strip*s covers steel plates and strips of thicknesses ranging from 0.20 to 6 mm, and they are delivered in hot-dip or hot-dip and flatting conditions.

4.2.6 Cast steel

Steel castings have good processing properties, and complex shapes are readily fabricated while maintaining specific properties of the steel. At present, cast steel is often used in fabricating complex joints connecting spatial tubular members. Hence, they are commonly used in the construction of large-scale roof structures of railway stations, airports, stadia etc.

It should be noted that steel castings are advantageous in reducing cutting processes and metal consumption. They also possess higher strengths at elevated temperatures and creep resistances, when compared to those of the rolled (or forged) steel of the same grades. However, due to the presence of internal defects, cast steel cannot be improved by either forging or cold working, and their mechanical properties (mainly ductility and toughness) are somehow marginally inferior.

Cast steel are commonly classified into medium and high carbon steel according to the mass fraction of carbon. In general, as the mass fraction of carbon increases, their strength increase while their toughness and weldability decrease. Low-carbon steel is suitable for those components which require good toughness and welding performances, and hence, they are always employed in construction. It should be noted that steel castings are normally heat treated, i.e. normalized and tempered or annealed, to refine their grains and to reduce residual stresses. The following two documents are commonly referred to:

GB/T 11352 *Carbon steel casting for general engineering purposes* covers forged carbon steel for general structures.

GB/T 7659 *Steel casting suitable for welded structures* covers steel castings with good weldability for general structures.

4.3 Types, Sections and Specifications of Steel Products

4.3.1 Steel plates and strips

Steel plates and strips refer to those steel products which are flat and long, and they are directly rolled into shapes. Steel strips are thin products, and they are typically made into coils for easy transportation. Both steel plates and strips are illustrated in Figure 4.2.

Figure 4.2 Steel plates (left) and steel strips (right)

In GB/T 15574 *Steel products classification*, steel plates and strips are divided into:

- Hot rolled sheets and plates (flat plates),
- Hot rolled steel strips (rolled plates),
- Cold rolled sheets and plates (flat plates),
- Cold rolled steel strips and sheets,
- Coated steel strips (mostly coiled).

Steel plates are classified according to their thicknesses (t): thin plates ($t \leq 3$ mm), medium thick plates ($3 < t \leq 20$ mm), thick plates ($20 < t \leq 60$ mm), extra thick plates ($t > 60$ mm). In practice, medium thick plates and extra thick plates are collectively referred to as medium thick and thick plates.

Steel strips are classified according to their widths (b): narrow strips ($b < 600$ mm) and wide strips ($b \geq 600$mm).

Coated steel strips are classified according to their coatings: single-sided coated strips, double-sided coated strips, metal coated strips and colour coated strips.

Refer to Appendix D for designations of various steel products.

(1) Hot rolled steel plates and strips

GB/T 709 *Dimensions, shapes, weights and tolerances of hot-rolled steel plates and sheets* covers single-rolled steel sheets, single-rolled wide steel strips, slit steel strips, and continuous-rolled steel sheets with a rolling width of not less than 600 mm. Details of these steel plates and strips are summarized in Table 4.3.

Table 4.3 Nominal ranges for hot rolled steel plates and strips

Type	Nominal thickness	Nominal width	Nominal length
Plates or Sheets	Single-rolled: 3 mm ~ 450 mm Continuous-rolled: ≤ 25.4 mm	Single-rolled: 600 mm ~ 5,300 mm Continuous-rolled: 600 mm ~ 2,200 mm	2 m ~ 25 m
Strips	≤ 25.4 mm	Wide: 600 mm ~ 2,200 mm Slit: 120 mm ~ 900 mm	In coil

GB/T 3274 *Hot-rolled steel plates, sheets and strips of carbon structural steel and high strength low alloy structural steel* covers hot-rolled steel plates and strips of carbon structural steel and low alloy structural steel with a thickness of not more than 400 mm. Their dimensions follow GB/T 709 and their grades, chemical composition and mechanical properties follow GB/T 700 and GB/T 1591.

(2) Cold rolled steel plates and strips

GB/T 708 *Dimensions, shapes, weights and tolerances for cold-rolled steel plates and sheets* covers cold-rolled wide steel strips, slit steel strips and sheared steel plates with a width of not less than 600 mm. Details of these plates and strips are summarized in Table 4.4.

Table 4.4 Nominal ranges for cold rolled steel plates and strips

Type	Nominal thickness	Nominal width	Nominal length
Plates and strips	0.30 mm ~ 4.00 mm	600 mm ~ 2,050 mm	1 m ~ 6 m

GB/T 11253 *Cold-rolled sheets and strips for carbon structural steel* covers the grades, chemical composition and mechanical properties of cold-rolled steel sheets and strips. Their dimensions follow GB/T 708 and GB/T 1591.

(3) Coated steel plates

Metal coatings are commonly provided in steel plates for corrosion protection, such as galvanizing, aluminizing, and aluminium-zinc coatings. Among them, galvanized steel sheets are the most widely used in construction. It should be noted that colour-coated steel sheets are also available. Details of these coated steel plates are summarized in Table 4.5.

Table 4.5 Classification and standards of coated steel plates

Standard	Scope of application	Structural steel grade
GB/T 2518 Continuously hot-dip zinc and zinc alloy coated steel sheet and strip [a]	Steel plates and steel strips with a thickness of 0.20mm to 6.0mm are mainly used for production of inner and outer covering parts and structural parts that require moulding and corrosion resistance in industries such as automobiles, construction, home appliances etc..	S220GD+Z(ZF, ZA, AZ) S250GD+Z(ZF, ZA, AZ) S280GD+Z(ZF, ZA, AZ) S300GD+Z(ZF, ZA, AZ) S320GD+Z(ZF, ZA, AZ) S350GD+Z(ZF, ZA, AZ) S390GD+Z(ZF, ZA, AZ) S420GD+Z(ZF, ZA, AZ) S450GD+Z(ZF, ZA, AZ) S550GD+Z(ZF, ZA, AZ)
GB/T 12754 Prepainted steel sheet[b]	Color-coated steel sheets and strips with a thickness of 0.20 mm to 2.0 mm are mainly used for interior and exterior use of buildings, and for home appliances etc..	Typical desingation: TS300GD+AZ (base plates should follow the corresponding standards of coated steel sheets and strips)
[a]. The meaning of the steel grade code is: S - structural steel, 3 digits - minimum yield strength (N/mm^2), G - no specified steel properties, D - hot-dip, Z - pure zinc coating, ZF - iron-zinc alloy coating, AZ - aluminum-zinc alloy coating. [b]. The meaning of the steel grade code is: T - color coating, S - structural steel, 3 digits - minimum yield strength (N/mm^2), G - heat treatment, D - hot-dip, Z - hot-dip galvanized substrate, ZF - hot-dip iron-zinc alloy substrate, AZ - hot-dip aluminum-zinc alloy substrate, ZA - hot-dip zinc-aluminum alloy substrate.		

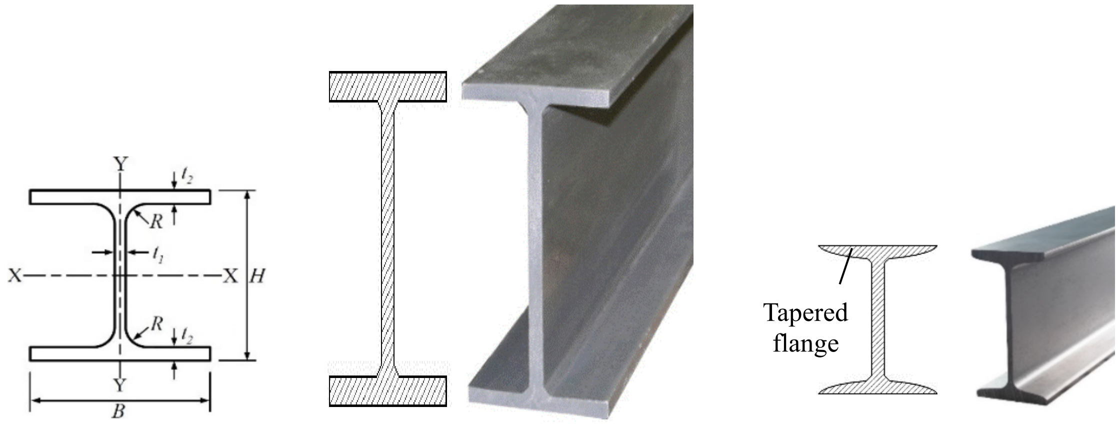
(4) Cold-formed steel plates

GB/T 33162 *Continuously hot-rolled steel sheet and strip for cold-forming steel sections* covers hot-rolled steel plates and strips for cold-formed steel with a thickness of not more than 25.4 mm. The steel grades have the suffix "-LW" (LW means "cold-formed") for the corresponding grades in GB/T 699, GB/T 700, GB/T 1591, and GB/T 4171, i.e. 20-LW, Q235-LW, Q345-LW, Q390-LW, Q420-LW, Q460-LW, Q500-LW, Q550-LW, Q620-LW, Q690-LW, Q355NH-LW, Q420NH-LW, Q460NH-LW, Q500NH-LW, and Q550NH-LW. Dimensions, shapes, weights and tolerances of steel plates and strips follow GB/T 709, and their grades, chemical composition and mechanical properties follow GB/T 33162.

4.3.2 Steel sections

Steel sections are important structural steel products widely used in construction, and the most widely used sections are H-sections, joists, T-sections, channels and angles. These H-sections are primary structural members commonly used in buildings and bridges. It should be noted that H-sections are generally classified into three groups according to their ratios of section height H to flange width B as follows:

- sections with flanges having large widths, i.e. H / B ≈ 1
  These sections are commonly used as columns to resist large axial loads.
- sections with flanges having medium to small widths, i.e. H / B ≈1.5 to 2.0
  These sections are commonly used as beams to resist large bending moments, or beam-columns to resist combined actions of axial loads and bending moments.



H/B ≈ 1

H/B ≈ 1.5 to 2.0

(In China, large I-sections are commonly classified as H-sections)

a) H-section

b) Joist or small I-section

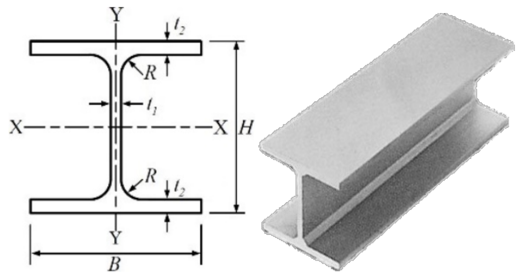
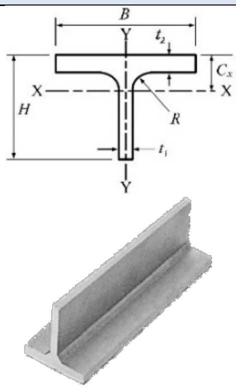
Figure 4.3 Common steel sections

(1) Hot rolled H-sections and split T-sections

Hot rolled H-sections are manufactured with the use of two horizontal and two vertical rollers in a rolling mill. The axes of these four rollers should be located within the same plane so that the rolling performs on four sides of the sections at the same time. By adjusting the distances between pairs of the rollers, the thicknesses of both the flanges and the webs are readily increased or decreased.

GB/T 11263 *Hot-rolled H and Split T Sections* specifies various requirements on dimensions, weights and permissible variations of both hot rolled H-sections and split T-sections. The grades, the chemical composition and the mechanical properties of the steel shall follow GB/T 700, GB/T 712, GB/T 714, GB/T 1591, GB/T 4171 and GB/T 19879. These H-sections are delivered in the hot rolled condition while split T-sections are cut from these hot-rolled H-sections.

Table 4.6 Cross-section designations of hot-rolled H-sections and split T-sections

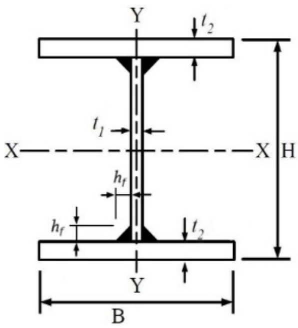
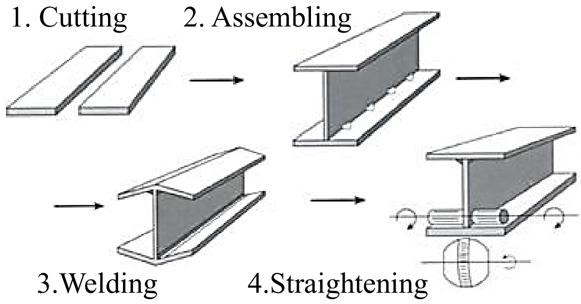
Type	Hot-rolled H-section	Hot-rolled split T-section
Section view		
Annotation	*H* - height; *B* - width; t_1 - web thickness; t_2 - flange thickness; *R* - fillet radius; *C*x - the center of gravity	
Designation	**HW** ***H*** × ***B*** × $\boldsymbol{t_1}$ × $\boldsymbol{t_2}$ Section size (mm): height, width, web thickness, flange thickness. Hot rolled steel code: H=hot rolled H-section, T=split T-steel; W=wide flange (Wide), M=middle flange (Middle), N=narrow	
Size range (mm)	H = 100 ~ 900, B = 75 ~ 400, t_1 = 5 ~ 21, t_2 = 7 ~ 28.	H = 50 ~ 450, B = 75 ~ 400, t_1 = 5 ~ 21, t_2 = 7 ~ 28.

(2) Welded H-sections

Welded H-sections with plates of various thicknesses are readily manufactured at relatively small volumes. For large H-sections with thick plates, or non-standard H-sections with different flange widths and thicknesses, welded H-sections often offer economical solutions.

GB/T 33814 *Welded H-sections* and YB 3301 *Welded H-sections* (which is an industry standard in metallurgy) are applicable to selection, production (including welding materials standards and welding processes), and acceptance of welded H-sections. The steel shall follow GB/T 699, GB/T 700, GB/T 712, GB/T 714, GB/T 1591, GB/T 3274, GB/T 4171, and GB/T 1987.

Table 4.7 Cross-section designation of welded H-sections

Type	Welded H-section steel
Section view and production process	 
Annotation	*H* - height, *B* - width, t_1 - web thickness, t_2 - flange thickness, *R* - fillet radius, h_f - weld leg size
Designation	**WH** ***H*** × ***B*** × t_1 × t_2 Section size (mm): height, width, web thickness, flange thickness. Welded H-section code: "W" = welded and "H" = H-section.
Size range (mm)	H = 100 ~ 2000, B = 50 ~ 850, t_1 = 3.2 ~ 20, t_2 = 4.5 ~ 55.

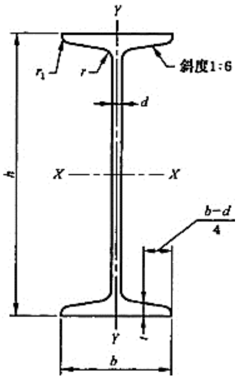
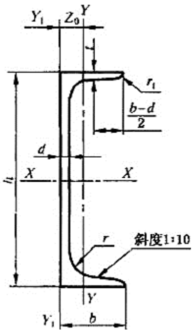
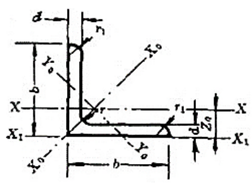
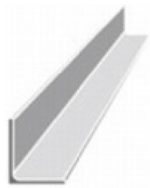
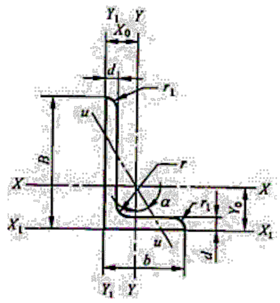
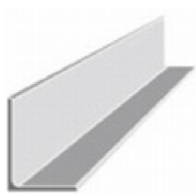
JG/T 137 *High-frequency welded light gauge H-sections for construction* (which is an industry standard in construction) covers medium-sized H-sections which are manufactured with continuous high frequency welding. Such welding is usually performed in continuous production lines, and hence, quality and precision is readily guaranteed. Typical section heights range from 100 mm to 500 mm while typical section widths range from 50 mm to 250 mm. These medium-sized H-sections are commonly used in low to medium rise industrial buildings and structural steelwork with modest lengths and spans. The steel should follow GB/T 700 and GB/T 1591.

(3) Joists, channel and angles

GB/T 706 *Hot-rolled steel sections* covers hot-rolled joists (or small-sized I-sections), channels and angles. The grades, the chemical composition and the mechanical properties of the steel shall follow GB/T 700 and GB/T 1591.

These joists, channels and angles are commonly used as secondary structural members in low to medium-rise buildings and roofs of modest spans. For both joists and channels, the flanges are tapered because of simple rolling, and hence, the flange thicknesses are decreased moderately towards the flange tips. For both equal and unequal angles, the plate thicknesses of both legs are the same.

Table 4.8 Cross-section designations of joists, channels and angles

Type	Joist	Channel	Equal angle	Unequal angle
Section view	 	 	 	 
Annotation	h - height, b - flange width, d - web thickness, t –thickness of flange at mid-width, r - fillet radius, r_1 - flange end radius, Z_0 - center of gravity distance.		B - long side width, b - short side width, d - side thickness, r - fillet radius, r_1 - flange end radius, X_0, Y_0, Z_0 - center of gravity distance.	
Designation	**I** **h × b × d** Section size (mm): Height (long side width), flange width (short side width), web thickness (side thickness). “ I ” = Joist or I-section, “ [” = Channel, “∠”= Angle steel Note: I 450×150×11.5 is abbreviated as I 45a, [200×75×9 is abbreviated as [20b, ∠200×200×24 is abbreviated as ∠200×24.			
Size range (mm)	h = 100 ~ 630, b = 68 ~ 180, d = 4.5 ~ 17.	h = 50 ~ 400, b = 37 ~ 104, d = 4.5 ~ 14.5.	b = 20 ~ 250, d = 3 ~ 35.	B = 25 ~ 200, b = 16 ~ 125, d = 3 ~ 18.

4.3.3 Cold-formed steel

Cold-formed steel sections, also known as light gauge steel sections, are readily manufactured into a variety of complex cross-sectional shapes. They are made of steel strips or sheets cut to fixed widths, and then, bent with various tools at room temperature. Cold-formed steel sections are highly efficient structural sections, and they are widely used in secondary structural members in buildings, roof structures and building envelopes.

GB/T 6725 *General requirements of cold-formed steel sections* covers various technical requirements for cold-formed sections, including grades, chemical composition, mechanical properties, surface quality, etc.. It is applicable to cold-formed steel sections made of cold-rolled steel sheets and strips as well as hot-rolled or coated steel sheets and strips produced by cold rolling. Both the steel grades and their chemical composition specified in GB/T 6725 shall follow GB/T 699, GB/T 700, GB/T 714, GB/T 1591, GB/T 2518, GB/T 3280, GB/T 3524, GB/T 4171, GB/T 12754, and GB/T 33162 while their mechanical properties shall meet the requirements of GB/T 6725.

GB/T 6723 *Cold-formed open steel sections for general structures* covers nine types of open steel sections. The grades, the chemical composition, the mechanical properties and the surface quality etc. of these steel sections shall meet the requirements of GB/T 6725. Internal bents, ribs and lipped edges are readily provided in these steel sections to improve their structural efficiency.

