UDC669.15-194:642/628

# Structural Steels in the New Iron Age

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**Abstract:**

*In the current new iron age with steel demand explosively increasing, especially in Asia, the historical position and future of structural steels in the Japanese construction market are discussed. Steelmakers have developed many types of civil engineering structural steels to meet the needs for the higher performance, greater corrosion resistance and durability of civil engineering structures; for composite structures; and for labor-saving, rapid and less polluting construction methods. In the building construction sector, steel-frame structures are used frequently, consuming enormous quantities of steel. Statistically speaking, steel frames are chiefly used in low- and medium-rise buildings. Building structural steels have changed with the social factors of the times. H shapes, high-strength steels and fire-resistant steels have been commercialized to meet specific social needs. Recent steel-frame production problems such as poor-quality steel frames are mentioned and the resultant establishment of a Japanese industrial standard for rolled steels for building structures is introduced. The future outlook for building structural steels is also discussed.*

## 1. Introduction

### 1.1 General

The history of civilization is often divided into the Stone Age, Bronze Age, and Iron Age by the principal type of material used during each period. Although its origins differ depending on geographical region, the Iron Age started approximately a few thousand years ago and continues to date.

Recently, many advanced materials have been developed, and new products made from such advanced materials have been created mainly in the high-technology fields. The position of iron (more accurately, the term "steel" should be used, but "iron" and "steel" are used interchangeably here) as a basic material in our lives is firmly established. World steel consumption is expected to grow further if the use of timber is reduced as a measure to protect the global environment. In fact, steel demand has been skyrocketing in China and other Asian countries, and this situation will spread further.

### 1.2 Position of structural steels in construction market

Historically speaking, the use of structural steels in the Japanese construction market constituted a "construction steel age" as steelmakers developed specifications as well as design and construction standards for the sheet piles, H shapes, cold-formed steel,and other structural steel products developed in the

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United States and European nations and introduced into Japan in close technical cooperation with government agencies and universities. As the shipbuilding, electric home appliance, and automobile industries progressed rapidly, they placed strong technological demands on steels, and the steel industry made the utmost effort to meet these demands. The development of structural steels, however, was not fast enough to meet the progress of technology over a long period of time. Except for special national projects, steel sales units in the construction market were numerous in types and small in lots, but were not adapted to mass production. Users did not prescribe exacting technical requirements, and such technical requirements, if any, did not directly lead to increased steel productivity. As a result, the construction market got to the stage where customers had to select structural steels from among the products mass-produced by steelmakers.

In recent years, the steel industry has developed new steel production and application technologies, established a system to minimize the total construction cost, and acquired the ability to meet user requirements. Based on this ability, steel manufacturers are developing construction steels in anticipation of the progress of construction technology. In the past few years, steel manufacturers have launched new products together with their application technology, such as fire-resistant steel, TMCP (thermomechanical control process) steel, low-YR (yield ratio) steel, narrow-YP (yield point) range steel, soil-cement-steel composite piles, and diaphragm wall sheet piles. We recognize that now is the time for us to accelerate this trend and develop innovative construction materials in close coordination with our customers.

### 1.3 Recent progress of construction market

**Fig. 1** shows the quantitative position of construction steels in Japan's total steel demand by comparing the domestic consumption of carbon steels and construction steels for the past 20 years or so. The proportion of construction steels compared with total steel consumption has hovered around 50%. When seen in greater detail, the consumption of construction steels was 34,953,000 tons and accounted for 49.9% of total steel consumption in fiscal 1988, exceeded 50% for the first time in fiscal 1989, remained at that level for five years in succession, and fell below 50% in fiscal 1994. In line with the expansion of the so-called "bubble" economy in Japan, the consumption of construction steels grew steeply, peaking at 41,505,000 tons or 51% of the total steel consumption in fiscal 1990, and was 31,460,000 tons or 48.7% in fiscal 1994.

