NIPPON STEEL TECHNICAL REPORT No. 97 JANUARY 2008

UDC 624 . 014 . 2

# Recent Trends and Future Direction in the Technology for Structural Steels Used in Buildings

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## Abstract

***This paper summarizes technology relating to building products by showing the development of steel framed buildings from the start of shape production and introduces steels for building use developed by Nippon Steel, along with the development of building technology. Also addressed is the ten-year decline in public trust of the reliability of steel framed buildings caused by the heavy damage resulting from Great Hanshin earthquake, and the detection of fake building certification in Japan. And schemes applied to restore the confidence under Nippon Steel's leadership are introduced. Future prospects in building products technology are also discussed. Prospects include a structural hierarchy to allow high-performance steels to be applied with the best combination. New high-strength steel is being developed through the research.***

## 1. Brief history of the Development of Steel-framed Buildings

In Japan, nearly 30% of ordinary steel demand is for buildings. About seven million tons of ordinary steel are used annually for frameworks in steel-framed buildings, specifically, buildings of steel or steel-reinforced-concrete construction. The development of steel-framed buildings, which comprise a major market for steels, can be divided into three phases. Phase I marks the period around 1960 in which the demand for steel-framed buildings increased markedly thanks to our predecessors' organized marketing efforts following the start of production of shape (June 1959) and light gauge shape (June 1955). In that period, steel-framed buildings were comparable to buildings of reinforced concrete construction in terms of newly constructed floor area. In Phase II up until 1980, reflecting Japan's rapid economic growth, steel-framed buildings steadily increased to become the most popular domestic method of construction, surpassing wooden buildings.

A turning point in the history of structural steels came in the 1980s when the plastic design was introduced as a new seismic design method. Then, new structural steels, including the low yield ratio seismic resistant steel (SN steel) and TMCP steel, were developed. Many of these new steels and the fire-resistant steel (FR steel) that was developed subsequently were proposed and commercialized by structural engineers in Nippon Steel. There were also special steels, such as the high strength steel in the 600 N/mm$^2$ grade and Hyper-beams, which were newly developed to meet specific customer needs. Thus, it may be said that Phase III, which started in the 1980s, was a period in which various new steels offering widely different performance were produced (**Fig. 1**).

## 2. Development of Steel-framed Buildings in the Past Decade

The past decade was a period in which the public confidence in steel-framed buildings—which had steadily been obtained until Phase III—was sorely lost by the Great Hanshin Earthquake of January 1995.

In the Great Hanshin Earthquake, numbers of steel-framed build-

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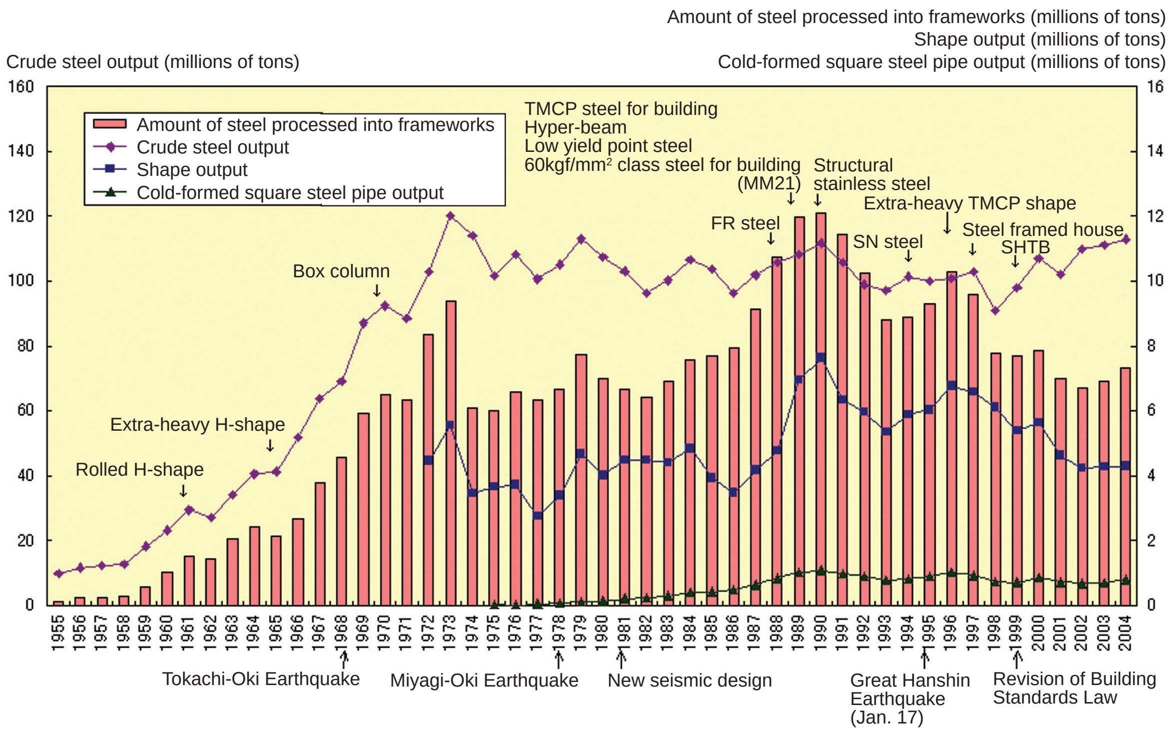


**Fig. 1 Development of steel for building structural use**

ings designed as seismic resistant suffered tremendous damage, including fractures of welded beam-column joints, fracture of beam-end flanges, brittle fractures in extra-heavy columns and cold-formed square steel pipes, and damage to exposed column bases. In the "Development of Technology for Improving the Safety of Structures by Use of Next-Generation Steels (1996-1998)", a comprehensive technology development project sponsored by the hereafter called MLIT (Ministry of Land, Infrastructure and Transport[1)]), the Japan Iron and Steel Federation strove to improve the seismic resistance of structures, specifically steel-framed buildings, through governmental-industrial-academic cooperation.