Table 4.9 Cross-section designations of cold-formed open sections

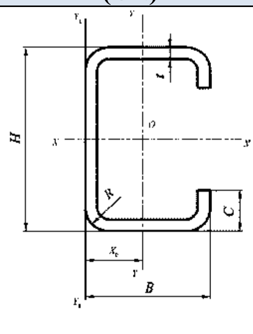
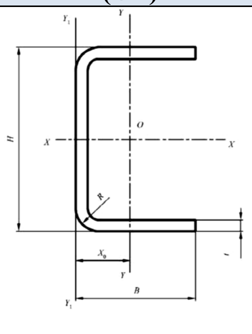
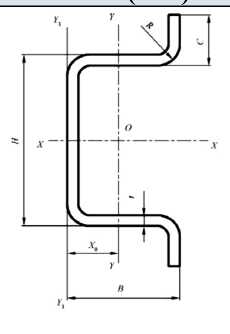
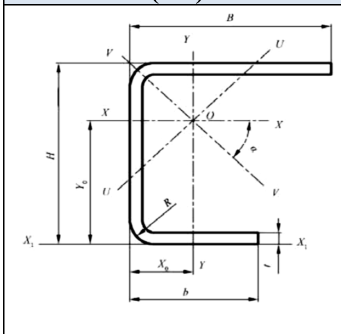
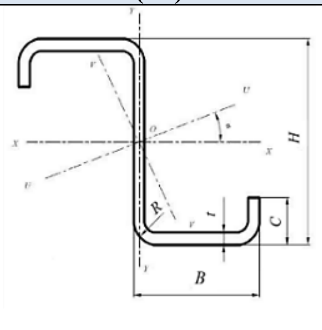
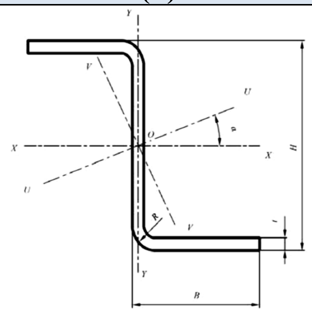
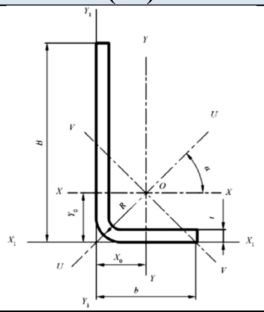
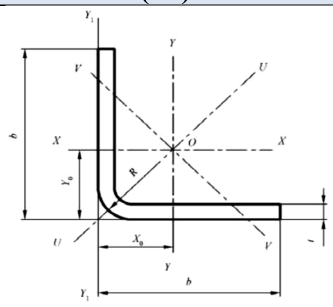
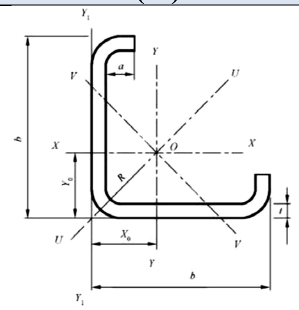
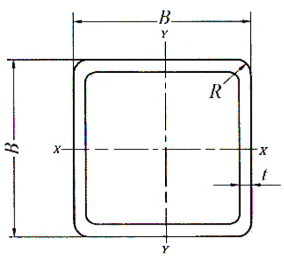
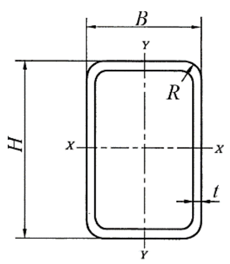
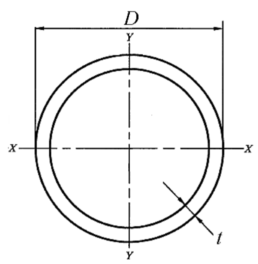
Type (Code)	**Lipped C-section (CN)**	**C-section (CD)**	**Externally lipped C-section (CW)**
Section view			
	Unequal C-section (CB)	**Lipped Z-section (ZJ)**	**Z-section (Z)**
			

Table 4.9 Cross-section designations of cold-formed open sections (continued)

Type (Code)	Unequal angle (JB)	Euqal angle (JD)	Lipped equal angle (JJ)
Section view			
Annotation	*H* – section height, *B* – section width, *C* - lipped edge, *t* - thickness; *R* - conner radius		
Designation	**CN** ***H*** × ***B*** × ***C*** × ***t*** Section size (mm): height, width, lipped edge, thickness. Section type (code)		
Size range (mm)	Cold-formed lipped C-sections (CN): *H* = 60 ~ 600, *B* = 30 ~ 250, *C* = 10 ~ 60, *t* = 2.5 ~ 16. Cold-formed lipped Z-sections (ZJ): *H* = 100 ~ 400, *B* = 40 ~ 120, *C* = 20 ~ 40, *t* = 2.0 ~ 10.		

GB/T 6728 *Cold-formed hollow steel sections for general structures* covers three types of tubes, namely square, rectangular and circular tubes . The grades, the chemical composition, the mechanical properties, the surface quality and the welding quality etc. of these sections shall meet the requirements of GB/T 6725. These tubes vary significantly in sizes, and a wide range of section sizes are available for applications in construction.

Table 4.10 Cross-section designations of cold-formed tubes

Type (Code)	Square tube (F)	Rectangular tube (J)	Circular tube (Y or ϕ)
Section view			
Annotation	*B* – section height, *t* - wall thickness, *R* - outer corner radius.	*H* – section height, *B* – section width, *t* - wall thickness, *R* - outer corner radius.	*D* – outer diameter, *t* - wall thickness.
Specification	***F*** × ***H*** × ***B*** × ***t*** Section size (mm): section height, section width or outer diameter, wall thickness. Section type (code)		
Size range (mm)	*B* = 20 ~ 500, *t* = 1.2 ~ 16.	*H* = 30 ~ 600, *B* = 20 ~ 400, *t* = 1.5 ~ 16.	*D* = 21.3 ~ 610, *t* = 1.2 ~ 16.

JG/T 178 *Cold-formed steel hollow sections for building structures* covers cold-formed (welded) square and rectangular tubes in construction. The main differences between JG/T 178 and GB/T 6728 are manufacturing methods, carbon equivalence, mechanical properties, and non-destructive testing of welds. In addition, for the same delivery conditions and the same section shapes, JG/T 178 covers larger thicknesses, and hence, thicker steel products, when compared with GB/T 6728.

Two different grades of steel tubes are present in JG/T 178 according to product performance and quality specifications as follows:

- Class I: High grade

  Class I steel tubes are steel products of guaranteed carbon equivalence with specific chemical composition and mechanical properties. Low temperature impact properties, fatigue properties and non-destructive tests for welding of the products can all be used under the terms of standard agreements. They are suitable for applications as primary structural members in buildings as well as bridges and structures under large cyclic loads.

- Class II: Ordinary grade

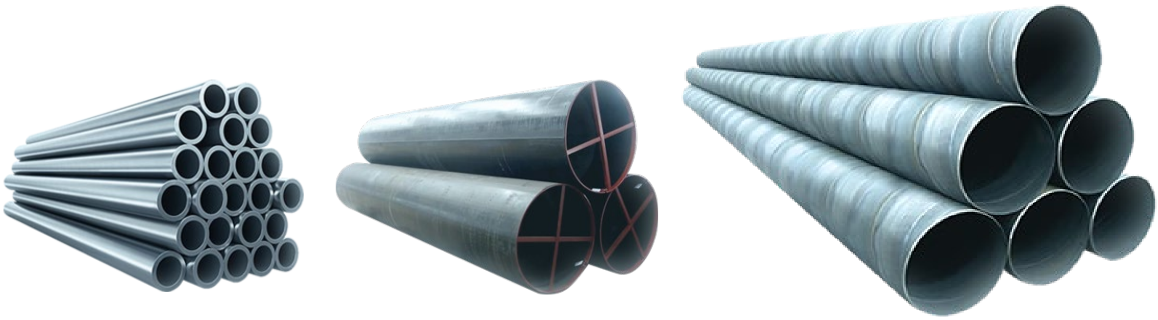
  Class II steel tubes are steel products with same chemical composition and mechanical properties of the parent steel. They are suitable for applications as primary structural members in buildings and structures under no or small cyclic loads.

4.3.4 Steel tubes

There are two groups of steel tubes, and they are classified according to their manufacturing methods:

- Hot rolled (seamless) steel tubes
  Hot rolled (seamless) steel tubes are manufactured by piercing and rolling onto steel bars or billets at elevated temperatures.
- Cold-formed (welded) steel tubes
  Cold-formed (welded) steel tubes are manufactured by cold-forming steel plates, and then, welding at room temperature. It should be noted that these cold-formed steel tubes are further classified into i) longitudinally welded tubes, and ii) spirally welded tubes according to their welding patterns.

Due to a low production cost and a capability to produce tubes with a wide range of diameters, the cold-formed (welded) steel tubes are widely adopted to replace the hot rolled (seamless) steel tubes in many structural applications.



i) Hot-rolled (seamless) tubes ii) Cold-formed (welded) tubes with longitudinal welding iii) Cold-formed (welded) tubes with spiral welding

Figure 4.4 Hot rolled (seamless) and cold-formed (welded) steel tubes

Unified series of dimensions, i.e. the outer diameter D and the wall thickness t, have been adopted in both GB/T 17395 *Dimensions, shapes, masses and tolerance of seamless steel tubes*, and GB/T 21835 *Dimensions and masses per unit length of welded steel tubes*. These series of standard dimensions of steel tubes are provided as follows

- The outer diameter D and the wall thickness t are divided into three categories:
  i) a series of standardized $D \times t$ of ordinary steel tubes,
  ii) a series of standardized $D \times t$ of precision steel tubes, and
  iii) a series of standardized $D \times t$ of stainless steel tubes.
- The outer diameter D of the steel tubes is divided into three series:
  i) Series 1 consists of a standard (recommended) series of tubes,
  ii) Series 2 consists of a non-standard series of tubes, and
  iii) Series 3 consists of special series of tubes.

- The wall thickness *t* of the ordinary cold-formed (welded) steel tubes is divided into two series:
  i) Series 1 consists of a standard range of thicknesses, and
  ii) Series 2 consists of a non-standard range of thicknesses.

(1) Hot rolled (seamless) steel tubes

GB/T 8162 *Structural seamless steel tubes for construction* covers hot rolled (seamless) steel tubes for machinery and general engineering structures. The outer diameters D and the wall thicknesses *t* (or S) of these steel tubes follow GB/T 17395.

Table 4.11 Steel grades, chemical composition, mechanical properties and nominal ranges of hot rolled (seamless) steel tubes

Type	Hot rolled (expanded) steel tubes and cold drawn (rolled) steel tubes.
Steel grades and chemical composition	High quality carbon structural steel shall follow GB/T 699; High strength low alloy structural steel shall follow GB/T 8162; Alloy structural steel shall follow GB/T 3077.
Mechanical properties	Tensile and impact properties of specific delivery conditions of high quality carbon structural steel, high strength low alloy structural steel and steel tubes shall follow GB/T 8162; Longitudinal tensile properties of alloy structural steel tubes after heat treatment shall follow GB/T 8162; Mechanical properties of steel tubes delivered in cold drawn (rolled) condition shall be negotiated between the supplier and the buyer.
Nominal sizes	Typical length L = 3 m ~12 m. The outer diameter D and the wall thickness *t* (or S) shall follow GB/T 17395: D = 34 mm ~ 1,016 mm, S = 2.0 mm ~ 120 mm.

Note: GB/T 3077 covers “Alloy structural steel”.

(2) Cold-formed (welded) tubes

GB/T 13793 *Steel tubes with longitudinal electric (resistance) welding* covers steel tubes in machinery and construction, and the out diameter D of these steel tubes is not larger than 711 mm. The outer diameter D and the wall thickness *t* of all steel tubes follow GB/T 21835.

Table 4.12 Steel grades, chemical composition, mechanical properties and nominal sizes of cold-formed (welded) steel tubes: longitudinal welding

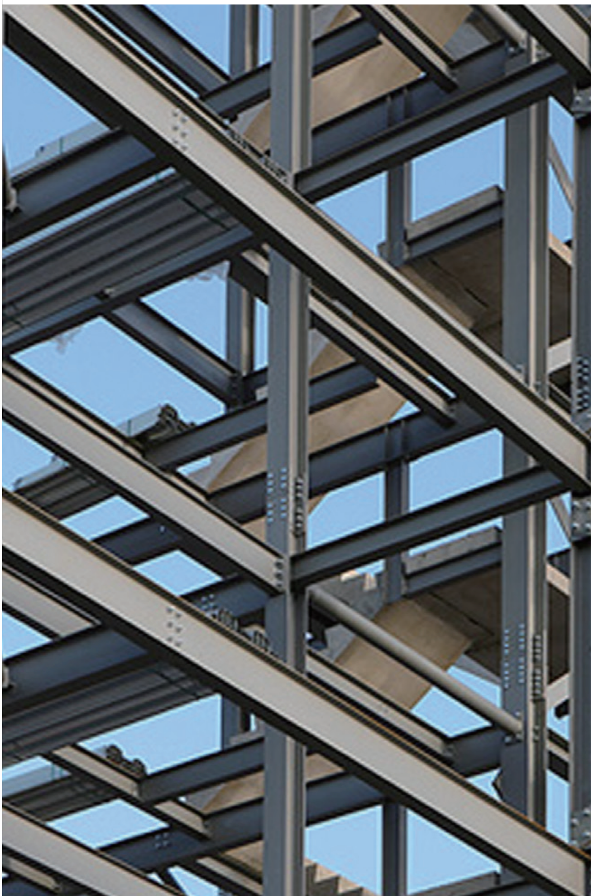
Type	Accuracy of *D*: normal accuracy (PD.A); precision (PD.B); high precision (PD.C). Accuracy of *t*: normal accuracy (PT.A); precision (PT.B); high precision (PT.C). Accuracy of bending: normal accuracy (PS.A): precision (PS.B); high precision (PS.C).
Steel grades and chemical composition	All steel shall follow: i) Grades 08, 10, 15, 20 in GB/T 699, or ii) Q195, Q215A (B), Q235A (B, C), Q275A (B, C) in GB/T 700, or iii) Q355B(C), Q390B(C), Q420B(C), Q460C(D) in GB/T 1591.
Mechanical properties	Tensile properties of steel tubes and welded joints shall follow Table 6 of GB/T 13793. The impact resistances of the steel tubes should be negotiated between the supplier and the buyer.
Nominal sizes	Typical length L = 4 m ~ 12 m. Outer diameter D = 10.2 mm ~ 1440 mm; Wall thickness t = 0.50 mm ~ 65 mm.

YB/T 4112 *Welded steel tubes with atmospheric corrosion resistance for structural purposes* covers cold-formed (welded) steel tubes with longitudinal welding. As these steel are weather steel, these tubes are readily employed in exposed structures and buildings. The outer diameter D and the wall thickness t of these steel tubes follow GB/T 21835. Typical lengths of these steel tubes range from 3 m to 12.5 m. The steel grades and their chemical composition shall follow Q265GNH, Q295GNH, Q310GNH, Q355GNH, Q235NH, Q295NH, Q355NH, Q415NH and Q460NH in GB/T 4171. The tensile and impact properties of these steel tubes shall follow the requirements of YB/T 4112.

YB/T 381 *Cold-formed welded circular tubes for building structures* covers cold-formed (welded) circular steel tubes with longitudinal welding, and they are commonly employed in general structural steelwork and industrial buildings. The steel grades include Q235 steel in GB/T 700, or Q235, Q390, Q420 steel in GB/T 1591, or Q235GJ, Q345GJ, Q390GJ and Q420GJ steel in GB/T 19879. For thick steel plates, it is also required to specify through-thickness characteristics according to GB 5313.

Section 5

Mechanical Properties and Key Data



5 Mechanical Properties and Key Data

Many materials specifications in China have been developed in line with the international community of the iron and steel industry, and hence, they follow closely with the international practice. These include various definitions of mechanical properties and weldability, as well as relevant testing methods and procedures. Key data of these mechanical properties in various national structural steel design codes are also described.

5.1 Mechanical properties

Key mechanical properties of the steel include strength and ductility, impact toughness, and fatigue resistances, and they are described in the following sections.

5.1.1 Strength and ductility

Strength is an ability of the steel to resist large plastic deformation and fracture under applied loads. The strength of the steel is usually expressed as a force applied per unit cross-sectional area. Ductility is an ability of the steel to exhibit large deformations before fracture. Standard tensile tests are carried out according to specific procedures on steel coupons which are machined to standardized dimensions. Key test standards in China on strength and ductility are:

- GB/T 2975 *Steel and steel products - Location and preparation of samples and test pieces for mechanical testing*
- GB/T 228.1 *Metallic materials - Tensile testing - Part 1: Methods of test at room temperature*
- GB/T 228.2 *Metallic materials - Tensile testing - Part 2: Method of test at elevated temperature*

It should be noted that:

a) When the coupon exhibits a yielding phenomenon, the corresponding stress is the yield strength of the steel R_e . For some steel, small variations in the measured stresses during yielding are measured, and hence, the upper yield strength R_{eH} and the lower yield strength R_{eL} should be distinguished as follows:

   — The upper yield strength is the maximum stress attained before the first drop in force, i.e. $R_{\mathrm{eH}} = F_{\mathrm{sU}}/S_0$ while the lower yield strength is the minimum stress attained during the yielding process, i.e. $R_{\mathrm{eL}} = F_{\mathrm{sL}}/S_0$.

   F_{sU} and F_{sL} are the upper and the lower yield forces (kN) applied to the coupon during the yielding process, and S_0 is the original cross-sectional area (mm^2) of the coupon within its parallel gauge length.

   — The upper yield strength R_{eH} is usually adopted as the yield strength of the steel R_e .

- For those steel with no obvious yield point such as quenched and tempered steel and high strength steel, the stress corresponding to a proof strain ε_p at 0.2%, i.e. $R_{p0.2}$, should be adopted.

b) The tensile strength R_m is the maximum stress attained in the test at the occurrence of necking, i.e. $R_m = F_m/S_0$ where F_m is the maximum force (kN) applied to the coupon throughout the entire test.

c) The strength ratio R_e/R_m is a measure of ductility of the steel. The higher the tensile strength, the lower is the ratio, and this corresponds to a larger reserve in resistance.

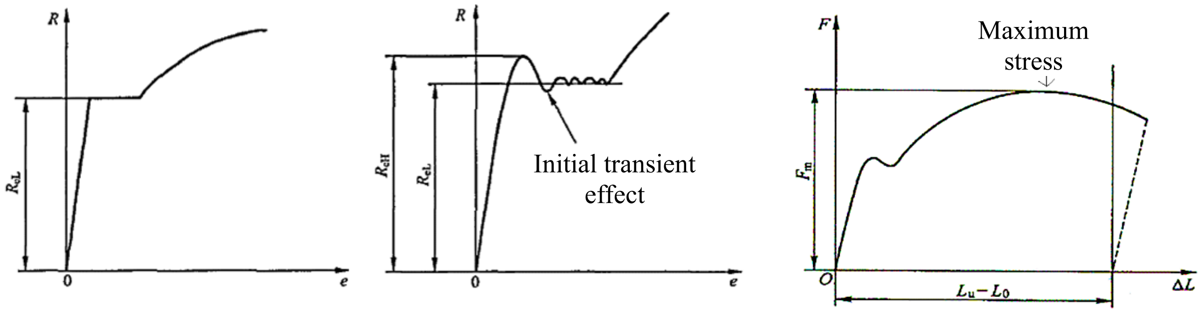


Figure 5.1 Typical stress-strain curves

d) The elongation limit A (%) of the coupon after fracture refers to the ratio of the elongation $(L_u - L_0)$ of the gauge length L_u after fracture to the original gauge length L_0, i.e. $A = (L_u - L_0)/L_0 \times 100\%$。

e) For steel plates with a thickness larger than or equal to 50 mm, it may be necessary to examine their through thickness characteristic to assess susceptibility of these plates against laminar tearing. The through thickness characteristic is expressed as a reduction in the cross-sectional area, Z (%), of a specially designed coupon of these plates in a tensile test, i.e. $Z = (S_0 - S_u)/S_0 \times 100\%$ where S_u is the cross-sectional area of the neck after fracture, and S_0 is the original cross-sectional area at the break location.

To guarantee a good through thickness characteristic, the content of sulphur (S) should be strictly controlled to reduce sulphide defects and inclusions.

5.1.2 Impact toughness

Impact toughness of the steel refers to its ability to absorb mechanical work or energy when it fractures under dynamic loads, i.e. its susceptibility against brittle fracture under impact. The key test standard is GB/T 229 *Metallic materials - Charpy pendulum impact test method*. Factors affecting the impact toughness of the steel include the chemical composition, the heat treatments, the smelting method, the processing technology and the presence of any internal defect. It should be noted that:

a) The impact absorption energy K_U (J) (or K_V (J)) refers to the impact energy absorbed by a standard specimen, commonly referred as a Charpy specimen, with a U-shaped (or a V-shaped) notch in the impact test. The value of this energy should not be less than 27J.

The greater the work in breaking the specimen in the impact test, the higher is the impact toughness of the steel. With a good toughness of the steel, the risk of brittle failure is minimized or even eliminated.

b) As temperature falls, the critical temperature at which the steel is transformed from a ductile to a brittle material is called the transition temperature T_t(°C). The transition temperatures differ amongst various steel, and it should be determined through experiments. To avoid a low temperature brittle fracture of a steel structure, the ambient temperature must exceed the transition temperature of the steel. Therefore, important structures in cold areas, especially those subjected to dynamic loading, should ensure adequate impact toughness at both normal temperature (20 °C ± 5 °C) and sub-zero temperatures (-20 °C or -40 °C).