Despite some quantitative variations, the ratio of civil engineering structural steels to building structural steels has remained at an almost constant 1:2 during the past decade. Civil engineering and building construction are often considered the same for the construction market, but are greatly different in terms of marketing and technology. One big difference is that the civil engineering market is mainly influenced by government orders, while the building construction market is affected by private sector orders. The design of civil engineering projects is led and authorized by government agencies, whereas buildings are mainly constructed for private companies and to ensure their safety, must be designed according to the Building Standards Law. This slight difference in design flow becomes a large difference at the construction stage. Construction steels are divided into civil engineering steels and building structural steels. Market trends and outlook for each group are described below.

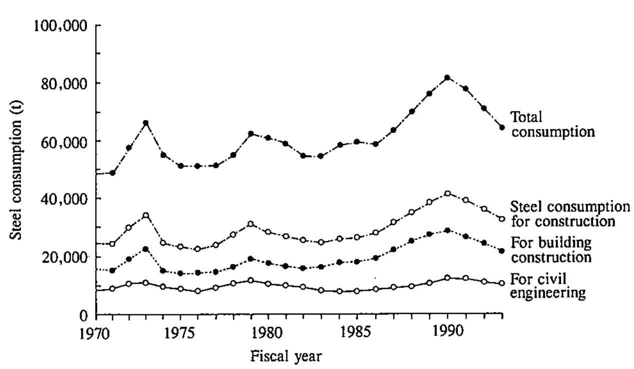



**Fig. 1** Consumption of carbon steels for use in construction industry

## 2. Civil Engineering Structural Steels

### 2.1 Present status of civil engineering steel structures

As a steel market, the civil engineering field is mainly occupied by public works. The amount of civil engineering investment from the public sector grew at an annual average rate of 3.1% from fiscal 1985 to 1992 on a real basis (1985 price basis). Although there were demand fluctuations, the overall consumption of civil engineering structural steels grew at an annual average rate of only 1.8% in the same period. As shown in **Fig. 2**, steel consumption per ¥100 million of investment in public civil engineering works has been declining. To check this trend and to increase the usage of steel, it is important that steel production and application technology be improved to minimize the total construction cost and expedite the construction of steel structures.

In 1992, bars and pipes both accounted for about 25% of civil engineering structural steel market, followed by sheet piles at 15% and plates at 12%. These four categories of steel products account for nearly 80% of the total consumption of civil engineering structural steels. The areas where steel structures are applied are shown in **Fig. 3**. Concrete structures are converted into equivalent steel structures according to the amount of steel used to build them. Steel structures are mainly used in port facilities, river facilities, and bridges.

### 2.2 Present status of civil engineering structural steels

The Japan-US Structural Impediments Initiative (SII) talks highlighted the opening of the Japanese construction market to foreign contractors, the various problems concerned with the award of contracts for public civil engineering works, and problems concerning labor shortages. Demand for civil engineering structural steels diversified in response to these problems as well as to meet requirements for labor saving; low polluting, rapid-completion and maintenance-free construction; and cost savings.

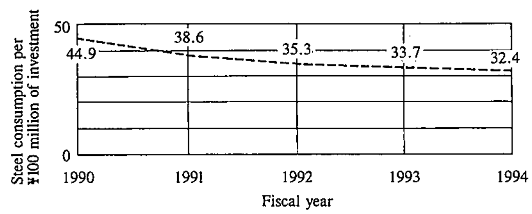



**Fig. 2** Steel consumption per ¥100 million of investment in public civil engineering works

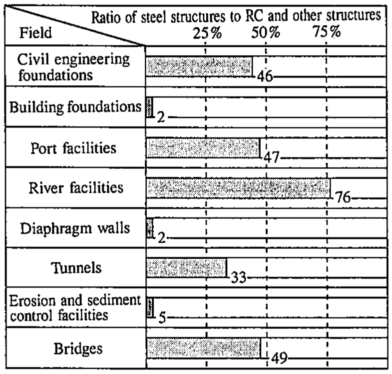



**Fig. 3** Ratio of steel structures by civil engineering or building construction field in fiscal 1993

With the advancement of ceramic materials and the opening of the Japanese construction market to foreign construction materials, the choice of construction materials has greatly increased. As a result of all these moves, the variety of civil engineering structural steels diversified as well. Centering on product development, the way the steelmakers cope with these market trends is described below.