5.1.3 Fatigue resistance

Fatigue in the steel refers to a fracture phenomenon caused by a cumulative damage as the result of long-term fluctuating stresses and strains. Fatigue is a brittle failure, and it is very sensitive to the presence of any defects such as cracks, notches etc. The stresses at fatigue failure are always significantly lower than the yield strengths of the steel. If the fluctuating maximum stresses are sufficiently low, fatigue failure will never occur no matter how many loading cycles are applied. Key test standard is GB/T 3075 *Metallic materials - Fatigue testing - Axial-force-controlled method.*

It should be noted that:

a) Fatigue strength is the maximum repeated stress in the steel due to repeated cyclic loads which causes fracture of the steel, and this strength depends on the number of load cycles under consideration. The lower the maximum repeated stress, the larger the number of load cycles before fatigue will be.

b) The fatigue strength is also related to loading patterns, and presence of any stress concentration and defects in the steel.

c) In a fatigue test, cyclic actions are applied to the test specimen under specific ranges of maximum and minimum stresses. After completion of a large number of cyclic actions and there is no failure occurred in the specimen, then the maximum stress applied in the test is referred as the fatigue strength limit. It should be noted that the numbers of stress cycles commonly adopted in these fatigue tests are in the order of $2x10^6$ to 10×10^6 cycles while 2×10^6 is considered to be the minimum number for practical reasons.

5.2 Weldability

Weldability of the steel describes various performance of welded connections after welding. Steel of good weldability is easily welded by routine welding methods and processes while cracks, pores, slag inclusions, etc. are largely absent. In general, the mechanical performance of these welded connections and their adjacent heat-affected zones are expected to be not inferior to those of the base plates.

It should be noted that a carbon equivalence, $C_{\mathrm{eq}}(\%)$, or a weld crack sensitivity indicator, $P_{\mathrm{cm}}(\%)$, is evaluated according to the chemical composition of the steel to assess its susceptibility against quenched hardening, cold cracking and embrittlement. According to GB 50661 *Code for welding of steel structures*, C_{eq} is likely to be acceptable for those steel with a carbon content ≤ 0.18% while $P_{\mathrm{cm}}(\%)$ is likely to be acceptable for low-carbon micro-alloy element steel with a carbon content between 0.07% and 0.22%. For different types of steel, different formulae and criteria for the carbon equivalence or the weld crack sensitivity indicator should be adopted.

Related testing standards:

GB/T 2650 *Destructive tests on welds in metallic materials - Impact tests*

GB/T 2651 *Tensile test methods on weld and deposited metal*

GB/T 2652 *Destructive tests on welds in metallic materials - Longitudinal tensile test on weld metal in fusion welded joints*

GB/T 2653 *Bend test methods on welded joints*

GB/T 2654 *Hardness test methods on welded joints*

GB/T 226 *Test method for macrostructure and defect of steel by etching*

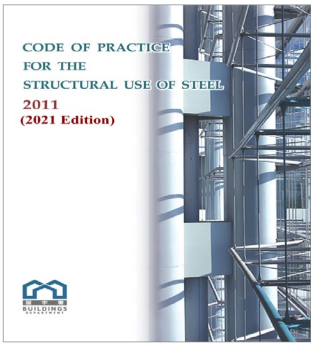
GB/T 11345 *Non-destructive testing of welds - Ultrasonic testing - Techniques, testing levels, and assessment*

GB/T 3323.1 *Non-destructive testing of welds - Radiographic testing - Part 1:X- and gamma-ray techniques with film*

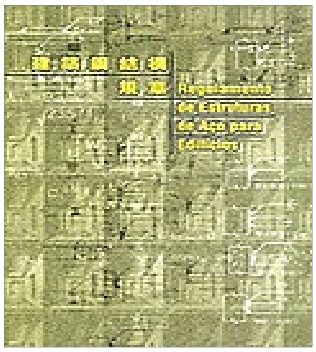
5.3 Key Design Data Mechanical Properties

In this section, key design data of mechanical properties in various national structural steel design codes are described.

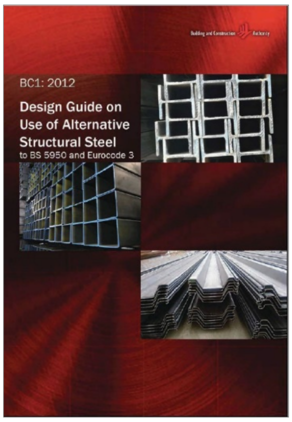
a) Mainland China - Code for Design of Steel Structures



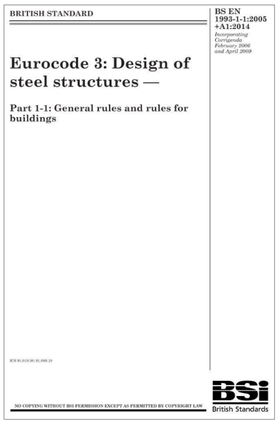
b) Hong Kong - Code of Practice for the Structural Use of Steel 2011



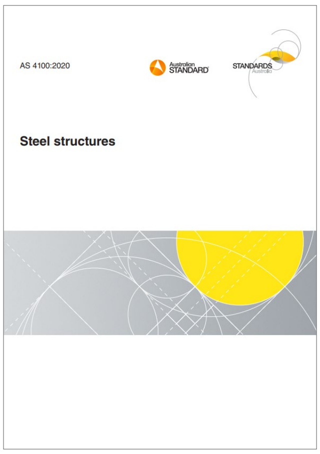
c) Macau - Code of Structural Steel for Buildings



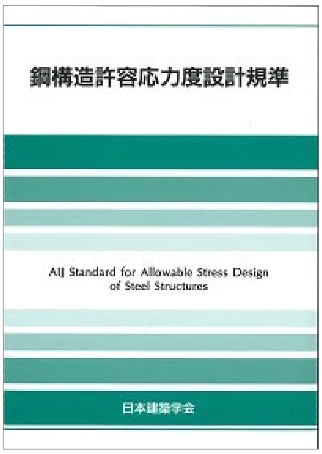
d) Singapore - Design Guide on Use of Alternative Structural Steel to BS 5950 and Eurocode 3



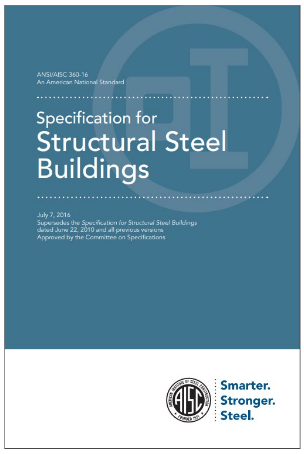
e) Europe - Eurocode 3: Design of steel structures - Part 1-1



f) Australia – Australian Standard–Steel Structures



g) Japan–Design Standard for Steel Structures - Based on Allowable Stress Concept - 2005 Edition



h) American–Specification for Structural Steel Buildings

Figure 5.2 Design codes for structural steel design

5.3.1 Mainland China - GB 50017-2017 *Code for Design of Steel Structures*

GB 50017 adopts a performance-based design approach, and it is implemented in 2017.

(1) Design strengths

Design strengths of steel are presented in Table 5.1 according to steel thickness or diameter of the steel products.

Table 5.1 Design strengths (N/mm²)

Steel			Tension, compression and bending strength	Shear strength	End bearing (plane and closely fitted)	Nominal yield strength	Minimum ultimate tensile strength
Grade		Thickness or diameter (mm)	f	f_v	f_{ce}	f_y	f_u
Carbon structural steel	Q235	≤16	215	125	320	235	370
		>16, ≤40	205	120		225	
		>40, ≤100	200	115		215	
High strength low-alloy sturctural steel	Q345	≤16	305	175	400	345	470
		>16, ≤40	295	170		335	
		>40, ≤63	290	165		325	
		>63, ≤80	280	160		315	
		>80, ≤100	270	155		305	
	Q390	≤16	345	200	415	390	490
		>16, ≤40	330	190		370	
		>40, ≤63	310	180		350	
		>63, ≤100	295	170		330	
	Q420	≤16	375	215	440	420	520
		>16, ≤40	355	205		400	
		>40, ≤63	320	185		380	
		>63,≤100	305	175		360	
	Q460	≤16	410	235	470	460	550
		>16, ≤40	390	225		440	
		>40, ≤63	355	205		420	
		>63, ≤100	340	195		400	
Steel plates for building structures	Q345GJ	>16, ≤50	325	190	415	345	490
		>50, ≤100	300	175		335	

Notes: 1. "Diameter" denotes steel bar of solid core while "Thickness" denotes the steel thickness or the steel tube wall thickness at the location of calculation. For members in axial tension and axial compression, it is the thickness of the thicker plate element of the section.

2. Grade Q345 steel and its requirements have been replaced by Grade Q355 steel in GB/T 1591-2018.

(2) Partial factors of resistance

Design strength is given by the yield strength of the steel divided by an appropriate partial factor of resistance γ_R, as shown in Table 5.2.

Table 5.2 Partial factors of resistance in GB 50017-2017

<table>
<tr><th>Material</th><th colspan="2">Stress type</th><th colspan="2">Design strength</th></tr>
<tr><td rowspan="7">Normal steel</td><td rowspan="4">Tension, compression and bending</td><td>Q235</td><td colspan="2">$f = f_y/\gamma_R = f_y/1.090$</td></tr>
<tr><td>Q345, Q390</td><td colspan="2">$f = f_y/\gamma_R = f_y/1.125$</td></tr>
<tr><td>Q420, Q460</td><td rowspan="2">$f = f_y/\gamma_R$</td><td>γ_R = 1.125 (t ≥ 6 ~ 40mm)
or 1.180 (t > 40 ~ 100mm)</td></tr>
<tr><td>Q345GJ</td><td>γ_R = 1.059 (t ≥ 6 ~ 16mm)
or 1.059 (t > 16 ~ 40mm)
or 1.095 (t > 40 ~ 60mm)
or 1.120 (t > 60 ~ 100mm)</td></tr>
<tr><td>Shear</td><td>All</td><td colspan="2">$f_v = f_y/\sqrt{3}$</td></tr>
<tr><td rowspan="2">End bearing (plane and closely fitted)</td><td>Q235</td><td colspan="2">$f_{ce} = f_u/1.15$</td></tr>
<tr><td>Q345, Q390, Q420
Q460, Q345GJ</td><td colspan="2">$f_{ce} = f_u/1.175$</td></tr>
</table>

Note: 1. f_y is the yield strength of the steel, and f_u is the minimum tensile strength of the steel.
2. The force majeure component coefficient refers to the coefficient that takes into account uncertainty of material performance and reliability of structural design when the structural design is carried out in accordance with the ultimate limit state method.
3. Grade Q345 steel and its requirements have been replaced by Grade Q355 steel in GB/T 1591.

(3) Grades and quality of steel

Commonly used steel are Q235, Q345, Q390m, Q420, Q460 and Q345GJ steel. Their quality shall follow the requirements of the current Chinese standards, including GB/T 700 *Carbon structural steel*, GB/T 1591 *High strength low-alloy structural steel* and GB/T 15879 *Steel plate for building structures*. With recent development in modern steel technology and advanced structural engineering, Q690 steel is attracting a keen interest from construction professionals, and hence, a rising trend of adopting Q690 steel in construction projects is anticipated.

5.3.2 Hong Kong – HKSC 2011 (2023) *Code of Practice for the Structural Use of Steel (2023 Edition)*

The Code of Practice for the Structural Use of Steel adopts a limit state approach.

(1) Design strengths

The design value of steel strength, p_y , of the steel is given by:

$$p_y = \frac{Y_S}{\gamma_{m1}} \leq \frac{U_S}{\gamma_{m2}}$$

where, Y_S is the yield strength, which is defined as the upper yield strength, R_{eH}, or the smaller of the 0.2% proof stress, $R_{p\,0.2}$, and the stress at 0.5% total elongation, $R_{t\,0.5}$;
U_S is the minimum tensile strength; and
γ_{m1}, γ_{m2} are material factors.

The Code of Practice allows steel manufactured to different standards to be used for hot rolled plates and sections, hot-rolled or finished and cold-formed steel tubes in Hong Kong.

Their design strengths are given Table 5.3.

Table 5.3 Design strength p_y (N/mm^2) in accordance with different standards

BS EN	Thickness (mm)					
Grade	≤ 16	≤ 40	≤ 63	≤ 80	≤ 100	≤ 150
S235	235	225	215	215	215	205
S275	275	265	255	245	235	225
S355	355	345	335	325	315	295
S450	450	430	410	390	380	--
S460	460	440	430	410	400	--

BS EN	Thickness (mm)		
Grade	**≤ 50**	**≤ 100**	**> 100**
S550	550	530	490
S690	690	650	630

GB	Thickness (mm)			
Grade	≤ 16	≤ 40	≤ 60	≤ 100
Q235	215	205	200	190
Q345	305	295	265	250
Q390	345	330	310	295
Q420	375	355	320	305
Q550	520	500	475	445
Q690	630	615	605	585

JIS 3136	Thickness (mm)		
Grade	≤ 16	≤ 40	≤ 100
SN400A	235	235	215
SN400B	235	235	215
SN400C	235	235	235
SN490B	325	325	295
SN490C	325	325	295

ASTM Grade	Thickness (mm)	Design strength p_y
ASTM A36	≤ 200	250
	> 200	220
ASTM A572 Grade 50	All thickness	345
ASTM A500 Grade B	≥ 4.6mm for circular tubes	290
	≥ 4.6mm for rectangular tubes	315
ASTM A992 Grade 50	All for hot rolled shapes	345
ASTM A913 Grade 50	All for qenched & self tempered	345
ASTM A913 Grade 60	All for quenched & self tempered	415
ASTM A913 Grade 65	All for quenched & self tempered	450
ASTM A656 Grade 80	All for quenched & self tempered	550
ASTM A656 Grade 100	All, quenched & self tempered	690

AS Grade	Design values, depending on thickness p_y (N/mm^2)
200	200
250	230 ~ 250
300	280 ~ 300
350	320 ~ 350
400	380 ~ 400
450	420 ~ 450
AS/NZ 3597 Grade 600	600 min.
AS/NZ 3597 Grade 690	620 ~ 690

(2) Material factors

Table 5.4 Material factors and strength grades for various classes of steel

Steel material	Strength	Class	γ_{m1}	γ_{m2}	Acceptable quality assurance system	Compliance with reference material standard	Additional test required	Remarks
Normal steel	Ys ≤ 460	1	1.0	1.20	Y	Y	N	Normal use.
		2	1.1	1.30	Y	N	Y	Can be used subject to satisfactory tests.
		3	*	*	N	—	Y	Restricted use with limited applications.
High -strength steel	460 < Ys ≤ 690	1H	1.0	1.05	Y	Y	N	Normal use.

Notes: 1. These factors are minimum values to be used in design;
2. " * " is for Class 3 steel, whose yield strength $p_y \leq 170\text{N/mm}^2$, and tensile strength $U_S \leq 300\text{N/mm}^2$;
3. Reference standards refer to acceptable standards adopted in Australia AS, China GB, Japan JIS, U.S.A. ASTM and British versions of European Standards BS EN;

5.3.3 Macau – REAE 2001 *Code of Structural Steel for Buildings*

REAE 2001 provides rules and provisions on the general principles of structural steel design and construction, and references to EN1993-1 is needed.

(1) Design strengths, ductility and impact toughness

The nominal value of a mechanical property is the characteristic value of the steel to be used, i.e. a design value. The characteristics of different types of steel shall be determined according to their mechanical properties, which can be measured by tensile tests, impact and bending tests.

EN 10025 is adopted as the steel materials specification of steel plates and sections as structural members in the Code. The characteristic values of various mechanical properties of steel are shown in Table 5.5.

Table 5.5 Mechanical properties of steel

Grade	Quality	Yield strength f_y and tensile strength f_u (N/mm^2)				Minimum elongation limit (%) (L_0=5.65/S_0)			Minimum impact energy (J)	
		Nominal thickness (mm)				Nominal thickness (mm)			Nominal thickness (mm)	
		$t \leq 40$		$40 < t \leq 100$		$3 < t \leq 40$	$40 < t \leq 63$	$63 < t \leq 100$	Test temperature (°C)	$10 < t \leq 15$
		f_u	f_u	f_y	f_u					
S235	JR	235	360	215	340	26	25	24	20	27
	JO								0	27
	J2								-20	27
S275	JR	275	430	255	410	22	21	20	20	27
	JO								0	27
	J2								-20	27
S355	JR	355	510	335	490	22	21	20	20	27
	JO								0	27
	J2								-20	27
	K2								-20	40

JR, JO, J2, and K2 indicate quality levels of the steel. Quality increases from JR to K2 to reflect stringent requirements on weldability and impact toughness.

(2) Weldability

Most steel with the quality levels of JR, JO, J2 and K2 are good for welding. Weldability is readily assessed by the equivalent carbon content (CEV) that is determined according to the results of ladle analyses. The maximum CEV values for steel of all grades are summarised in Table 5.6.

Table 5.6 Maximum CEV

Grade	Quality	Maximum CEV - Max.C (%) at nominal thickness - t (mm)	
		$t \leq 40$	$40 < t \leq 150$
S235	JR, JO, J2	0.35	0.38
S275	JR, JO, J2	0.40	0.42
S355	JR, JO, J2, K2	0.45	0.47

5.3.4 Singapore - BC1: 2012 *Design Guide on Use of Alternative Structural Steel to BS 5950 and Eurocode 3*

The British standards BS 5950 or BS EN 1993 continue to be used to design steel structures in Singapore. Under this design guide, alternative steel materials not manufactured to British Standards may be allowed in structural design based on BS 5950 and SS EN 1993. To be consistent, this design guide outlines the material performance requirements and quality assurance requirements to be imposed on all steel materials, including those manufactured to British Standards, intended for use in accordance with BS 5950 and SS EN 1993, in the context of Singapore.

(1) Design strengths

For Class 1 steel plates, hot rolled sections, hollow sections, steel for cold forming, hot rolled steel bars and sheet piles, the design strength P_y is given by:

$P_y = Y_s/1.0 \leq U_s/1.2$, or $P_y \leq 460\text{N/mm}^2$;

$P_y = Y_s/1.0 \leq 690\text{N/mm}^2$, for steel plates with a nominal yield strength of at least 460N/mm^2, where plastic design shall not be allowed;

Y_s is the minimum yield strength (N/mm^2) of structural steel; and

U_s is the minimum tensile strength (N/mm^2) of structural steel.

For Class 2 steel plates, hot rolled sections, hollow sections, steel for cold forming, hot rolled steel bars and sheet piles, the design strengths P_y are given in Table 5.7.

Table 5.7 Design parameters of Class 2 structural steel

Design strength P_y (N/mm^2) for thickness (mm) less than or equal to					
16	40	63	80	100	150
$P_{y0} = \frac{Y_s}{1.0} \leq U_s/1.3$ or 460N/mm^2	$0.95P_{y0}$	$0.92P_{y0}$	$0.90P_{y0}$	$0.85P_{y0}$	$0.80P_{y0}$

For Class 3 structural steel, regardless of the nominal strengths, the design parameters corresponding to different thicknesses are given in Table 5.8.

Table 5.8 Design parameters of Class 3 structural steel

Thickness t (mm) ≤	16	40	63	80	100	150
Design strength (N/mm^2)	170	160	155	150	145	135

(2) Ductility

The gauge length shall be calculated using the following equation:

$$L_0 = 5.65\sqrt{S_0}$$

where S_0 is the cross-section area.

The elongation limit after fracture within the gauge length shall be at least 15% for nominal yield strengths not greater than 460 N/mm^2; and it shall be at least 10% for nominal yield strengths greater than 460 N/mm^2.

5.3.5 Europe - EN 1993-1-1: 2005 *Design of steel structures - Part 1-1: General rules and rules for buildings*

EN 1993-1-1 gives basic design rules for steel structures, complying with various principles and requirements for structural safety and serviceability. It deals with design basis, materials, durability, analysis methods, resistances and deformations.

(1) Design strengths

The nominal values of the yield strength, f_y , and the ultimate strength, f_u , for structural steel are summarized in Table 5.9.

Table 5.9 Nominal values of yield strength f_y and ultimate tensile strength f_u for hot rolled structural steel

Standard and Grade	Nominal plate thickness t (mm)			
	t ≤ 40mm		40mm < t ≤ 80mm	
	f_y (N/mm^2)	f_u (N/mm^2)	f_y (N/mm^2)	f_u (N/mm^2)
E N 10025-2				
S 235	235	360	215	360
S 275	275	430	255	410
S 355	355	510	335	470
S 450	440	550	410	550
E N10025-3				
S 275 N/NL	275	390	255	370
S 355 N/NL	355	490	335	470
S 420 N/NL	420	520	390	520
S 460 N/NL	460	540	430	540
E N10025-4				
S 275 M/ML	275	370	255	360
S 355 M/ML	355	470	335	450
S 420 M/ML	420	520	390	500
S 460 M/ML	460	540	430	530
E N10025-5				
S 235 W	235	360	215	340
S 355 W	355	510	335	490
E N10025-6				
S 460 Q/QL/QL1	460	570	440	550
E N10210-1				
S 235 H	235	360	215	340
S 275 H	275	430	255	410
S 355 H	355	510	335	490
S 275 NH/NLH	275	390	255	370
S 355 NH/NLH	355	490	335	470
S 420 NH/NHL	420	540	390	520
S 460 NH/NLH	460	560	430	550
E N10219-1				
S 235 H	235	360	-	-
S 275 H	275	430	-	-
S 355 H	355	510	-	-
S 275 NH/NLH	275	370	-	-
S 355 NH/NLH	355	470	-	-
S 460 NH/NLH	460	550	-	-
S 275 MH/MLH	275	360	-	-
S 355 MH/MLH	355	470	-	-
S 420 MH/MLH	420	500	-	-
S 460 MH/MLH	460	530	-	-

(2) Ductility

a) A minimum ductility is required that should be expressed in terms of limits for:

- the ratio f_u / f_y of the specified minimum ultimate tensile strength f_u to the specified minimum yield strength f_y should be not less than 1.10..
- the elongation at failure of a gauge length of $5.65\sqrt{A_0}$ should be not less than 15%, where A_0 is the original cross-sectional area.
- the ultimate strain $\varepsilon_u \geq 15\varepsilon_y$, where ε_u corresponds to the ultimate tensile strength f_u, and ε_y is the yield strain ($\varepsilon_y = f / E$).

b) Steel conforming with one of the steel grades listed in Table 5.9 should be accepted as satisfying these requirements.

5.3.6 Australia – AS 4100-1998 R2016 *Steel Structures*

AS 4100 sets out minimum requirements for design, fabrication, erection, and modification of steelwork in structures in accordance with the limit states design method. It applies to buildings, structures and cranes constructed of steel.

(1) Design strengths

The yield stress f_y and the tensile stress f_u used in design shall not exceed that given in Table 5.10. Test reports or test certificates that comply with the minimum requirements of the appropriate standards listed in Table 5.10 shall constitute sufficient evidence of compliance of the steel with these standards.

If unidentified steel is used, it shall be free from surface imperfections, and shall be used only where the physical properties of the steel and its weldability will not adversely affect stability and serviceability of the structure. The yield stress f_y of the unidentified steel in design, unless a full test in accordance with AS 1391 is made, shall be taken as not exceeding 170 N/mm^2, and the tensile strength f_u used in design shall be taken as not exceeding 300 N/mm^2.

Table 5.10 Strengths of steel complying with different AS/NZS steel standards

Steel Standard	Form	Steel grade	Thickness of material, t (mm)	Yield stress, f_y (N/mm^2)	Tcensile strength, f_u (N/mm^2)
AS/NZS 1163 (Note 3)	Hollow sections	C450	All	450	500
		C350	All	350	430
		C250	All	250	320
AS/NZS 1594	Plate, strip, sheet floor plate	HA400	All	380	460
		HW350	All	340	450
		HA350	All	350	430
		HA300/1 HU300/1	All	300	430
		HA300 HU300	All	300	400
		HA250 HA250/1 HU250	All	250	350
		HA200	All	200	300
	Plate and strip	HA4N	All	170	280
		HA3	All	200	300
		HA1	All	(Note 1)	(Note 1)
		XF500	$t \leq 8$	480	570
		XF400	$t \leq 8$	380	460
		XF300	All	300	440
AS/NZS 3678 (Note 2 and 3)	Plate and floor plate	450	$t \leq 20$	450	520
		450	$20 < t \leq 32$	420	500
		450	$32 < t \leq 50$	400	500
		400	$t \leq 12$	400	480
		400	$12 < t \leq 20$	380	480
		400	$20 < t \leq 80$	360	480
		350	$t < 12$	360	450
		350	$12 < t \leq 20$	350	450
		350	$20 < t \leq 80$	340	450
AS/NZS 3678 (Note 3)	/	350	$80 < t \leq 150$	330	450
		WR350	$t \leq 50$	340	450
		300	$t \leq 8$	320	430
		300	$8 < t \leq 12$	310	430
		300	$12 < t \leq 20$	300	430
		300	$20 < t < 50$	280	430
		300	$50 < t < 80$	270	430
		300	$80 < t \leq 150$	260	430
		250	$t \leq 8$	280	410
		250	$8 < t \leq 12$	260	410
		250	$12 < t \leq 50$	250	410
		250	$50 < t \leq 80$	240	410
		250	$80 < t \leq 150$	230	410
		200	$t \leq 12$	200	300

Table 5.10 Strengths of steel complying with different AS/NZS steel standards (continued)

Steel Standard	Form	Steel grade	Thickness, *t* (mm)	Yield stress, f_y (N/mm^2)	Tcensile strength, f_u (N/mm^2)
AS/NZS 3679.1 (Note 3)	Flats and sections	350	$t \leq 11$	360	480
		350	$11 < t < 40$	340	480
		350	$t \geq 40$	330	480
		300	$t < 11$	320	440
		300	$11 \leq t \leq 17$	300	440
		300	$t > 17$	280	440
	Hexagons, rounds and squares	350	$t \leq 50$	340	480
		350	$50 < t < 100$	330	480
		350	$t \geq 100$	320	480
		300	$t \leq 50$	300	440
		300	$50 < t < 100$	290	440
		300	$t \geq 100$	280	440
AS 3597	Plate	500	$5 \leq t \leq 110$	500	590
		600	$5 \leq t \leq 110$	600	690
		700	$t \leq 5$	650	750
		700	$5 < t \leq 65$	690	790
		700	$65 < t \leq 110$	620	720

Notes:
1. For design purposes, yield and tensile strengths approximate those of structural Grade HA200. For specific information, contact the supplier.
2. Welded I-sections complying with AS/NZS 3679.2 are manufactured from hot-rolled structural steel plates complying with AS/NZS 3678, so the values listed for steel grades to AS/NZS 3678 shall be used for welded I-sections to AS/NZS 3679.2.
3. AS/NZS 3678, AS/NZS 3679.l and AS/NZS 1163 all contain, within each grade, a variety of impact grades not individually listed in the Table. All impact tested grades within the one grade have the same yield stress and tensile strength as the grade listed.

5.3.7 Japan – AIJ: 2005 *Design Standard for Steel Structures - 2005 Edition*

The standard is published by the Japanese Architectural Society (AIJ) which is based on allowable stress concept, and it has long served as the primary building design standard for structural steel.

(1) Allowable stresses for structural steel

Unless otherwise provided, structural steel shall be of the quality specified in the applicable standards given in Table 5.11, and of the shapes and sizes prescribed in Table 5.12.

Allowable stresses for structural steel under permanent loading are determined according to the nominal stresses F given in Table 5.13 for various steel grades, and various formulae listed in Table 5.14 for different actions.

Table 5.11 Standards Prescribing Quality of Structural Steel

Numbers	Titles
JIS G 3136	Rolled Steel for Construction Structures: SN 400 A, SN 400 B, SN 400 C, SN 490 B and SN 490 C
JIS G 3101	Rolled Steel for General Structures: SS 400, SS 490 and SS 540
JIS G 3106	Rolled Steel for Welded Structures: SM400 A, B and C; SM490 A, B and C; SM490 YA and YB; SM520 B, C and SM570
JIS G 3114	Hot-rolled Atmospheric Corrosion Resisting Steel for Welded Structures
JIS G 3475	Carbon Steel Tubes for Construction Structures: STKN 400 W, B, STKN 490 B
JIS G 3444	Carbon Steel Tubes for General Structural Purposes: STK 400 and STK 490
JIS G 3466	Carbon Steel Square Pipes for General Structural Purposes: STKR 400 and STKR 490
JIS G 3138	Rolled Steel Bars for Construction Structures: SNR 400 A and B, SNR 490 B
JIS G 3350	Light Gauge Steel for General Structures: SSC 400
JIS G 3353	Welded Light Gauge Steel H Sections for General Structures
JIS G 5101	Carbon Steel Castings: SC480
JIS G 5102	Casting for Welded Structures: SCW 410, SCW 480
JIS G 5201	Centrifugally Cast Steel Pipes for Welded Structures

Table 5.12 Standards Prescribing Shapes and Sizes of Structural Steel

Numbers	Titles
JIS G 3191	Shape, Dimensions, Weight and Tolerance for Hot Rolled Steel Bars and Bar-in-Coils
JIS G 3192	Dimensions, Weight and Permissible Variations of Hot Rolled Steel Sections
JIS G 3193	Dimensions, Weight and Permissible Variations of Hot Rolled Steel Plates, Sheets and Strip
JIS G 3194	Shape, Dimensions, Weight and Tolerance for Hot Rolled Flat Steel
JIS G 3475	Carbon Steel Tubes for Building Structures
JIS G 3444	Carbon Steel Tubes for General Structural Purposes
JIS G 3466	Carbon Steel Square Pipes for General Structural Purposes
JIS G 3350	Light Gauge Steel for General Structures
JIS G 3353	Welded Light Gauge Steel H Sections for General Structures
JIS G 3352	Steel Decks

Table 5.13 Nominal stresses *F* of structural steel (N/mm^2)

Thickness (mm)	Steel for construction structures		Steel for general structures			Steel for welded structures			
	SN400 SNR400 STKN400	SN490 SNR490 STKN490	SS400 STK400 STKR400 SSC400	SS490	SS540	SM400 SMA400	SM490 SM490Y SMA490 STKR490 STK490	SM520	SM570
$t \leq 40$	235	325	235	275	375	235	325	355	400
$40 < t \leq 100$	215	295	215	255	—	215	295	335 (325 for $t > 75$)	400

Table 5.14 Determination of allowable stresses (N/mm²)

Stresses (N/mm²)	Formula	Remarks
Allowable tensile stress	$f_{\mathrm{t}} = \dfrac{\mathrm{F}}{1.5}$	F see Table 5.13.
Allowable shear stress	$f_{\mathrm{s}} = \dfrac{\mathrm{F_s}}{1.5}, \qquad F_s = \mathrm{F}/\sqrt{3}$	F see Table 5.13.
Allowable compressive stress	a) On the gross section: $f_{\mathrm{c}} = \begin{cases} \left[1 - 0.4\left(\dfrac{\lambda}{\Lambda}\right)^2\right]\dfrac{F}{\nu}, & \lambda \le \Lambda \\ 0.277F\left(\dfrac{\lambda}{\Lambda}\right)^{-2}, & \lambda > \Lambda \end{cases}$ b) On the web of rolled shapes or built-up I sections at the toe of the fillet: $f_{\mathrm{c}}' = \dfrac{F}{1.3}$	F see Table 5.13. λ -- slenderness ratio of compression member; E -- modulus of elasticity (N/mm²); $\nu = \frac{3}{2} + \frac{2}{3}\left(\frac{\lambda}{\Lambda}\right)^2$; Λ -- critical slenderness ratio.

Note: For Allowable Bending Stress and Allowable Bearing Stress, see Ch.5 of AIJ: 2005.

5.3.8 America – AISC 360-16 *Specification for Structural Steel Buildings*

The specification is published by the American Institute of Steel Construction (AISC).

(1) Approved structural steel

Material test reports or reports of tests made by a fabricator or a testing laboratory shall constitute sufficient evidence of conformity with one of the ASTM standards listed in Table 5.15.

Table 5.15 ASTM Standards

Steel Form	Materials Standard	Test Standard
Hot-rolled structural shapes	ASTM A36/A36M, ASTM A709/A709M, ASTM A529/A529M, ASTM A913/A913M, ASTM A572/A572M, ASTM A992/A992M, ASTM A588/A588M, ASTM A1043/A1043M	ASTM A6/A6M
Hollow structural sections (HSS)	ASTM A53/A53M Grade B, ASTM A847/A847M, ASTM A500/A500M, ASTM A1065/A1065M, ASTM A501/A501M, ASTM A1085/A1085M, ASTM A618/A618M	Applicable ASTM standards
Plates	ASTM A36/A36M, ASTM A572/A572M, ASTM A242/A242M, ASTM A588/A588M, ASTM A283/A283M, ASTM A709/A709M, ASTM A514/A514M, ASTM A1043/A1043M, ASTM A529/A529M, ASTM A1066/A1066M	ASTM A6/A6M
Bars	ASTM A36/A36M, ASTM A572/A572M, ASTM A529/A529M, ASTM A709/A709M	ASTM A6/A6M
Sheets	ASTM A606/A606M, ASTM A1011/A1011M SS, HSLAS, AND HSLAS-F	ASTM A568/A568M

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Appendices

Appendix A Introduction to Iron Carbon Alloy

Iron is a transition element that melts at 1538 °C and vaporizes at 2738 °C under atmospheric pressure. The density at 20 °C is 7.87 g/cm^3. Iron is polymorphic. Figure A.1 is a cooling curve of pure iron. As can be seen from Figure A.1, pure iron crystallizes to δ-Fe at 1538 °C, with a body-centred cubic lattice. When the temperature continues to cool to 1394 °C, the δ iron is converted into γ-Fe (face centred cubic lattice). When the temperature continues to drop to 912 °C, the face-centred cubic γ-Fe is transformed into body-centred cubic α-Fe. The "b.c.c" form of steel will not change below 912 °C. Therefore, iron is a three-allotropic state material, namely δ-Fe, γ-Fe, and α-Fe. During the cooling process of pure iron, the grains are refined after the allotropic transformation.

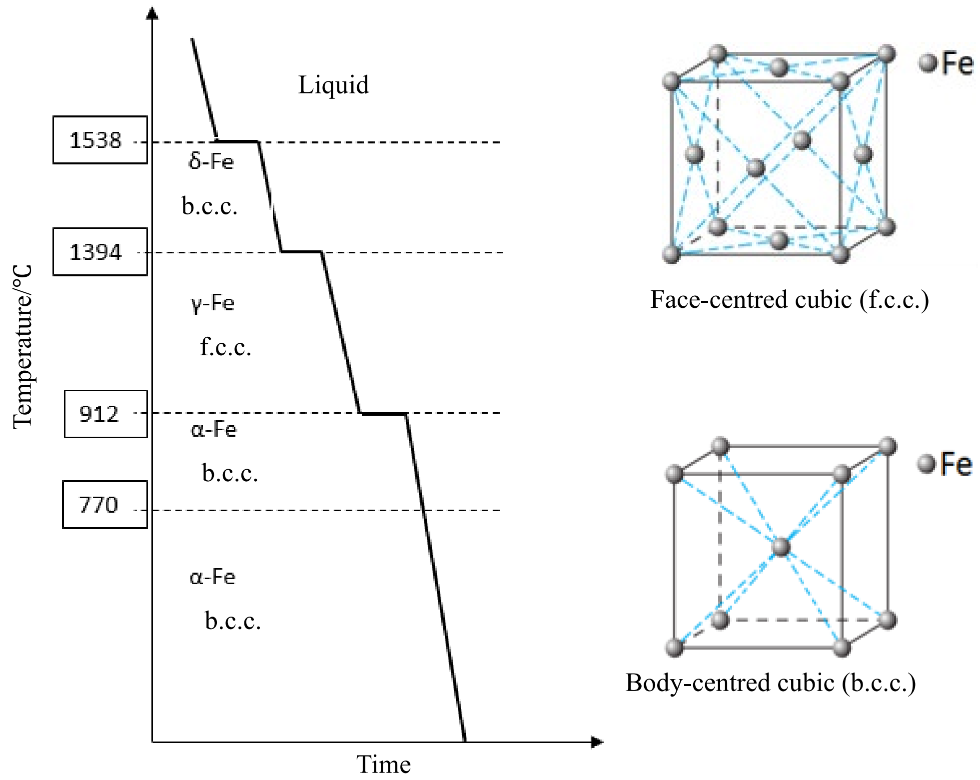


Figure A.1 Cooling curve and crystal structure change of pure iron

Carbon steel contains additional alloying elements such as manganese, silicon, chromium, and nickel etc. When different components are alloyed by smelting or sintering, these components form particular crystal structures and component phases due to physical and chemical interactions. 'Phase' refers to a component of the alloy possessing the same structure, uniform composition and properties. Phases are separated from each other by interfaces. For example, a pure metal is in the 'solid phase' when in the solid state and the liquid phase above the melting point. Below, mainly introduced are the iron-carbon alloys. Other alloying elements are not included.

Figure A.2 is a phase diagram of Fe-Fe_3C. The temperature, carbon concentration and description of each characteristic point in the figure are described in detail in Table A.1. The liquidus of the phase diagram is ABCD and the solidus is AECF. The GS line, also known as the A_3 line, is the starting line for the precipitation of ferrite from austenite during cooling, or the line when ferrite turns into austenite during heating. The ES line is the solubility curve of carbon in austenite. When the temperature is lower than this curve, cementite will precipitate from austenite, so the ES line is also called the A_{cm} line.

Table A.1 Characteristic points in the iron carbon phase diagram

Point	Temperature (°C)	Carbon (wt%)	Description
A	1538	0.000	Melting point of pure iron
E	1148	2.140	Maximum solubility of carbon in γ-Fe
D	1277	6.690	Melting point of cementite
G	912	0.000	α-Fe ⇆ γ-Fe transition temperature (A_3)
S	727	0.760	Eutectoid point (A_1)
P	727	0.022	Maximum solubility of carbon in α-Fe

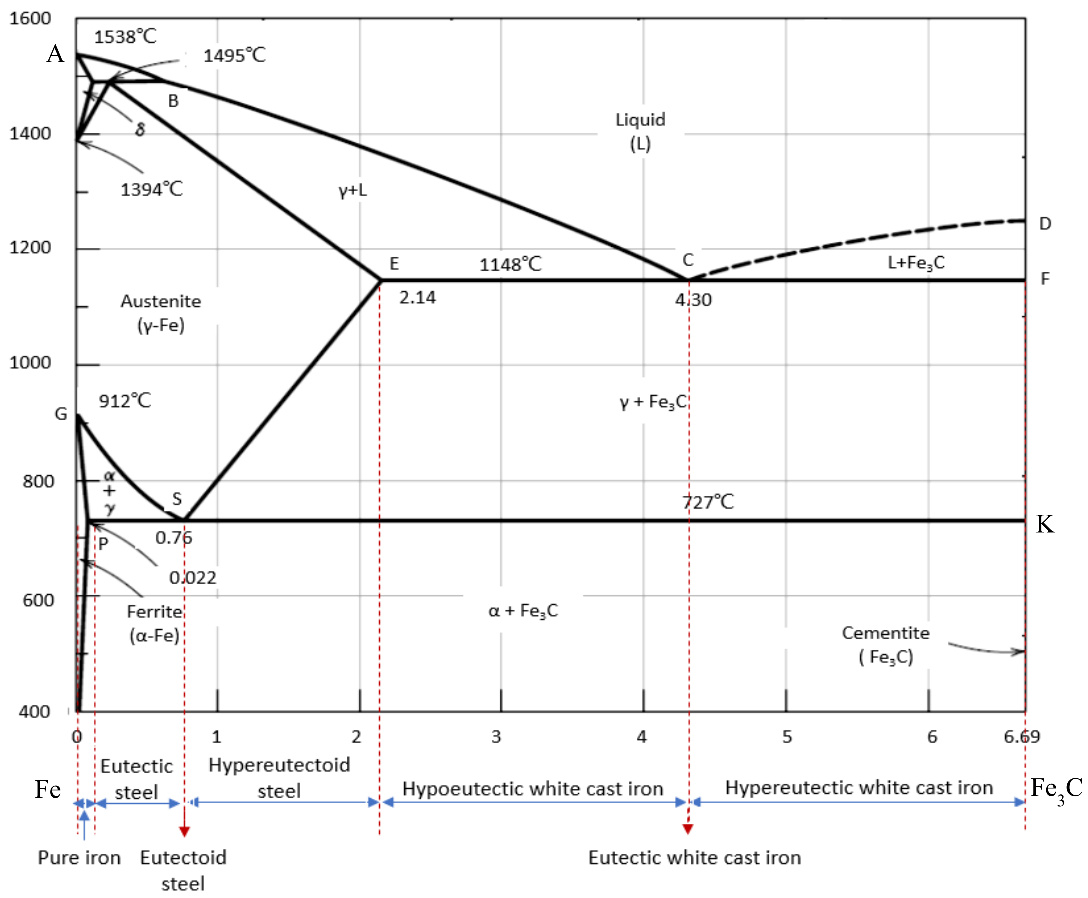


Figure A.2 Iron carbon phase diagram

The structure of an iron-carbon alloy is a combination of liquid crystallization and solid-state phase transition. It is usually divided into carbon steel and cast iron according to the presence of eutectic transformation. As shown in Figure A.2, the carbon concentration is less than 0.022% for industrial pure iron, between 0.022 and 2.14% for carbon steel, and greater than 2.14% for cast iron. Eutectic transformation refers to a liquid alloy of a certain composition, which simultaneously crystallizes at a certain temperature into two crystals with different compositions and lattices. The eutectoid transformation refers to the reaction of a single-phase solid alloy with a specific composition, which is decomposed into two new solid phases with particular crystal into structures at a constant temperature. A eutectic reaction is one in which a *liquid phase* forms two solid phases at a constant temperature. A eutectoid reaction is one in which a *solid phase* forms into two solid phases at a constant temperature.