– Meeting needs for high performance, corrosion resistance, and durability

Port, offshore, and coastal structures have increased in size with the progress of technology, resulting in calls for their long-lasting and maintenance-free operation. To meet these requirements, steelmakers have developed improved-cost-performance civil engineering structural steels by combining them with plastics and ceramics and adding cladding of corrosion-resistant metals.

In 1983, titanium-clad steel plates (composed of 1-mm thick titanium and 4-mm thick steel) were adopted as a maintenance-free heavy-duty corrosion protection material for the offshore piers of the Trans-Tokyo Bay Highway.

Steel wire with a tensile strength of 160 kgf/mm$^2$ was successfully used in the construction of the Honshu-Shikoku Bridges (with the longest span of 1,100 m) after the completion of the Great Kanmon Bridge. The Great Akashi Bridge with a span of 1,990 m required steel wire of greater strength, and so steel wire with a tensile strength of 180 kgf/mm$^2$ was developed to fill this need. Steel wire with a tensile strength of up to 200 kgf/mm$^2$ is now required by the bridge construction market.

To accomplish weight savings, high-strength steel plates, such as HT70 and HT80, were entirely adopted for the Great Osaka Port Bridge and are partly used in the Honshu-Shikoku Bridges. In recent years, HT100 steel has been developed by applying the TMCP process.

– Meeting needs for composite structures

Steelmakers have historically supplied steels, mainly for use in steel structures. After the Great Hanshin Earthquake of January 17, 1995, the need has mounted for composite structures that combine the advantages of both steel and concrete structures to achieve a more rational design and higher toughness. Nippon Steel has taken the initiative to developing steel products that can accomplish a greater composite effect with concrete. The Company developed the stud welding process that can simultaneously weld multiple deformed reinforcing bars as a method for joining steel and concrete in composite structures.

In recent years, Nippon Steel has developed new steel shapes and plates fitted with 2 to 3 mm high surface projections to improve concrete's bond to steel. Such steel plates are used to make externally or internally ribbed steel pipes by the spiral pipemaking process. Spiral welded pipes with internal spiral ribs are filled with concrete and used as quick-building piers for railroad and highway bridges. Spiral welded pipes with external spiral ribs are used in the composite foundation construction method whereby on-site soil is mixed with a stabilizer-like cement milk and agitated to build a soil-cement pile, and then a spiral welded pipe with external spiral ribs is driven into the soil-cement pile (see **Fig. 4**). Nippon Steel also developed the "NM segments" that can be joined without bolting and used in place of conventional steel segments as water tunnel segments that can withstand internal pressure. The NM segments (see **Fig. 5** and **Photo 1**) are made by joining H shapes into a frame and filling the H-shape frame with standard concrete. Nippon Steel believes that the NM segments will prove valuable as internal pressure-resistant segments in the shield tunneling method.

– Meeting needs for labor-saving, rapid completion, and low-polluting construction methods

The shortage of skilled workers calls for prefabrication and use of automated or robotized machinery in the construction of steel structures. Steel structures must also be built by such methods that do not produce noise and vibration detrimental to the local environment. If construction steels are to be used without resistance, they must be supplied as "systematized products" that combine design, fabrication, installation, and

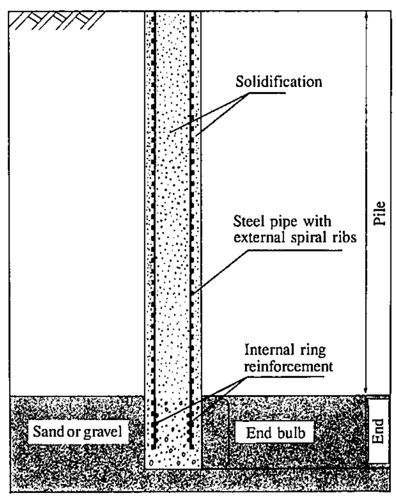



**Fig. 4** Schematic illustration of soil-cement-steel composite pile

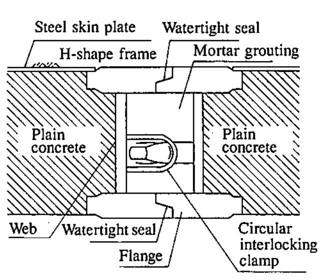



**Fig. 5** Construction of NM segments

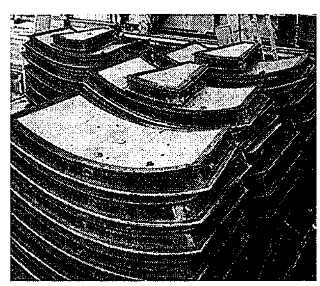


**Photo 1** NM segments

maintenance technologies.

Of particular interest in this respect is the method of building a variety of structures by making use of interlocking joints on steel sheet piles. The construction of many underground structures at great depth in cities has necessitated the development of high-strength steel diaphragm walls as retaining structures to substitute for reinforced concrete diaphragm walls that are greater in thickness, lower in reliability, and more labor intensive to build. Nippon Steel supplies steel diaphragm walls to the diaphragm wall market, including "GH-R elements" or H shapes with interlocking joints on its flanged edges (see **photo 2**). Straight-web sheet pile elements are also used in the construction of tall highway bridge piers (see **Photo 3**) and caisson-type pile foundations.

### 2.3 Future trends

The Great Hanshin Earthquake was undoubtedly severer than initially thought. Concrete exhibited many failure modes. Investigating these failure modes and designing concrete and reinforced concrete structures by considering the results of such investigations are important for minimizing structural damage in future earthquakes. Particularly, there were many cases of damage and building collapsing arising from the insufficient toughness of reinforced concrete structures, such as damage to and collapsing of reinforced concrete piers for highway and railroad bridges, and shear failure of tall, reinforced concrete columns. Focusing on this situation, Nippon Steel will develop new composite structures and seismic isolation structures. Of course, it is also necessary to address the problem of steel bridge bearing supports that deform as a result of steel structure failure and the buckling of steel bridge girders and piers. The conventional steel bridge design concept of minimizing the material cost by using as thin steel plates as possible should be reviewed in the light of structural buckling as well as increased construction labor. Alternative design concepts should be developed and proposed. Nippon Steel will work to supply low-cost steel structure systems to meet market needs.