Differences in the metallographic phase of the steel directly affects its mechanical properties. The roles of the different metallographic structures in specific carbon steel and the respective carbon contents are listed in Table A.2.

Table A.2 Influence of microstructural constituents on properties of steel

Constituents	Carbon Content (wt%)	Tensile strength	Ductility	Toughness	Hardness	Weldability	Corrosion
Austenite	Max 2.140	↓	↑	↑	↓	↓	↑
Ferrite	Max 0.022	↓↓	↑	-	↓↓	↑	——
Cementite	6.700	↑↑	↓↓	↓↓	↑↑	↓↓↓	——
Pearlite	0.760	↑	↓	-	↑	↓	——
Bainite	——	——	——	↑	↑↑	↓	——
Tempered Martensite	——	↑↑↑	——	↑↑	↑↑↑	↓	——

The identification of microstructural constituents:

Austenite: Austenite is a solid solution dissolving carbon in face-centred cubic iron that contains up to a maximum content of 2.14% carbon, also known as the gamma-phase iron (γ-Fe). It is ductile and soft with a certain tensile strength in the high-temperature zone. The microscopic appearance of austenite is always large-grained.

Ferrite: Ferrite is a solid solution of quite limited carbon solubility in a body-centred cubic crystal structure consisting of at most 0.022% carbon, also known as the alpha-phase iron (α-Fe). Similar to pure iron, ferrite is very ductile and soft with a low tensile strength.

Cementite: Cementite, or iron carbide with the chemical formula Fe3C, is an intermetallic compound of iron and carbon. As a relatively high-carbon steel that contains 6.67% carbon, cementite is very hard and brittle. It appears as a brilliant white network or needle-like crystals around pearlite in slow cooling.

Pearlite: Pearlite is an aggregate of ferrite and cementite, which is an intimate mixture resulting from the eutectoid reaction when austenite of 0.76% carbon is slowly cooled below 727°C (the eutectoid temperature). As the two phases are alternately arranged and uniformly distributed in the lamellar microstructure of pearlite, pearlite exerts the maximum hardening power with relatively good ductile and high strength.

Martensite: Martensite is an interstitial supersaturated solid solution of carbon with a highly strained body-centred tetragonal lattice. It is formed by the rapid cooling of austenite, also called quenching. The cooling rate is too high to let carbon atoms diffuse out of the crystal structure to form cementite. Martensite is the hardest transformation product of austenite. Since martensite is a metastable phase of steel, it is usually reheated to relieve the cooling stresses and minimize cracking, to obtain a stable microstructure of the so-called tempered martensite.

Bainite: In addition to pearlite and martensite, bainite is another micro-constituent resulting from the decomposition of austenite. It forms at a moderate cooling rate that is faster to suppress the transformation from austenitic to ferrite and pearlite, but not fast enough to form martensite. In consequence, bainite is both harder and tougher than pearlite, but not so hard as martensite. The microstructural appearance as featherlike and acicular respectively are called "upper bainite" and "lower bainite", according to the temperature range of the transformation.

During the process of manufacturing steel, the cooling rate in the rolling process and the carbon content in the steel play an important role in the phase transformation in steel. Ferrite and pearlite are usually obtained at a slow cooling rate, bainite can be obtained at a moderate cooling rate, martensite can be obtained at a rapid cooling rate. The amount of carbon directly affects the amount of transformation of cementite and martensite in steel. Figure A.3 shows the isothermal transformation diagram of the supercooled austenite of the eutectoid steel. During the continuous cooling process, different cooling rates result in different phases. In the figure, M_s is the martensite starting transition temperature. Different steel have different isothermal transformation curves for supercooled austenite. Usually, in the production process, the generation of a certain phase needs the appropriate temperature range to be maintained for a certain period, so that the austenite can be fully transformed.