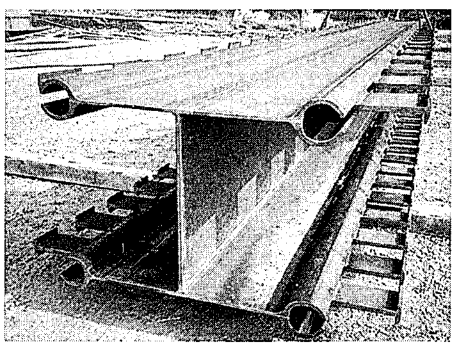


**Photo 2** GH-R element for steel diaphragm wall

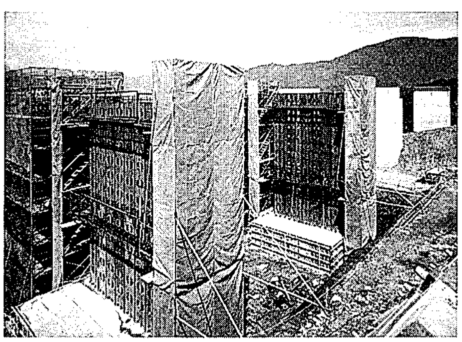


**Photo 3** Construction of steel element-concrete composite pier

## 3. Building Structural Steels

### 3.1 Present status of building steel-frame structures

The construction starts statistics of buildings by structural type show that steel-frame buildings exceeded wooden-frame buildings in floor area and accounted for 40% of total building floor area in the late 1980s. In recent years, steel-frame buildings have yielded their top position to wooden-frame buildings, partly because of the business recession. From a forest conservation standpoint, it is difficult to think that construction of wooden-frame buildings will increase in the future. The shortage of skilled workers is preventing an increase in the construction of reinforced-concrete buildings and gradually reducing the construction of steel-frame, reinforced-concrete buildings (see **Fig. 6**)[1].

The annual average production level of steel frames during the past decade is estimated at an astonishing 10 million tons. Rough estimates put steel frame production at 4 to 5 million tons in the United States and at a half of that level in the European Community (EC). Judging from this data, Japan produces more than 50% of global steel frame output and is literally the world's largest steel frame producing country.

When classified by scale, steel-frame buildings with one or two stories account for about 70% of all steel-frame buildings in Japan, and low-rise buildings with a maximum of five stories account for 93% of the total. If steel-frame buildings with 16 or more stories are classified as high-rise buildings, they account for a mere 1% or so of all steel-frame buildings constructed in Japan. Most of the steel-frame buildings in Japan each have a total floor area of about 300 $m^2$, which translates into about 30 tons of steel consumption. Similar estimates can be made from some 300,000 steel-frame building construction starts per year and steel-frame production of 10 million tons per year. Steel frames used in the construction of towering skyscrapers and long-span buildings are the most conspicuous place steel is used, but most steel-frame buildings are actually small in scale and low in height.

### 3.2 Present status of building structural steels

Here, Japan's steel-frame buildings are reviewed from the materials standpoint. The earnest introduction and diffusion of heavyweight steel frames for buildings started with the operation of H-shape mills at the Yawata and Sakai Works in 1961. Up

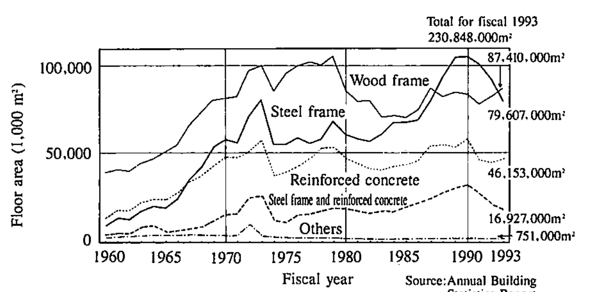



**Fig. 6** Fiscal year change for structural type and floor area of buildings from 1960 to 1993[1]

until then, steel frames were mostly riveted from angles, channels, and plates, and H shapes—which now account for 70% of steel frames—were highlighted as a breakthrough structural steel product. It was only 10 years ago that H shapes completely supplanted angles and channels as steel frame members at labor-intensive steel frame fabrication shops.

In the late 1960s, high-strength bolts took the place of rivets as mechanical fasteners for steel frames, and welding because part of the basic steel frame fabrication process and was introduced for making on-site joins as well.

Learning from the damage inflicted by an earthquake off Tokachi, Hokkaido, in 1968 and an earthquake off Miyagi Prefecture in northern Japan in 1978, the seismic design requirements of the Building Standards Law were extensively strengthened in 1981. Known as the "new earthquake-resistant design method", the conventional elastic allowable stress design and elastic-plastic design criteria were applied to building designs to enable buildings to withstand earthquakes at small and extremely large magnitudes. The energy absorption capacity of structures is expected to ensure their stability in extremely strong earthquakes. Under the new earthquake-resistant design method, rigid frame structures were simple to build and were advantageous over other structural types. In the mid-1970s, the production of cold-formed square steel pipes or box columns was started, bringing the box columns into the spotlight. In the peak years, box columns were used at an annual rate of 1 million tons as building columns and became the typical construction material for low- and medium-rise buildings. Of the construction materials used in steel-frame buildings in recent years, 70% are H shapes, followed by box columns at 15%, and plates, flat bars and other shapes at 15%. Low- and medium-rise steel-frame buildings are constructed mainly of H shapes and box columns, and the proportion of plates increases with increasing building height (see **Fig. 7**).