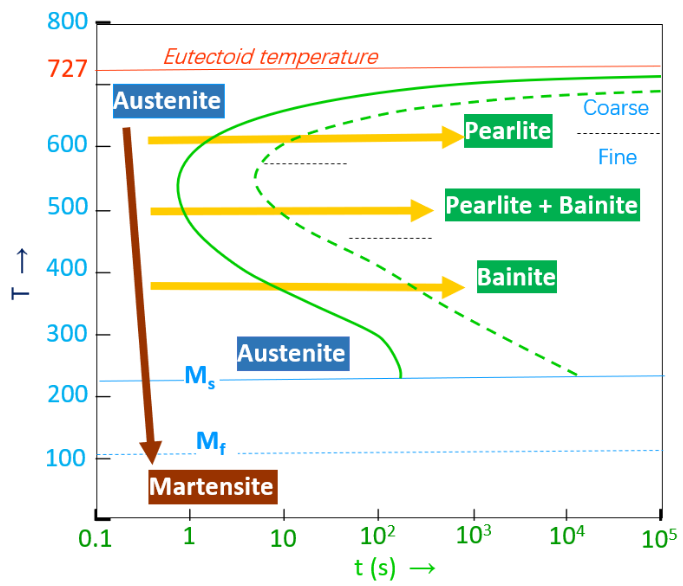


Figure A.3 Eutectoid steel isothermal transformation diagram

Appendix B Distribution Map of Chinese Steel Enterprises

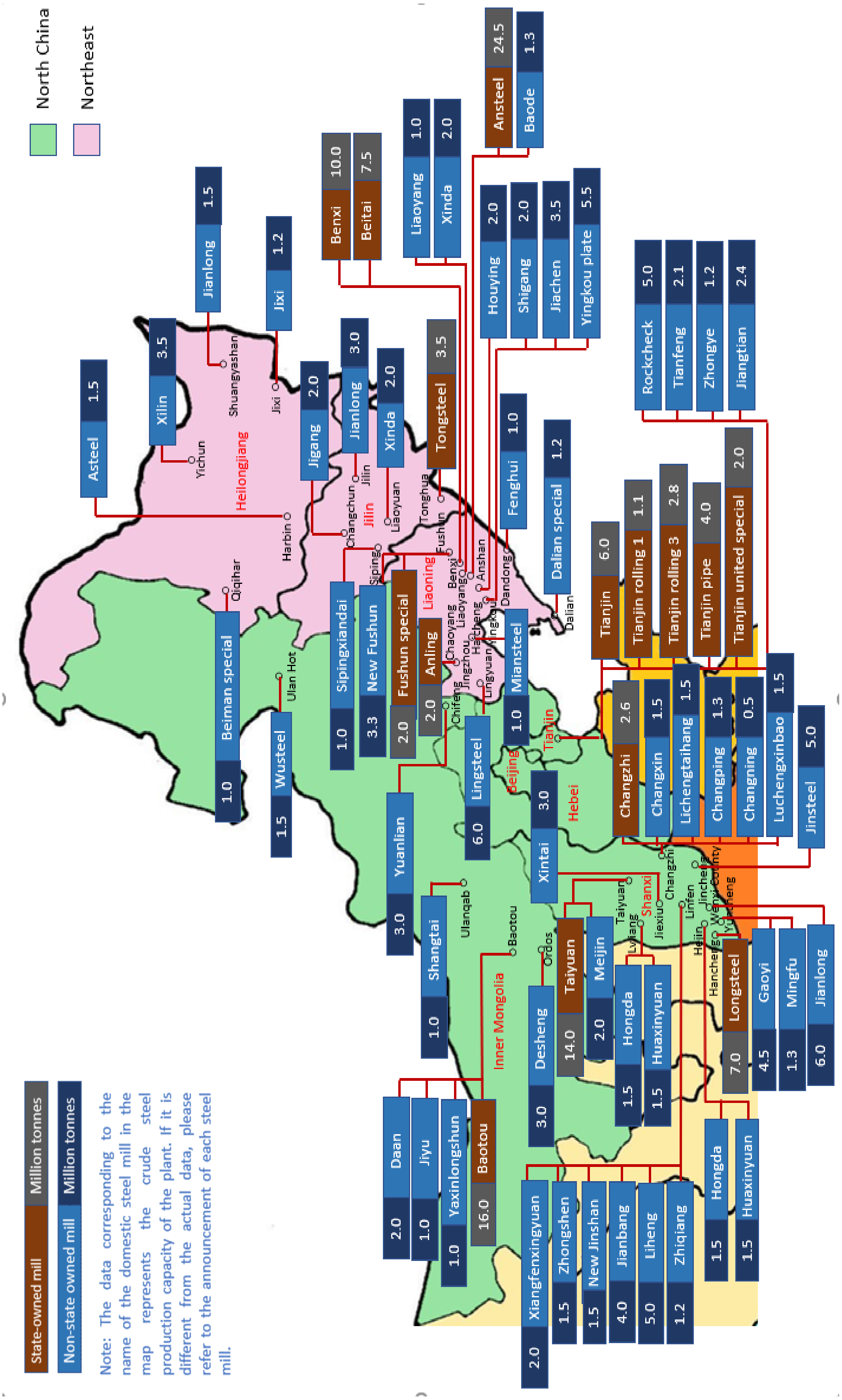


Figure B.1 Mills in North and Northeast China

Figure B.2 Mills in Northwest and Southwest

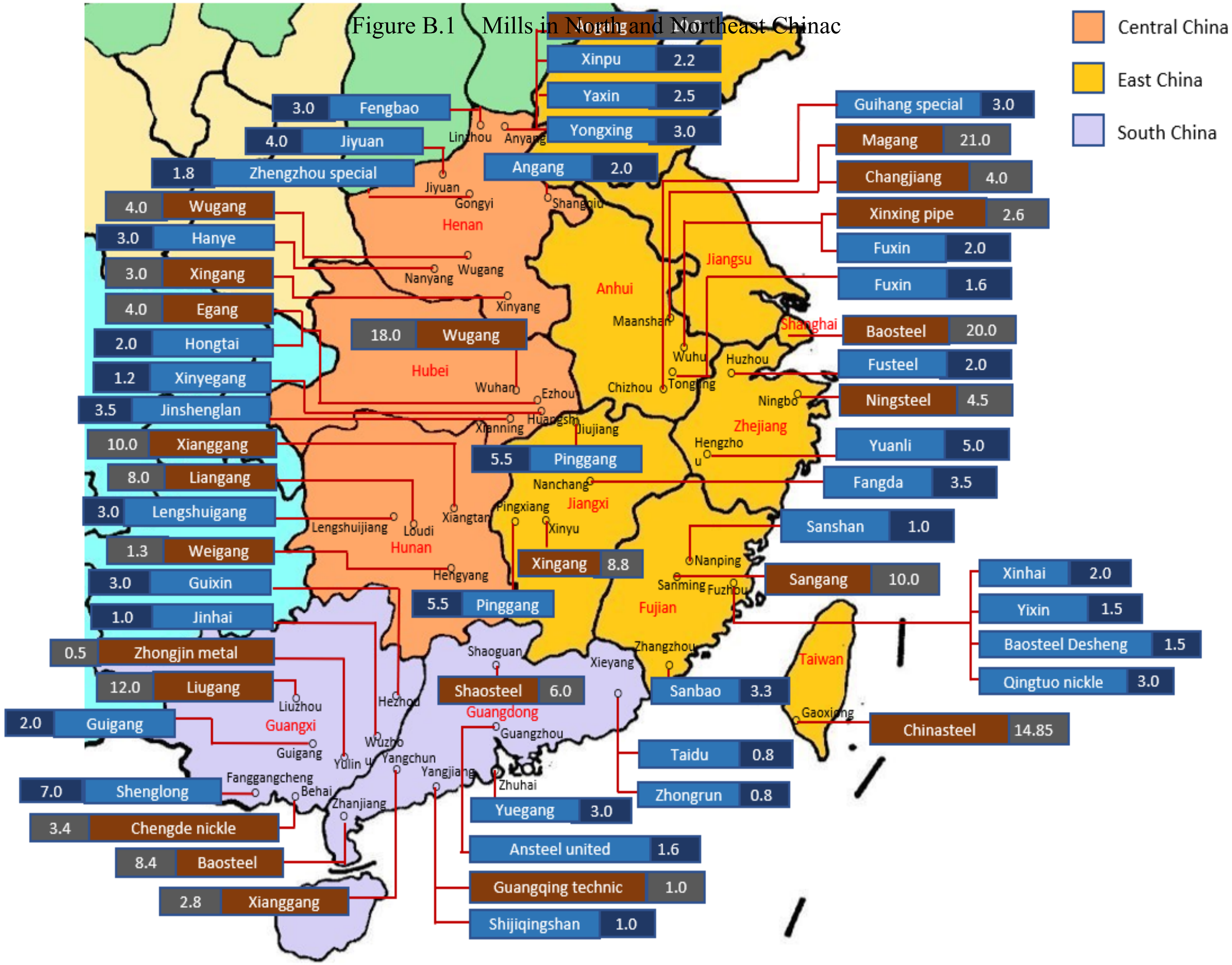


Figure B.3 Mills in Central, East and South China

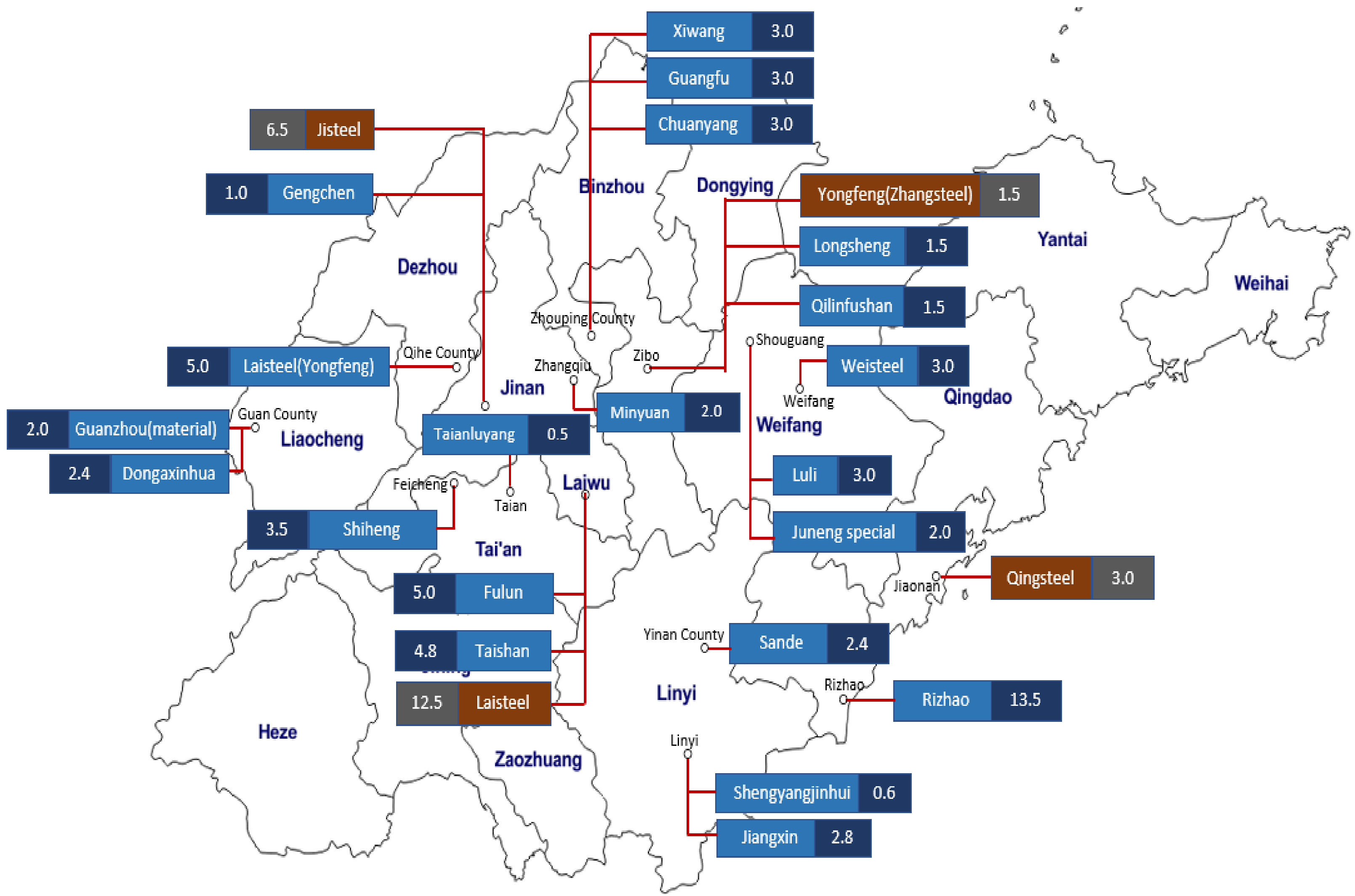


Figure B.4 Mills in Shandong province

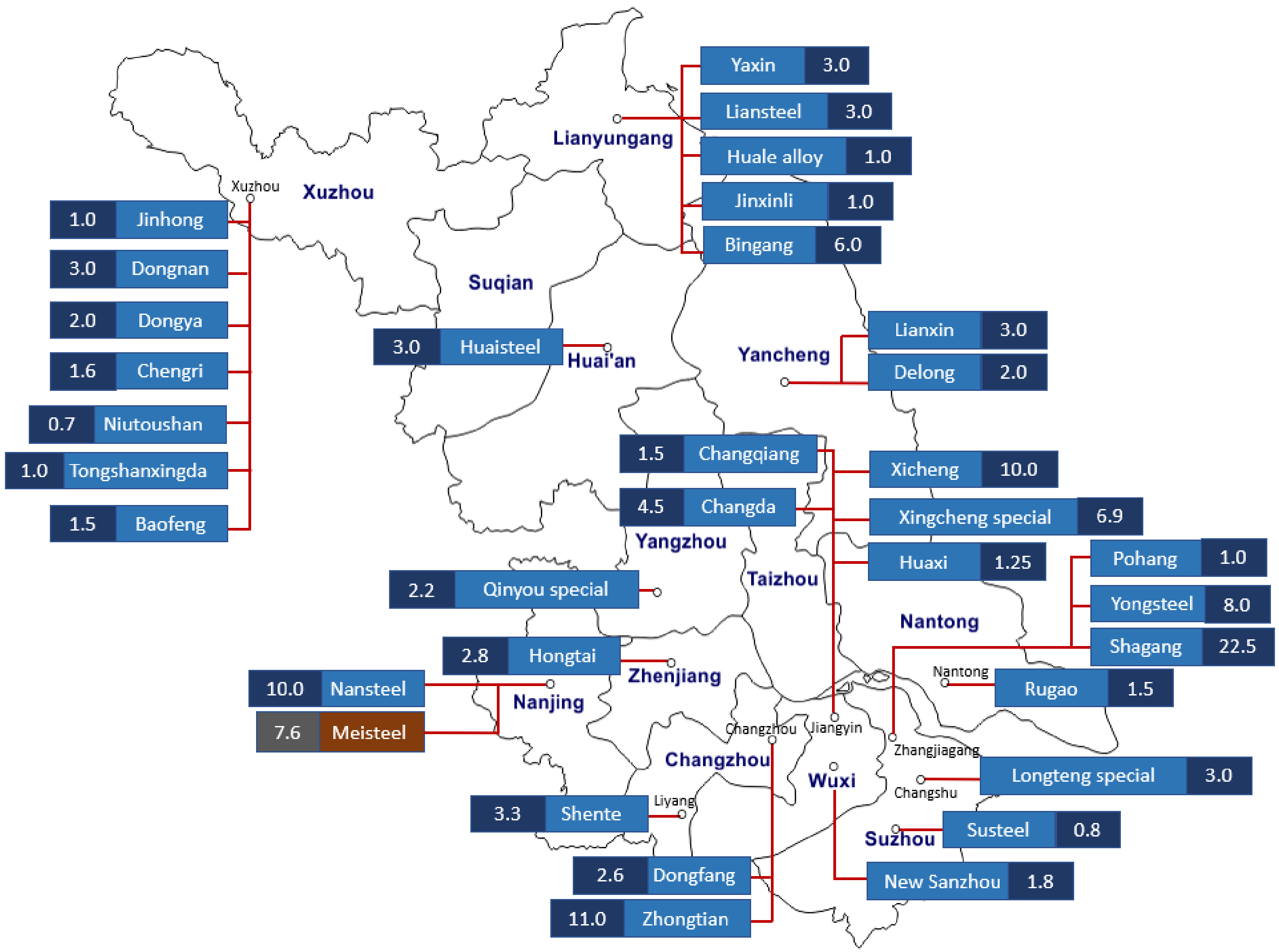


Figure B.5 Mills in Jiangsu province

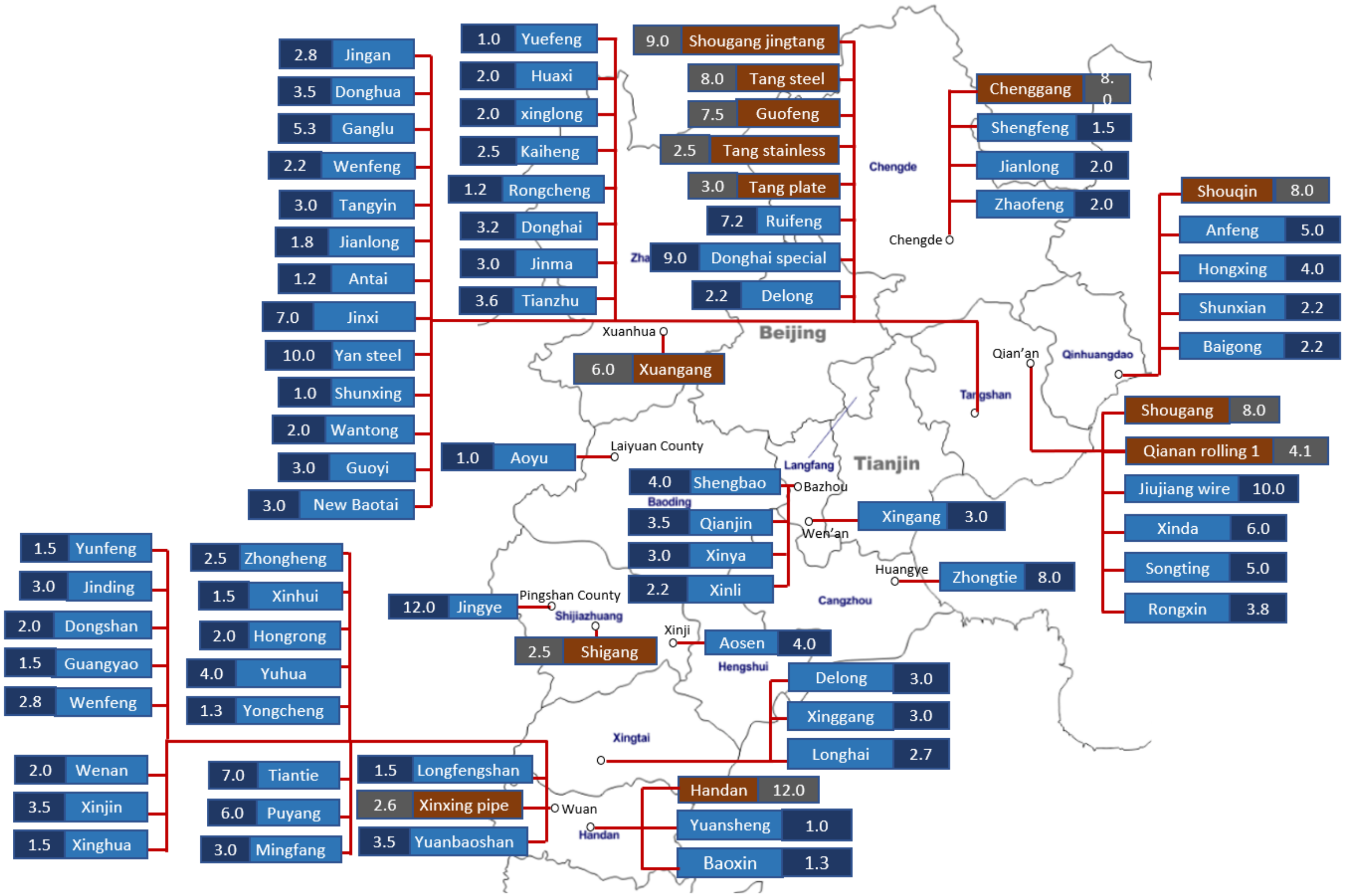


Figure B.6 Mills in Hebei province

Appendix C Chemical Composition and Mechanical Properties of Structural Steel

Table C.1 Chemical composition of carbon structural steel to GB/T 700 - 2006

Grade	Level	Chemical composition (%), ≤				
		C	Si	Mn	P	S
Q195	—	0.12	0.30	0.50	0.035	0.040
Q215	A	0.15	0.35	1.20	0.045	0.050
	B					0.045
Q235	A	0.22	0.35	1.40	0.045	0.050
	B	0.20[a]			0.045	0.045
	C	0.17			0.040	0.040
	D	0.17			0.035	0.035
Q275	A	0.24	0.35	1.50	0.045	0.050
	B	0.21[b]			0.045	0.045
	C	0.20			0.040	0.040
	D				0.035	0.035

[a]. With the consent of the purchaser, the carbon content of Q235B can be ≤ 0.22%.
[b]. When the thickness is greater than 40mm, the carbon content of Q275B can be ≤ 0.22%.

Table C.2 Mechanical properties of carbon structural steel to GB/T 700 - 2006

Grade	Level	Tensile test							Impact test	Bend test[d]	
		Yield Strength[a] R_{eH} (N/mm^2), ≥ / Elongation after fracture A (%), ≥						Tensile strength[b] R_m (N/mm^2)	Impact Energy KV_2 (J) ≥	180° Bending diameter d	
		Thickness or diameter (mm)								Thickness[e] (mm)	
		≤16	>16 ~40	>40 ~60	>60 ~100	>100 ~150	>150 ~200			≤ 60	> 60 ~ 100
Q195	—	195	185	—	—	—	—	315 ~ 430	—	0 (L) 0.5a (H)	—
		33	33	—	—	—	—				
Q215	AB	215	205	195	185	175	165	335 ~ 450	27 (B)	0.5a (L) a (H)	1.5a (L) 2a (H)
		31	31	30	29	27	26				
Q235	AB CD	235	225	215	215	195	185	370 ~ 500	27[c] (BCD)	a (L) 1.5a(H)	2a (L) 2.5a (H)
		26	26	25	24	22	21				
Q275	AB CD	275	265	255	245	225	215	410 ~ 540	27 (BCD)	1.5a (L) 2a (H)	2.5a (L) 3.0a (H)
		22	22	21	20	18	17				

[a]. The yield strength of Q195 is for reference only, not in delivery conditions.
[b]. For steel with a thickness greater than 100 mm, the lower limit of tensile strength is allowed to be reduced by 20 N/mm^2, the upper limit of tensile strength of wide strips (including sheared plates) is not for delivery conditions.
[c]. For Q235B steel with thickness less than 25mm, if the supplier can guarantee the impact energy, the inspection can be neglected with the consent of the purchaser.
[d]. $B = 2a$, B is the width of the sample, and a is the thickness or diameter of the sample. L indicates that the sample direction is vertical, and H indicates that the sample direction is horizontal.
[e]. When the thickness (or diameter) of the steel is greater than 100mm, the bending test is determined by both parties.

Table C.3 Chemical composition of quality carbon structural steel to GB/T 699 - 2015

Grade	Chemical composition (%)							
	C	Si	Mn	P	S	Cr	Ni	Cu
				≤				
15	0.12~0.18	0.17~0.37	0.35~0.65	0.035	0.035	0.25	0.30	0.25
20	0.17~0.23	0.17~0.37	0.35~0.65	0.035	0.035	0.25	0.30	0.25
15Mn	0.12~0.18	0.17~0.37	0.70~1.00	0.035	0.035	0.25	0.30	0.25
20Mn	0.17~0.23	0.17~0.37	0.70~1.00	0.035	0.035	0.25	0.30	0.25

Table C.4 Mechanical properties of quality carbon structural steel to GB/T 699 - 2015

Grade	Specimen Blank Dimension (mm)	Normalizing Heating Temperature (°C)	Mechanical properties[a]					Delivery hardness without heat treatment
			Yield strength R_{eh} (N/mm^2)	Tensile strength *R* (N/mm^2)	Elongation at fracture *A* (%)	Area reduction at fracture *Z* (%)	Impact energy KU_2 (J)	
			≥					≤
15	25	920	375	225	27	55	—	143
20	25	910	410	245	25	55	—	156
15Mn	25	920	410	245	26	55	—	163
20Mn	25	910	450	275	24	50	—	197

[a] The mechanical properties in the table are applicable to steel bars of *D* (nominal diameter) or *t* (thickness) 80mm, when 80≤D(t)≤250, *A* and *Z* are allowed to decrease by 2% and 5% respectively than the values specified in this table, When 120≤D(t)≤250, it is allowed to forge(roll) to 70mm~80mmm for sampling, and the result should meet the requirements of this table.

Table C.5 Chemical composition of high strength low alloy structural steel to GB/T 1591-2018

Grade	Level	Chemical composition[a] (%)														
		C	Si	Mn	P	S	Nb	V	Ti	Cr	Ni	Cu	Mo	N	B	Als
		≤														≥
Q355	BC DE F	0.14 ~0.24	0.50 ~0.55	0.90 ~1.65	0.035 (B) 0.030 (C) 0.025 ~0.030 (D) 0.025 (E) 0.020 (F)	0.035 (B) 0.030 (C) 0.025 (D) 0.020 (E) 0.010 (F)	0.005 ~0.05	0.01 ~0.12	0.006 ~0.05	0.30	0.30 ~0.50	0.40	0.10	0.012 ~0.015	—	0.015
Q390	BC DE	0.15 ~0.20	0.60 ~0.55	0.90 ~1.70			0.01 ~0.05	0.01 ~0.20	0.006 ~0.05	0.30	0.50	0.40	0.10	0.015	—	0.015
Q420	BC DE	0.16 ~0.20	0.55 ~0.60	1.00 ~1.70			0.01 ~0.05	0.01 ~0.20	0.006 ~0.05	0.30	0.80	0.40	0.10 ~0.20	0.015 ~0.025	—	0.015
Q460	CDE	0.16 ~0.20	0.55 ~0.60	1.00 ~1.70			0.01 ~0.05	0.01 ~0.20	0.006 ~0.05	0.30	0.80	0.40	0.10 ~0.20	0.015 ~0.025	—	0.015
Q500	CDE	0.18	0.60	1.80 ~2.00	0.035 (B) 0.030 (C) 0.030 (D) 0.025 (E)	0.035 (B) 0.030 (C) 0.025 (D) 0.020 (E)	0.01 ~0.11	0.01 ~0.12	0.006 ~0.05	0.60	0.80	0.55	0.20	0.015 ~0.025	0.004	0.015
Q550	CDE	0.18	0.60	2.00			0.01 ~0.11	0.01 ~0.12	0.006 ~0.05	0.80	0.80	0.80	0.30	0.015 ~0.025	0.004	0.015
Q620	CDE	0.18	0.60	2.00 ~2.60			0.01 ~0.11	0.01 ~0.12	0.006 ~0.05	1.00	0.80	0.80	0.30	0.015 ~0.025	0.004	0.015
Q690	CDE	0.18	0.60	2.00			0.01 ~0.11	0.01 ~0.12	0.006 ~0.05	1.00	0.80	0.80	0.30	0.015 ~0.025	0.004	0.015

[a] The ranges of the chemical composition are used for as-rolled steel, normalized steel, normalizing rolling steel and thermomechanical processed steel.

Table C.6 Delivery conditions and CEV of high strength low alloy structural steel to GB/T 1591-2018

Grade			Carbon equivalent value CEV (%), ≤								
Grade[a]		Level	Nominal thickness (mm)								
			≤16	>16~30	>30~40	>40~63	>63~100	>100~120	>120~150	>150~250	>250~400
Q355	AR	BCD	0.45		0.47		0.47			0.49	—
	N	BCDEF	0.43				0.45	0.45			^
	M	BCDEF	0.39	0.39		0.40	0.45		0.45	—	—
Q390	AR	BCD	0.45		0.47		0.48			—	—
	N	BCDE	0.46				0.48	0.49			^
	M	BCDE	0.41	0.43		0.44	0.46		0.46	—	—
Q420	AR	BC	0.45		0.47		0.48			0.49	—
	N	BCDE	0.48				0.50	0.52			^
	M	BCDE	0.43	0.45		0.46	0.47		0.47	—	—
Q460	AR	C	0.47		0.49		0.49			—	—
	N	CDE	0.53				0.54	0.55			^
	M	CDE	0.45	0.46		0.47	0.48		0.48	—	—
Q500	M	CDE	0.47	0.47		0.47	0.48		0.48	—	—
Q550	M	CDE	0.47	0.47		0.47	0.48		0.48	—	—
Q620	M	CDE	0.48	0.48		0.48	0.49		0.49	—	—
Q690	M	CDE	0.49	0.49		0.49	0.49		0.49	—	—

[a] AR: as rolled; N: normalized or normalizing rolling; M: thermomechanical processed;
^ Determined by agreement.

Table C.7 Mechanical properties of high strength low alloy structural steel to GB/T 1591-2018

Grade	Level	Tensile and impact test[a b c]	Nominal thickness or diameter (mm)								
			≤16	>16~40	>40~63	>63~80	>80~100	>100~150	>150~200	>200~250	>250~400[c]
			≥								
Q355	B C D E F	R_{eH}(N/mm^2)	355	345	335	325	315~325	295~320	285	275	265
		R_m(N/mm^2)	470 ~ 630		450 ~ 630			430 ~ 600	450 ~ 600		450~600
		A(%)	22		21~22	20~22	18~22	18~22	17~21	17~21	17
		KU(J)	34 (B), 34 (C), 34 (D), 31 (E), 27 (F)								
Q390	B C D E	R_{eH}(N/mm^2)	390	380	360	340	340	320~335	310	300	—
		R_m(N/mm^2)	490 ~ 650		460 ~ 650			450 ~ 620	470~620	470~620	—
		A(%)	20~21		20	19~20	19~20	19	19	19	—
		KU(J)	34 (B), 34 (C), 34 (D), 31 (E)								
Q420	A B C D E	R_{eH}(N/mm^2)	420	400~410	390	370~380	360~370	340~365	330	320	—
		R_m(N/mm^2)	520 ~ 680		470 ~ 680			460 ~ 650	500 ~ 650	500 ~ 650	—
		A(%)	19~20		19	18~19	18~19	18~19	18	18	—
		KU(J)	34 (B), 34 (C), 40 (D), 31 (E)								
Q460	C D E	R_{eH}(N/mm^2)	460	440~450	430	410	400~410	380~390	380	370	—
		R_m(N/mm^2)	540 ~ 720		500 ~ 720			490 ~ 710	510~690	510~690	—
		A(%)	17~18		17	17	17	17	17	16	—
		KU(J)	34 (C), 40 (D), 31 (E)								
Q500	C D E	R_{eH}(N/mm^2)	500	490	480	460	450	—	—	—	—
		R_m(N/mm^2)	610 ~ 770		600 ~ 760	590 ~ 750	540 ~ 730	—	—	—	—
		A(%)	17		17	17	17	—	—	—	—
		KU(J)	55 (C), 47 (D), 31 (E)								
Q550	C D E	R_{eH}(N/mm^2)	550	540	530	510	500	—	—	—	—
		R_m(N/mm^2)	670 ~ 830		620 ~ 810	600 ~ 790	590 ~ 780	—	—	—	—
		A(%)	16		16	16	16	—	—	—	—
		KU(J)	55(C), 47(D), 31(E)								
Q620	C D E	R_{eH}(N/mm^2)	620	610	600	580	—	—	—	—	—
		R_m(N/mm^2)	710 ~ 880		690 ~ 880	670 ~ 860	—	—	—	—	—
		A(%)	15		15	15	—	—	—	—	—
		KU(J)	55 (C), 47 (D), 31 (E)								
Q690	C D E	R_{eH}(N/mm^2)	690	680	670	650	—	—	—	—	—
		R_m(N/mm^2)	770 ~ 940		750 ~ 920	730 ~ 900	—	—	—	—	—
		A(%)	14		14	14	—	—	—	—	—
		KU(J)	55 (C), 47 (D), 31 (E)								

a. R_{eH} – upper yield strength, R_m – lower yield strength, A – elongation at fracture, KU - impact absorbed energy; when the yield is not obvious, the nominal plastic elongation strength $R_{p0.2}$ should be used instead of the upper yield strength R_{eH};

b. When the test temperature is not specified, the impact test under temperature of 0℃、-20℃、-40℃、-60℃ should be conducted for the Level C、D、E、F of as-rolled steel, normalized steel, normalizing rolling and thermomechanical processed steel separately.

c. In this table, the longitudinal specimen is used in the impact test, and the transverse specimen can also be used.

Table C.7 Mechanical properties of high strength low alloy structural steel to GB/T 1591-2018 (continued)

180° bend test (D = bending center diameter, a = sample thickness or diameter)		
Sample direction	Nominal thickness or diameter	
	≤16mm	>16mm ~100mm
For steel plates and steel strips of width ≥ 600 mm, the tensile test uses transverse specimens; for other steel materials, the tensile test uses longitudinal specimens.	D = 2a	D = 3a

Table C.8 Chemical composition of quenched and tempered structural steel to GB/T 16270-2009

Grade	Level	Chemical composition [a,b] (%), ≥															
		C	Si	Mn	P	S	Cu	Cr	Ni	Mo	B	V	Nb	Ti	CEV[c] Product thickness (mm)		
															≤ 50	> 50 ~ 100	>1 00 ~ 150
Q460	CD	0.2	0.8	1.7	0.025	0.015	0.5	1.5	2	0.7	0.005	0.12	0.06	0.05	0.47	0.48	0.5
	EF				0.02	0.01											
Q500	CD	0.2	0.8	1.7	0.025	0.015	0.5	1.5	2.1	0.7	0.005	0.12	0.06	0.05	0.47	0.7	0.7
	EF				0.02	0.01											
Q550	CD	0.2	0.8	1.7	0.025	0.015	0.5	1.5	2	0.7	0.005	0.12	0.06	0.05	0.65	0.77	0.83
	EF				0.02	0.01											
Q620	CD	0.2	0.8	1.7	0.025	0.015	0.5	1.5	2.1	0.7	0.005	0.12	0.06	0.05	0.65	0.77	0.83
	EF				0.02	0.01											
Q690	CD	0.2	0.8	1.8	0.025	0.015	0.5	1.5	2	0.7	0.005	0.12	0.06	0.05	0.65	0.77	0.83
	EF				0.02	0.01											
Q800	CD	0.2	0.8	2	0.025	0.015	0.5	1.5	2.1	0.7	0.005	0.12	0.06	0.05	0.72	0.82	—
	EF				0.02	0.01											
Q890	CD	0.2	0.8	2	0.025	0.015	0.5	1.5	2	0.7	0.005	0.12	0.06	0.05	0.72	0.82	—
	EF				0.02	0.01											
Q960	CD	0.2	0.8	2	0.025	0.015	0.5	1.5	2.1	0.7	0.005	0.12	0.06	0.05	0.82	—	—
	EF				0.02	0.01											

[a] According to the needs of the production plant, one or several alloying elements may be added. The maximum value shall follow the provisions in the table, which shall be reported by Dong Ying in the certificate of the quality director.
[b] At least one of Nb, Ti, V, and Al should be added to the grain, and the minimum amount of at least one element is 0.015% (Als for Al), and Alt can be used instead of Als. It is 0.018%.
[c] CEV=C+Mn/6+(Cr+Mo+V)/5+(Ni+Cu)/15.