In the late 1980s, the Japanese government was pressured from various quarters to expand domestic demand. In response to this call and from the standpoint of increasing demand in the construction industry, which accounts for half the steel consumed in Japan, the steelmakers not only boosted steel production, but also successively developed new building structural steels with advanced functions.

With Japan amidst a truly bubble economy, the construction industry demanded materials for accomplishing taller and larger buildings. To meet this demand, the steel industry pushed forth with development of new building structural steels.

Steels with new functions were commercialized one after another. Among such examples were TMCP steel with improved weldability for columns in ultrahigh-rise steel-frame buildings, high-strength steel with a tensile strength of 60 kgf/mm², and fire-resistant steel with a fire-resistant coating that was reduced or eliminated.

Fixed outer dimension H shapes were also commercialized by improving the section and accuracy of conventional H shapes. As substitutes for welded H shapes, this inovation established a new market of over 1 million tons in size in an extremely short time.

The development of steel-concrete composite structures made great progress. Square or round steel pipes filled with concrete were commercialized as structural members.

### 3.3 Problems with steel-frame production

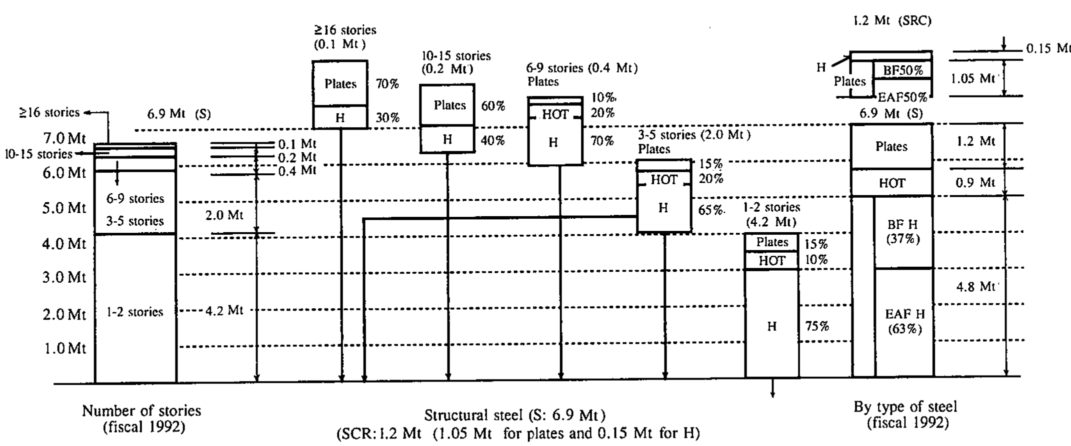
New building structural steels with sophisticated functions were actively developed in the late 1980s, but the basic performance of these steels was not reviewed until the 1990s, although some learned people pointed out that need earlier.

Defective steel frames reported in the mass media about 1990 stemmed from faulty steel frame production systems. Similar problems are presumed to be prevalent in the steel frame fabrication and distribution phases. An example is the circulation of false mill sheets.

To solve the problems associated with steel frame quality, the Committee on the Appropriate Quality of Steel-Frame Buildings was formed under the jurisdiction of the Ministry of Construction's Building Construction Technology Council. Based on the findings submitted by the committee in March 1992, an action program was implemented to achieve appropriate quality in all phases of steel frame production, and design, material, fabrication, and construction.

As a material specification for steel-frame buildings, JIS G 3136 "Rolled Steels for Building Structures" had been under preparation for about 2 years from May 1993, and was published in June 1994 as part of the action program. This standard for building structural steels, designated SN, is summarized as follows:

- Strength: Two levels of 400 and 490 N
- Applicable types: Hot-rolled plates, sheets and strip, flat




BF: Made by integrated steelmakers, EAF: Made by electric arc furnace steelmakers, H: H shapes, HOT: Hot-rolled steel,
Mt: Million tons, S: Steel-frame buildings, SRC: Steel-frame and reinforced-concrete buildings

**Fig. 7** Proportions of buildings by number of stories, construction start year, and type of steel used bars, and shapes (6 to 100 mm in thickness).

- Grades: Three grades with tensile strength of 400 N and two grades with tensile strength of 490 N in accordance with performance required for building structural parts.
- Mechanical properties: Addition of mechanical properties, such as maximum yield point, maximum yield ratio, and minimum reduction of area in thickness direction, as required for specific grades.
- Chemical composition: Establishment of upper limits for Ceq (carbon equivalent) and *P*cm (weld cracking sensitivity index), and increase in severity of upper limits for phosphorus and sulfur contents.
- Thickness tolerances: Review of minus tolerances.

Based on conventional steel standards, service performance properties peculiar to building structural steels are incorporated. The SN steel standard was not established under the leadership of manufacturers as with conventional JIS standards, but was developed to ensure a balance between the performance requirements of users and the technological capabilities of manufacturers. The Building Structural Steel Technical Committee was founded under the auspices of the General Steel Technical Committee, Iron and Steel Divisional Council, Japanese Industrial Standards Committee (JISC). Manufacturers organized the Building Structural Steel Study Committee with its secretariat in the Japan Iron and Steel Federation, while academics, designers, contractors, fabricators, and others formed the "Building Structural Steel User Working Group" with its secretariat located in the Building Center of Japan. The two groups exchanged their opinions and reached consensus on the new SN steel standard.

After the establishment of JIS G 3136, the relevant notifications of the Ministry of Construction were revised in September 1994, and the use of Grade SN steels started in combination with conventional building structural steels. The measures for improving, reviewing and disseminating associated standards toward the integration of building structural steel standards will be implemented under the leadership of the Committee on the Appropriate Quality of Steel-Frame Buildings in cooperation with associated organizations. Another urgent topic is the development and popularization of the methods of constructing details and joining structural members by mechanical fasteners to ensure seismic performance.

### 3.4 Future trends of building structural steels

JIS G 3136 is the world's first standard concerning building structural frames for which about 10 million tons of steel are annually used in Japan. People concerned with steel-frame construction are obliged to improve this standard that will probably become the Japanese Industrial Standard with the largest volume of materials covered.

At this point in the survey, it is apparent that the Great Hanshin Earthquake generated earthquake forces exceeding level 2 (or the level of an extremely strong earthquake), damaging steel-frame buildings in the same way as concrete and reinforced-concrete buildings. Despite this damage and except for some steel-frame buildings that were constructed improperly, the earthquake-resistant performance requirement that injuries and deaths due to the collapse of steel-frame buildings in extremely strong earthquakes be avoided as much as possible was almost achieved. Many of the steel-frame buildings in the Hanshin area can be used again by repairing or reinforcing the damaged parts.

Steel-frame buildings are advantageous over reinforced-concrete buildings and steel-frame and reinforced-concrete buildings in that they can be repaired easily and quickly, contributing to resource conservation.

Another type of structural steel that must be standardized is coated sheet steel. We must start studying steel-frame houses where coated sheets of about 1 mm in thickness are used as structural members, thereby contributing to an improvement in the social environment.

Many civil engineering and building structures were damaged in the Great Hanshin Earthquake. Given this disaster, this issue of the Nippon Steel Technical Report is mainly composed of papers on urban disaster prevention and earthquake-resistant research. We keenly feel the necessity of working toward the development and diffusion of more economical and durable steel-frame buildings by making the best use of our experience gained from the Great Hanshin Earthquake.

## Reference

1) Construction Prices Investigation Institute: Annual Building Construction Statistics. 1994