Table C.9 Mechanical properties of quenched and tempered structural steel to GB/T 16270-2009

Grade	Level	Tensile test[a]				Impact test[a]
		Yield strength[b] R_{eH} (N/mm²), ≥ / Tensile strength R_m (N/mm²), ≥			Elongation at fracture A (%) ≥	Impact energy KV_2 (J) ≥
		Thickness (mm)				
		50	>50~100	>100~150		
Q460	CDEF	460	440	400	17	47 (CD) 34 (EF)
		550~720		500~670		
Q500	CDEF	500	480	440	17	47 (CD) 34 (EF)
		590~770		540~720		
Q550	CDEF	550	530	490	16	47 (CD) 34 (EF)
		640~820		590~770		
Q620	CDEF	620	580	560	15	47 (CD) 34 (EF)
		700~890		650~830		
Q690	CDEF	690	650	630	14	47 (CD) 34 (EF)
		770~940	760~930	710~900		
Q800	CDEF	800	740	—	13	34 (CD) 27 (EF)
		840~1000	800~1000	—		
Q890	CDEF	890	830	—	11	34 (CD) 27 (EF)
		940~1100	880~1100	—		
Q960	CDEF	960	—	—	10	34 (CD) 27 (EF)
		980~1150	—	—		

[a] The tensile test is suitable for transverse specimens and the impact test is suitable for longitudinal tests.
[b] When the yielding phenomenon is not obvious, use $R_{P0.2}$.

Table C.10 Chemical composition of atmospheric corrosion resisting structural steel to GB/T 4171-2008

Grade	Chemical composition (%)								
	C	Si	Mn	P	S	Cu	Cr	Ni	Other
Q265GNH	≤0.12	0.10~0.40	0.20~0.50	0.07~0.12	≤0.020	0.20~0.45	0.30~0.65	0.25~0.50	a,b
Q295GNH	≤0.12	0.10~0.40	0.20~0.50	0.07~0.12	≤0.020	0.25~0.45	0.30~0.65	0.25~0.50	a,b
Q310GNH	≤0.12	0.25~0.75	0.20~0.50	0.07~0.12	≤0.020	0.20~0.50	0.30~1.25	≤0.65	a,b
Q355GNH	≤0.12	0.25~0.75	≤1.00	0.07~0.75	≤0.020	0.25~0.55	0.30~1.25	≤0.65	a,b
Q235NH	≤0.13[d]	0.10~0.40	0.20~0.60	≤0.030	≤0.030	0.25~0.55	0.40~0.80	≤0.65	a,b
Q295NH	≤0.15	0.10~0.50	0.30~1.00	≤0.030	≤0.030	0.25~0.55	0.40~0.80	≤0.65	a,b
Q355NH	≤0.16	≤0.50	0.50~1.50	≤0.030	≤0.030	0.25~0.55	0.40~0.80	≤0.65	a,b
Q415NH	≤0.12	≤0.65	≤1.10	≤0.025	≤0.030[d]	0.20~0.55	0.30~1.25	0.12~0.65[e]	a,b,c
Q460NH	≤0.12	≤0.65	≤1.50	≤0.025	≤0.030[d]	0.20~0.55	0.30~1.25	0.12~0.65[e]	a,b,c
Q500NH	≤0.12	≤0.65	≤2.00	≤0.025	≤0.030[d]	0.20~0.55	0.30~1.25	0.12~0.65[e]	a,b,c
Q550NH	≤0.16	≤0.65	≤2.00	≤0.025	≤0.030[d]	0.20~0.55	0.30~1.25	0.12~0.65[e]	a,b,c

[a.] In order to improve the performance of the steel, one or more trace alloy elements may be added: Nb 0.015%~0.060%, V 0.02%~0.12%, Ti 0.02%~0.10%, Alt≥0.20%. When the above elements are used in combination, at least the content of one of the elements should be at least the lower limit of the above chemical composition.
[b.] The following alloying elements can be added: Mo≤0.30%, Zr≤0.15%.
[c.] The total amount of Nb, V, Ti and other alloying elements should not exceed 0.22%.
[d.] The supply and demand sides negotiate that the content of S can be no more than 0.008%, the lower limit of Ni content cannot be required, and the content of C can be no more than 0.15%.

Table C.11 Mechanical properties of atmospheric corrosion resisting structural steel to GB/T 4171-2008

Grade	Tensile test[a]					Impact test[b]	Bend test[d]		
	Low yield strength R_{eL} (N/mm^2), ≥ / Elongation at fracture *A* (%), ≥				Tensile strength R_m (N/mm^2)	Impact energy KV_2 (J) ≥	180° bending centre diameter		
	Thickness (mm)						Thickness (mm)		
	≤16	>16~40	>40~60	>60~100			≤6	>6~16	>16
Q235NH	235	225	215	215	360~510	≥47J (B) ≥34J (C) ≥34J (D) ≥27J[c] (E)	a	a	2a
	25	25	24	23					
Q295NH	295	285	275	255	430~560		a	2a	3a
	24	24	23	22					
Q355NH	355	345	335	325	490~630		a	2*a*	3*a*
	22	22	21	20					
Q415NH	415	405	395	—	520~680		a	2*a*	3*a*
	22	22	20	—					
Q460NH	460	450	440	—	570~730		a	2*a*	3*a*
	20	20	19	—					
Q500NH	500	490	480	—	600~760		a	2*a*	3*a*
	18	16	15	—					
Q550NH	550	540	530	—	620~780		a	2*a*	3*a*
	16	16	15	—					
Q265GNH	265[c]	—	—	—	≥410		a	—	—
	27[c]	—	—	—					
Q295GNH	295	285[d]	—	—	430~560		a	2*a*	3*a*
	24	24[d]	—	—					
Q310GNH	310[c]	—	—	—	≥450		a	—	—
	26[c]	—	—	—					
Q355GNH	355	345[d]	—	—	490~630	Ibid.	a	2*a*	3*a*
	22	22[d]	—	—					

a. When the yielding phenomenon is not obvious, it can be used, RP0.2.
b. The direction of the impact specimen was longitudinal, and the size was 10 mm × 10 mm × 55 mm.
c. After negotiation between the supplier and the buyer, the average impact energy value can be ≥60J.
d. *a* is the thickness of the sample.

Table C.12 Chemical composition of steel plates for building structures to GB/T 19879-2015

Grade	Level	Chemical composition (%)												
		C	Si	Mn	P	S	V[b]	Nb[b]	Ti[b]	Als[a]	Cr	Cu	Ni	Mo
		≤			≤					≥	≤			
Q235GJ	B, C	0.20	0.35	0.60~1.50	0.025	0.015	—	—	—	0.015	0.30	0.30	0.30	0.08
	D, E	0.18			0.020	0.010								
Q345GJ	B, C	0.20	0.55	≤1.60	0.025	0.015	0.150	0.070	0.035	0.015	0.30	0.30	0.30	0.20
	D, E	0.18			0.020	0.010								
Q390GJ	B, C	0.20	0.55	≤1.70	0.025	0.015	0.200	0.070	0.030	0.015	0.30	0.30	0.70	0.50
	D, E	0.18			0.020	0.010								
Q420GJ	B, C	0.20	0.55	≤1.70	0.025	0.015	0.200	0.070	0.030	0.015	0.80	0.30	1.00	0.50
	D, E	0.18			0.020	0.010								
Q460GJ	B, C	0.20	0.55	≤1.70	0.025	0.015	0.200	0.110	0.030	0.015	1.20	0.50	1.20	0.50
	D, E	0.18			0.020	0.010								
Q500GJ	C	0.18	0.60	≤1.80	0.025	0.015	0.120	0.110	0.030	0.015	1.20	0.50	1.20	0.60
	D, E				0.020	0.010								
Q550GJ[c]	C	0.18	0.60	≤2.00	0.025	0.015	0.120	0.110	0.030	0.015	1.20	0.50	2.00	0.60
	D, E				0.020	0.010								
Q620GJ[c]	C	0.18	0.60	≤2.00	0.025	0.015	0.120	0.110	0.030	0.015	1.20	0.50	2.00	0.60
	D, E				0.020	0.010								
Q690GJ[c]	C	0.18	0.60	≤2.20	0.025	0.015	0.120	0.110	0.030	0.015	1.20	0.50	2.00	0.60
	D, E				0.020	0.010								

a. Allow the full aluminum content (Alt) to replace the acid-soluble aluminum content (Als). At this time, Alt should be not less than 0.020%. If any element of V, Nb or Ti is added to the steel, and the content is not less than 0.015%, the minimum aluminum content is not applicable.

b. When V, Nb, and Ti are added in combination, for V235GJ, Q345GJ, (V+Nb+Ti) ≤ 0.15%, and for Q390GJ, Q420GJ, and Q460GJ, (V+Nb+Ti) ≤ 0.22%.

c. When boron is added, B ≤ 0.003% in Q550GJ, Q620GJ, Q690GJ and quenched and tempered steel.

d. For the thickness direction performance steel sheets, the sulfur contents of Z15, Z25, and Z35 are not more than 0.010%, 0.007%, and 0.005%, respectively.

Table C.13 Carbon equivalent or welding crack susceptibility of steel plates for building structures under various delivery conditions to GB/T 19879-2015

Grade	Delivery condition [a]	Carbon equivalent value CEV (%) or Welding crack susceptibility P_{cm} (%) of nominal thickness *t* (mm)			
		$t \leq 50$[b]	$50 < t \leq 100$	$100 < t \leq 150$	$150 < t \leq 200$
		P_{cm} CEV ≤ / P_{cm} ≤			
Q235GJ	WAR、WCR、N	0.34 / 0.24	0.36 / 0.26	0.38 / 0.27	—
Q345GJ	WAR、WCR、N	0.42 / 0.26	0.44 / 0.29	0.46 / 0.30	0.47 / 0.30
	TMCP	0.38 / 0.24	0.40 / 0.26	—	—
Q390GJ	WCR、N、NT	0.45 / 0.28	0.47 / 0.30	0.49 / 0.31	—
	TMCP、TMCP+T	0.40 / 0.26	0.43 / 0.27	—	—
Q420GJ	WCR、N、NT	0.48 / 0.30	0.50 / 0.33	0.52 / 0.32	—
	QT	0.44 / 0.28	0.47 / 0.30	0.49 / 0.31	—
	TMCP、TMCP+T	0.40 / 0.26	Negotiated	—	
Q460GJ	WCR、N、NT	0.52 / 0.32	0.54 / 0.34	0.56 / 0.35	—
	QT	0.45 / 0.28	0.48 / 0.30	0.50 / 0.31	—
	TMCP、TMCP+T	0.42 / 0.27	Negotiated	—	
Grade	**Delivery condition[a]**	**Carbon equivalent value CEV (%) or Welding crack susceptibility P_{cm} (%) of nominal thickness *t* (mm)**			
		$t \leq 50$[b]			
		P_{cm} CEV ≤ / P_{cm} ≤			
Q500GJ	QT	0.52 / Negotiated			
	TMCP, TMCP+T	0.47 / 0.28[c]			
Q550GJ	QT	0.54 / Negotiated			
	TMCP, TMCP+T	0.47 / 0.29[c]			
Q620GJ	QT	0.58 / Negotiated			
	TMCP, TMCP+T	0.48 / 0.30[c]			
Q690GJ	QT	0.60 / Negotiated			
	TMCP, TMCP+T	0.50 / 0.30[c]			

[a] WAR: as-rolled, WCR: controlled rolling, N: normalized, NT: normalized + tempered, TMCP: thermomechanical processed, TMCP + T: thermomechanical processed + tempered, QT: quenched (including online direct quenching) + tempered.
[b] Q500GJ、Q550GJ、Q620GJ、Q690GJ maximum thickness is 40mm.
[c] For reference only.

Table C.14 Mechanical properties of steel plates for building structures to GB/T 19879-2015

Grade	Level	Tensile test: Low yield strength R_{eL} (N/mm2) / Tensile strength R_m (N/mm2) / Yield ratio — Plate thickness (mm) 6~16	>16~50	>50~100	>100~150	>150~200	Elongation at fracture A (%) ≥	Impact test: Impact energy KV_2 (J) ≥	Bend test[b]: 180° bending head diameter *D* — Thickness (mm) ≤16	>16
Q235GJ	B C D E	≥235	235~345	225~335	215~325	—	23	47	D=2*a*	D=3*a*
		400~510			380~510	—				
		≤0.80				—				
Q345GJ	B C D E	≥345	345~455	335~445	325~435	305~415	22	47		
		490~610			470~610	70~610				
		≤0.80				≤0.80				
Q390GJ	B C D E	≥390	390~510	380~500	370~490	—	20			
		510~660			490~640	—				
		≤0.83				—				
Q420GJ	B C D E	≥420	420~550	410~540	400~530	—	20			
		530~680			510~660	—				
		≤0.83				—				
Q460GJ	B C D E	≥460	460~600	450~590	440~580	—	18			
		570~720			550~720	—				
		≤0.83				—				

Grade	Level	Tensile test: Low yield strength[a] R_{eL} (N/mm2) — Thickness (mm) 12~20	>20~40	Tensile strength R_m (N/mm2)	Yield ratio ≤	Elongation at fracture A (%) ≥	Impact test: Impact energy (KV_2/J) ≥	Bend test[b]: 180° Bending head diameter D
Q500GJ	C D E	≥500	500 ~610	610~770	0.85	17	55 (C) 47 (D) 31 (E)	D=3*a*
Q550GJ	C D E	≥550	550 ~690	670~830				
Q620GJ	C D E	≥620	620 ~770	730~900				
Q690GJ	C D E	≥690	690 ~860	770~9’10				

a. If the yielding phenomenon is not obvious, the yield strength is $R_{P0.2}$.
b. *a* is the thickness of the sample.

Table C.15 Chemical composition of cold rolled steel sheets and strips of carbon structural steel to GB/T 11253-2019

Grade	Chemical composition (%), ≤				
	C	Si	Mn	P[a]	S
Q195	0.12	0.30	0.50	0.035	0.035
Q215	0.15	0.35	1.20	0.035	0.035
Q235	0.22	0.35	1.40	0.035	0.035
Q275	0.24	0.35	1.50	0.035	0.035
Q325	0.20	0.55	1.60	0.035	0.025

a. With the consent of the purchaser, P is a solid solution strengthening element, and the upper limit should be no more than 0.12% .

Table C.16 Mechanical properties of cold rolled steel sheets and strips of carbon structural steel to GB/T 11253-2019

Grade	Tensile test				Bend test[c, d]	
	Low yield strength R_{eL}[a] (N/mm^2)	Tensile strength R_m (N/mm^2)	Elongation at fracture[b] A (%)		180° bending centre diameter d	
			A_{50mm}	A_{80mm}		
Q195	≥195	315 ~ 430	26	24	Transverse specimen	0.5a
Q215	≥215	335 ~ 450	24	22		0.5a
Q235	≥235	370 ~ 500	22	20		1a
Q275	≥275	410 ~ 540	20	18		1a
Q325	≥325	510 ~ 680	18	16	--	--

a. $R_{P0.2}$ was used when yield is not obvious.
b A_{80mm} was used when the demand sidedidn't specify.
c. The test width $B \geq 20$ mm, $B = 20$ mm during the arbitration test.
d. a is the thickness of the sample.

Table C. 17 Chemical composition and mechanical properties of continuously hot-dip zinc and zinc alloy coated steel sheets and strips to GB/T 2518-2019

Grade	Chemical composition (%), ≤					Mechanical properties, ≤		
	C	Si	Mn	P	S	Yield strength[a,b] R_{eH} or $R_{P0.2}$ (N/mm^2)	Tensile strength[c] R_m (0N/mm^2)	Elongation at fracture[d] A (%)
S220GD	0.20	0.60	1.70	0.10	0.045	220	300	20
S250GD						250	330	19
S280GD						280	360	18
S300GD						300	370	18
S320GD						320	390	17
S350GD						350	420	16
S390GD						390	460	16
S420GD						420	480	15
S450GD						450	510	14
S550GD						550	560	—

[a] $R_{P0.2}$ was used when yield is not obvious.
[b] The test piece is a P6 sample in GB/T 228.1, and the direction is longitudinal.
[c] In addition to S550GD+Z (ZF), the tensile strength of other grades can require a range of 140 MPa.
[d] When the nominal thicknesses of the products are 0.5mm ~ 0.7mm, 0.35mm ~ 0.5mm, and 0.20mm ~ 0.35mm, the elongations at fracture are allowed to decrease by 2%, 4%, and 7%, separately.

TableC.18 Chemical composition of carbon steel castings for general engineering purposes to GB/T 11352-2009

Grade	Chemical composition (main element)[a] (%), ≤				
	C	Si	Mn	P	S
ZG200-400	0.20	0.60	0.80	0.035	0.035
ZG230-450	0.30				
ZG270-500	0.40		0.90		
ZG310-570	0.50				
ZG340-640	0.60				

[a] Residual elements are generally not analysed. See Table 1 of GB/T 11352-2009 for the limits.

TableC.19 Mechanical properties of c carbon steel castings for general engineering purposes to GB/T 11352-2009

Grade	Tensile test, ≥			Others	
	Low yield strength R_{eL}[a] (N/mm^2)	Tensile strength R_m (N/mm^2)	Elongation at fracture A (%)	Area reduction at fracture Z (%)	Min. impact energy A_{KV2} (J)
ZG200-400	200	400	25	40	30
ZG230-450	230	450	22	32	25
ZG270-500	270	500	18	25	22
ZG310-570	310	570	15	21	15
ZG340-640	340	640	10	18	10

a. When there is no obvious yield, use $R_{P0.2}$.
b. The performance of each grade listed in the table applies to castings with a thickness of less than 100mm. When it is more than 100mm thick, the yield strength in the table is for design use only.

Table C.20 Chemical composition of steel castings for welded structures to GB/T 7659-2010

Grade	Main element of chemical composition[a] (%)				
	C	Si	Mn	P	S
ZG200-400H	≤ 0.20	≤0.60	≤ 0.80	≤ 0.025	≤ 0.025
ZG230-450H			≤ 1.20		
ZG270-480H	0.17 ~ 0.25		0.08 ~ 1.20		
ZG300-500H			1.00 ~ 1.60		
ZG340-550H			1.00 ~ 1.60		

a. Residual elements are generally not analysed. See Table 1 of GB/T 7659-2010 for the limits.

TableC.21 Mechanical properties of steel castings for welded structures to GB/T 7659-2010

Grade	Tensile test			Others	
	Upper yield strength R_{eH}[a] (N/mm^2) ≤	Tensile strength R_m (N/mm^2) ≤	Elongation at fracture A (%) ≤	Area reduction at fracture Z (%) ≤	Min. impact energy A_{KV2} (J) ≤
ZG200-400H	200	400	25	40	45
ZG230-450H	230	450	22	35	45
ZG270-480H	270	480	20	35	40
ZG300-500H	300	500	20	21	40
ZG340-550H	340	550	15	21	35

a. When there is no obvious yield, use $R_{P0.2}$.

Appendix D Steel Grade Designations

Carbon structural steel and high-quality carbon structural steel

GB/T 700 *Carbon Structural Steel*

Q 235 A F

- Deoxidation method: F=Rimmed steel, Z=Killed steel (Optional), TZ=Special killed steel (Optional)
- Quality level [a]: A, B, C, D
- Yield strength: R_{eH} / (N/mm^2): 195, 215, 235, 275
- The first letter of Pinyin "Qu" means yield strength

[a.] The quality level is divided according to the impact test requirements: A is no impact, B is 20ºC normal temperature impact, C is 0ºC impact, and D is -20ºC impact.

GB/T 699 *Quality carbon structural steel*

15 Mn

- Mn = High manganese steel (0.7%~1.0%), F=Rimmed steel (optional), b-Semi-killed steel
- The average carbon content of the million points: 15, 20.

High strength low alloy steel and structural steel in the quenched and tempered condition

GB/T 1591 *High-strength low-alloy structural steel*

Q 355 N D Z25

- Through thickness property [b]: Z15、Z25、Z35
- Quality level [a]: B, C, D, E, F
- Delivery condition: AR (as-rolled), N (normalized), +N (normalizing rolling), M (thermomechanical processed)
- Yield strength value R_{eL} / (N/mm^2): 355, 390, 420, 460, 500, 550, 620, 690
- Yield strength

[a.] A = not impact, B = 20ºC normal temperature impact, C = 0ºC impact, D = -20ºC impact, and E = -40ºC impact.
[b.] The value is the average reduction of area ψ_z (%) in the thickness direction of the Z-direction steel, which shall meet the requirements of GB/T 5313.

GB/T 16270 *High strength structural steel plates in the quenched and tempered condition*

Q 460 E

- Quality level [a]: C、D、E、F
- Yield strength: R_{eH} / (N/mm^2): 460、500、550、620、690、800、890、960
- The first letter of Pinyin "Qü" means yield strength

[a.] The quality level is divided according to the impact test: C = 0ºC, D = -20ºC, E = -40ºC, and F = -60ºC.

Atmospheric corrosion resisting structural steel

GB/T 4171 *Atmospheric corrosion resisting structural steel*

Q 355 GNH C

- C — Quality level [a]: A、B、C、D、E
- GNH — First letter of Pinyin "Gao, Nai, and Hou" means high weather corrosion resistance [b]
- 355 — Yield strength R_{eL} / (N/mm^2): 235~550
- Q — The first letter of Pinyin "Qu" means yield strength

[a] The quality grade is divided according to the requirements of the V-notch impact test: A = no impact, B = 20ºC normal temperature impact, C = 0ºC impact, D = -20ºC impact, and E = -40ºC impact.

[b] High weathering steel (GNH) has good atmospheric corrosion resistance while weathering steel (NH) has good welding performance.

Steel plates for building structures

GB/T 19879 Steel plates for building structures

Q 345 GJ C Z25

- Z25 — Through thickness property [b]: Z15、Z25、Z35
- C — Quality level [a]: B、C、D、E
- GJ — Pinyin letters representing steel for high performance building structures
- 345 — Yield strength: R_{eL} / (N/mm^2): 235, 345, 390, 420, 460, 500, 550, 620, 690
- Q — The first letter of Pinyin "Qü" means yield strength·

[a] B = 20ºC normal temperature impact, C = 0ºC impact, D = -20ºC impact, and E = -40ºC impact.

[b] The value is the average reduction of area ψ_z (%) in the thickness direction of the Z-direction steel, which shall meet the requirements of GB/T 5313.

Steel plates and strips

GB/T 11253 Cold-rolled sheets and strips of carbon structural steel

Q 195

- 195 — Yield strength: R_{eL} / (N/mm^2): 195, 215, 235, 275, 325
- Q — The first letter of Pinyin "Qü" means yield strength

GB/T 2518 Continuously hot-dip zinc and zinc alloy coated steel sheets and strips

S 250 G D + Z

- Z — Coating: Z (Zinc), ZF (Zinc and Ferrite)
- D — Hot dip
- G — Characteristics of steel is not specified
- 250 — Minimum yield strength value (N/mm^2): 220, 250, 280, 320, 350, 550
- S — Structural steel

Cast steel

GB/T 11352 Carbon steel casting for general engineering purposes

ZG 270-500

- **500** — Tensile strength (N/mm^2): 400, 450, 480, 570, 640
- **270** — Yield strength (N/mm^2): 200, 230, 270, 310, 340
- **ZG** — Cast steel

GB/T 7659 Steel casting suitable for welded structures

ZG 300-500 H

- **H** — Welded steel
- **500** — Tensile strength (N/mm^2): 400, 450, 480, 500, 550
- **300** — Yield strength (N/mm^2): 200, 230, 270, 300, 340
- **ZG** — Cast steel

Appendix E Designations and Dimensions of Structural Steel

Table E.1 Nominal sizes of hot rolled steel sheets and strips to GB/T 709-2006

Type	Nominal dimension	Nominal thickness	Nominal width	Nominal length
Single -rolled plate	Dimension range	3 mm ~ 450 mm	600 mm ~ 5300 mm	2 m ~ 25 m
	Recommended dimension change multiples	0.5 mm (t < 30 mm) 1.0 mm (t ≥ 30 mm)	10 mm or 50 mm	50mm or 100mm
Continuous -rolled plate	Dimension range	≤ 25.4 mm	600 mm ~ 2200 mm	2 m ~ 25 m
	Recommended dimension change multiples	0.1 mm	10 mm	50mm or 100mm
Strip	Dimension range	≤ 25.4mm	Wide strip: 600mm ~ 2200mm Slitting strip: 120mm ~ 900mm	Coil
	Recommended dimension change multiples	0.1mm	10mm	--

Table E.2 Nominal sizes of cold rolled steel sheets and strips to GB/T 708-2019

Type	Nominal dimension	Nominal thickness	Nominal width	Nominal length (Plate)
Plate and strip	Dimension range	≤ 4.00 mm	≤ 2150mm	1m ~ 6m
	Recommended dimension change multiples	0.05mm (<1.0mm) 0.10mm (≥1.0mm)	10mm	50mm

Table E.3 Designations and dimensions of hot rolled H and split T sections to GB/T 11263-2017

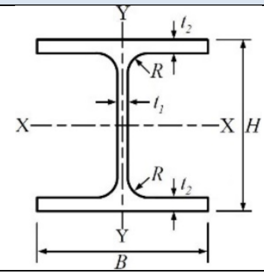
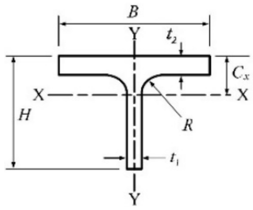
Item	Hot rolled H sections				Split T-sections		
Secion view							
	H – height, B – width, t_1 – web thickness, t_2 – flange thickness, R – fillet radius, C_x – centre of gravity.						
Class and code	Wide flange H-sections	Middle flange H-sections	Narrow flange H-sections	Thin wall H-sections	Wide flange Split T-sections	Middle flange Split T-sections	Narrow flange Split T-sections
	HW	HM	HN	HT	TW	TM	TN
Designation H×B (mm×mm)	100×100 125×125 150×150 175×175 200×200 250×250 300×300 350×350 400×400 *500×500	150×100 200×150 250×175 300×200 350×250 400×300 450×300 500×300 *550×300 600×300	*100×50 *125×60 150×75 175×90 200×100 250×125 300×150 350×175 400×150 400×200 450×150 450×200 475×150 500×150 500×200 550×200 600×200 625×200 *650×300 700×300 *750×300 800×300 *850×300 900×300 *1000×300	100×50 100×100 125×60 125×125 150×75 150×100 150×150 175×90 175×175 200×150 200×200 250×125 250×175 300×150 300×200 350×175 400×150 400×200	50×100 62.5×125 75×150 87.5×175 100×200 125×250 150×300 175×350 200×400	75×100 100×150 125×175 150×200 175×250 200×300 225×300 250×300 *275×300 300×300	*50×50 *62.5×60 75×75 87.5×90 100×100 125×125 150×150 175×175 200×200 225×150 225×200 250×150 250×200 275×200 300×200 312.5×200 *325×300 350×300 400×300 450×300
Note 1: The designations indicated with "*"are not commonly used. Note 2: For further details, refer to Table 1 and Table 2 of GB/T 11263-2017.							

Table E.4 Designations and dimensions of welded H-sections to GB/T 33814-2017

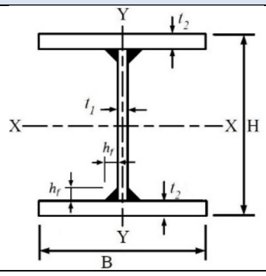
Item	Welded H sections
Section view	 *H* – height, *B* – width, t_1 – web thickness, t_2 – flange thickness, *R* – fillet radius, h_f – size of fillet.
Code	WH
Designation *H*×*B* (mm×mm)	100×50, 100×75, 100×100, 125×75, 125×125, 150×75, 150×100, 150×150, 200×100, 200×150, 200×200, 250×125, 250×150, 250×200, 250×250, 300×200, 300×250, 300×300, 350×175, 350×200, 350×250, 350×300, 350×350, 400×200, 400×250, 400×300, 400×400, 450×250, 450×300, 450×400, 500×250, 500×300 , 500×400, 500×500, 600×300, 600×400, 700×300, 700×350, 700×400, 800×300, 800×350, 800×400, 800×400, 900×350, 900×400, 1100×400, 1100×500, 1200×400, 1200×450, 1200×500, 1200×600, 1300×450, 1300×500, 1300×600, 1400×450, 1400×500, 1400×600, 1500×500, 1500×550, 1500×600, 1600×600, 1600×650, 1600×700, 1700×600, 1700×650, 1700×700, 1700×750, 1800×600, 1800×650, 1800 × 700, 1800×750, 1900×650, 1900×700, 1900×750, 1900×800, 2000×650, 2000×700, 2000×750, 2000×800, 2000×850
Note 1: For further details, refer to Appendix A of GB/T 33814-2017.	

Table E.5 Designations and dimensions of hot rolled sections to GB/T 706-2016

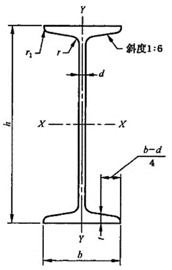
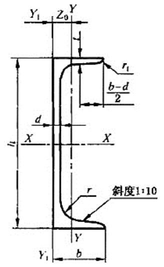
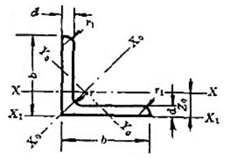
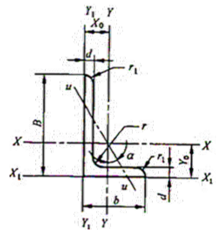
Item	Joist	Channel	Equal angle	Unequal angle
Section and mark				
	h – height, *b* – flange width, *d* – web thickness, *t* – thickness at mid-flange, *r* – fillet radius, r_1 – flange edge radius, Z_0 – centre of gravity.		*B* – side width, *b* – side (short side) width, *d* – side thickness, *r* – fillet radius, r_1 – flange edge radius, X_0, Y_0, Z_0 – centre of gravity.	
Code	**I**	**[**	∠	∠
Designation	Height *h* (cm)	Height *h* (cm)	Side length *b* (cm)	Side lengths *B&b* (cm)
	10, 12, 12.6, 11, 16, 18, 20a, 20b, 22a, 22b, 24a, 24b, 25a, 25b, 27a, 27b, 28a, 28b, 30a, 30b, 30c, 32a, 32b, 32c, 36a, 36b, 36c, 40a, 40b, 40c, 45a, 45b, 45c, 50a, 50b, 50c, 55a, 55b, 55c, 56a, 56b, 56c, 63a, 63b, 63c.	5, 6.3, 6.5, 8, 10, 12, 12.6, 14a, 14b, 16a, 16b, 18a, 18b, 20a, 20b, 22a, 22b, 24a, 24b, 24c, 25a, 25b, 25c, 27a, 27b, 27c, 28a, 28b, 28c, 30a, 30b, 30c, 32a, 32b, 32c, 36a, 36b, 36c, 40a, 40b, 40c.	2, 2.5, 3.0, 3.6, 4, 4.5, 5, 5.6, 6, 7, 7.5, 8, 9, 10, 11, 12.5, 15, 16, 18, 20, 22, 25.	2.5 & 1.6, 3.2 & 2, 4 & 2.5, 4.5 & 2.8, 5 & 3.2, 5.6 & 3.6, 6.3 & 4, 7 & 4.5, 7.5 & 5, 8 & 5, 9 & 5.6, 10 & 6.3, 10 & 8, 11 & 7, 12.5 & 8, 14 & 9, 15 & 9, 16 & 10, 18 & 11, 20 & 12.5.
Note 1: For further details, refer to Appendix A of GB/T 706-2016.				

Table E.6 Designations and dimensions of cold formed open sections for general structures to GB/T 6723-2017

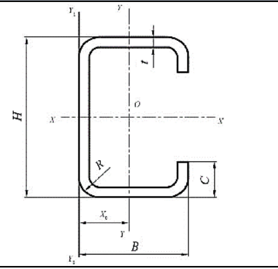
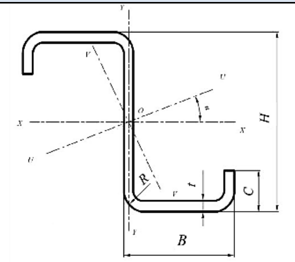
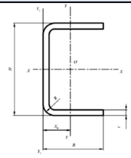
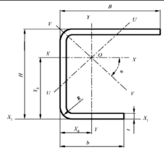
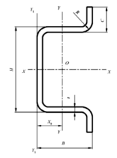
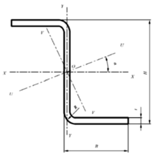
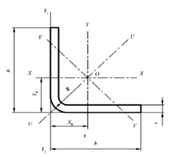
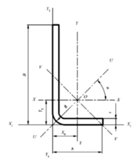
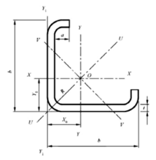
<table>
<tr><th>Item</th><th>Cold-formed lipped channel</th><th>Cold-formed lipped Z-section</th><th>Other sections</th></tr>
<tr><td rowspan="2">Section view</td><td></td><td></td><td rowspan="4">
Cold-formed channel (CD)

Cold-formed unequal channel (CB)

Cold-formed outer lipped channel (CW)

Cold-formed Z-section (Z)

Cold formed equal angle (JD)

Cold formed unequal angle (JB)

cold-formed lipped equal angle (JJ)</td></tr>
<tr><td colspan="2">B – side width, H – height, C – lipped EDge,
t – side thickness, R – corner radius.</td></tr>
<tr><td>Code</td><td>CN</td><td>ZJ</td></tr>
<tr><td>Designation
H×B×C×t
(all in mm)</td><td>60×30×10×2.5, 3.0,
80×40×15×2.0,
100×50×15×2.5,
100×50×20×2.5, 3.0,
120×50×20×2.5,
120×60×20×3.0,
140×50×20×2.0,
140×50×20×2.5,
140×60×20×2.5, 3.0,
160×60×20×2.0, 2.5,
160×70×20×3.0,
180×60×20×3.0,
180×70×20×3.0,
180×70×20×2.0, 2.5,
200×60×20×3.0,
200×70×20×2.0, 2.5, 3.0,
220×75×20×2.0, 2.5,
250×40×15×3.0,
300×40×15×3.0,
400×50×15×3.0,
450×70×30×6.0, 8.0,
500×100×40×6.0, 8.0, 10,
550×120×50×8.0, 10, 12,
600×150×60×12, 14, 16.</td><td>100×40×20×2.0, 2.5,
120×50×20×2.0, 2.5, 3.0,
140×50×20×2.5, 3.0,
160×60×20×2.5, 3.0,
160×70×20×2.5, 3.0,
180×70×20×2.5, 3.0,
230×75×25×3.0, 4.0,
250×75×25×3.0, 4.0,
300×100×30×4.0, 6.0,
400×120×40×8.0, 10.</td></tr>
</table>

Table E.7 Designations and dimensions of cold formed tubes for general structures to GB/T 6728-2017

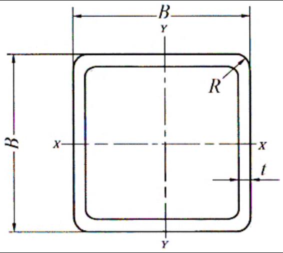
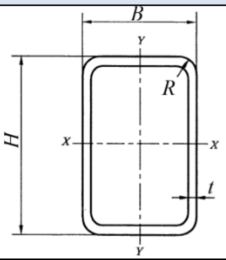
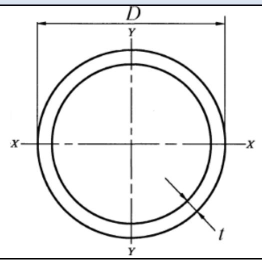
Item	**Cold-formed square tubes**		**Cold-formed rectangular tubes**			**Cold-formed circular tubes**	
Section view							
	B – Side length, *t* – Wall thickness, *R* – Outer corner radius.		*H* – Long side, *B* – Short side, *t* – Wall thickness, *R* – Outer corner radius.			*D* – Outer diameter, *t* – Wall thickness.	
Code	F		J			Y or *ϕ*	
Designation B × t H × B × t D × t (all in mm)	*B* (mm)	*t* (mm)	*H* (mm)	*B* (mm)	*t* (mm)	*D* (mm)	*t* (mm)
	20, 25, 30, 40, 50, 60, 70, 80, 90, 100, 110, 120, 130, 140, 150, 160, 170, 180, 190, 200, 220, 250, 280, 300, 350, 400, 450, 500.	1.2, 1.5, 1.75, 2.0, 2.5, 3.0, 4.0, 5.0, 6.0, 8.0, 10, 12, 14, 16.	30, 40, 50, 55, 60, 70, 80, 90, 95, 100, 120, 140, 150, 160, 180, 200, 220, 250, 260, 300, 350, 400, 450, 500, 550, 600.	20, 25, 30, 40, 50, 55, 60, 65, 80, 100, 120, 150, 180, 200, 250, 300, 350, 400.	1.5, 1.75, 2.0, 2.5, 3.0, 4.0, 5.0, 6.0, 8.0, 10, 12, 14, 16.	21.3, 26.8, 33.5, 42.3, 48, 60, 75.5, 88.5, 114, 140, 165, 219.1, 273, 325, 355.6, 406.4, 457, 508, 610.	1.2, 1.5, 1.75, 2.0, 2.5, 3.0, 4.0, 5.0, 6.0, 8.0, 10, 12, 12.5, 16.

Table E.8 Nominal dimensions of seamless steel tubes for structural purposes to GB/T 8162-2018

Common length *L*	3 m ~ 12 m
Outer diameter *D* (mm)	10, 13.5, 17, 21, 27, 34, 42, 48, 60, 76, 89, 114, 140, 168, 219, 273, 325, 356, 406, 457, 508, 610, 711, 813, 914, 1016.
Wall thickness *t* (mm)	0.25, 0.30, 0.40, 0.50, 0.60, 0.80, 1.0, 1.2, 1.4, 1.5, 1.6, 1.8, 2.0, 2.2, 2.5, 2.8, 3.0, 3.2, 3.5, 4.0, 4.5, 5.0, 5.5, 6.0, 6.5, 7.0, 7.5, 8.0, 8,5, 9.0, 9.5, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 22, 24, 25, 26, 28, 30, 32, 34, 36, 38, 40, 42, 45, 48, 50, 55, 60, 65,70, 75, 80, 85, 90, 95, 100, 110, 120.
Note: This table lists the dimensions of ordinary seamless steel pipes. The dimensions of precision seamless steel pipes and stainless-steel seamless steel pipes may be found in GB/T 17395.	

Table D.9 Nominal sizes of steel pipes with a longitudinal electric (resistance) weld to GB/T 13793-2016

Common length *L*	$D \leq 30$ mm, $L = 4$ m to 6 m, $D > 30$ mm ~ 70 mm, $L = 4$ m to 8 m, $D > 70$ mm, $L = 4$ m to 12 m.
Outer diameter *D* (mm)	10.2, 13.5, 17.2, 21.3, 26.9, 33.7, 42.4, 48.3, 60.3, 76.1, 88.9, 114.3, 139.7, 168.3, 219.1, 273.1, 323.9, 355.6, 406.4, 457, 508, 610, 711, 813, 914, 1016, 1067, 1118, 1219, 1422, 1626, 1829, 2032, 2235, 2540.
Wall thickness *t* (mm)	0.50, 0.60, 0.80, 1.0, 1.2, 1.4, 1.6, 1.8, 2.0, 2.3, 2.6, 2.9, 3.0, 3.6, 4.0, 4.5, 5.0, 5.4, 5.6, 6.3, 7.1, 8.0, 8,8, 10, 11, 12.5, 14.2, 16, 17.5, 20, 22.2, 25, 28, 30, 32, 36, 40, 45, 50, 55, 60, 65.
Note: This table lists the dimensions of ordinary welded steel pipes. The dimensions of precision welded steel pipes and stainless-steel welded steel pipes may be found in GB/T 21835.	

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Introduction to Chinese Structural Steel – Production Processes, Materials Specifications and Product Standards