After that, a number of major earthquakes occurred in the Chuetsu area of Niigata Prefecture (October 2004), southern Miyagi Prefecture (September 2005) and elsewhere. They reminded us again that Japan is particularly prone to earthquakes.

On the other hand, the collapse of the World Trade Center in the United States in September, 2001 was a shocking event. In particular, the fact that the buildings remained standing even after being struck by such large airplanes yet totally collapsed as a result of the fires that broke out subsequently rang alarm bells about the safety of steel-framed skyscrapers. Right after the catastrophe, Nippon Steel and other steelmakers in the Japanese Society of Steel Construction set about jointly to develop a new design method to prevent progressive collapse of steel-framed buildings as occurred with the World Trade Center[2)].

Then, in 2005, a case in which quakeproof strength was forged came to light. This case was not just a problem that concerned RC condominiums. It was also a challenge to the established building design, construction and confirmation procedures. Based on the "Law for Partial Revision of the Building Standards Law to Ensure the Safety of Buildings (June, 2006)", the Ministry of Land, Infrastructure and Transport reviewed the existing system that granted generous discretionary powers to the building supervisors. As a result, the related laws, structural regulations, etc. were made more stringent than ever. These came into effect in June, 2007. Concerning steels for buildings, the individual steelmakers are voluntarily improving the dimensional accuracy of their shapes in accordance with the precision specified in Japanese Architectural Standard Specification JASS6 Steel Work of the Architectural Institute of Japan. In response to the change in the method of indicating JIS marks based on the revised Industrial Standardization Law (June 2004), they have also started to indicate the chemical composition and mechanical properties of their shapes, and marking necessaries on their webs.

All those activities represent measures to assure the quality, specifically the seismic resistance, of shapes, since these are the principal steel for steel-framed buildings, in order to regain the general public trust in steel-framed buildings.

As has been described above, in the past decade, an all-out effort has been made to restore the confidence in steel-framed buildings, mainly by addressing seismic problems. In the meantime, a new market for structural steel has also been developed. This is a steel framed house using galvanized sheet as its framework. When it was learned that the steel framed house is becoming more widespread as a substitute for the two-by-four wooden construction of houses in the United States, we dispatched study teams to the United States and Europe. Research and development on the steel framed houses were started right after the Great Hanshin Earthquake. In September, 1997, detached two-storied steel houses were approved by the Ministry of Land, Infrastructure and Transport. The approval was officially notified some time later[3)]. Today the demand for steel framed houses, mainly apartment houses, has grown to some 20,000 units a year.

Formerly, from the standpoint of preventing delayed cracks in high strength bolts, the maximum tensile strength of high strength bolts was limited to F10T (1,000 N/mm$^2$). However, on the basis of the knowledge obtained from a series of exposure tests carried out by Japanese Society of Steel Construction in the period from April, 1968 through December, 1976, Nippon Steel developed a new material for bolts (steel bar) with low sensitivity to hydrogen-induced embrittlement cracking and a new thread relieving stress concentration and thereby came up with an ultrahigh-strength bolt (SHTB®) with a tensile strength of 1,400 N/mm$^2$ (F14T)—1.5 times that of F10T. The ultrahigh-strength bolt was approved by the Ministry of Land, Infrastructure and Transport in November, 1999. It was a forerunner in the subsequent movement to increase the strength of structural steels. The ultrahigh-strength bolt, together with the steel framed house, is one of the products that represent the progress of steel-framed buildings over the past 10 years.

## 3. Outlook for Steel-framed Buildings

What will be the future of steel-framed buildings? At the beginning of this 21st century, the Building Committee of the Japan Iron and Steel Federation conducted research on new types of steel construction in cooperation with the Building Research Institute and Japanese Society of Steel Construction. One of the new ideas that sprang from that research was the hierarchization of steel-framed buildings. This means clarifying the role assigned to each of the components of a steel framework according to its performance. This idea is an expansion of the conventional concept of skeleton infill. Namely, for each of the separate parts of a steel framework, the “appropriate steel” is to be used at the “appropriate part” in accordance with the required performance. Therefore, steel frameworks based on this new idea are significantly different from conventional ones made entirely of the same type of steel.

This idea led to the “Development of Buildings with New Construction Systems Employing Innovative Structural Materials”—a joint project of the Cabinet Office, the Ministry of Economy, Trade and Industry, the Ministry of Land, Infrastructure and Transport, etc. The project is now under way.

The project described above to create a building which uses a damping device to effectively absorb seismic energy (**Photo 1**: Building using buckling-restrained bracing) to reduce the seismic resistance required of the steel for columns and which, through use of a high-strength steel (800 N/mm$^2$ grade, twice the conventional strength), is capable of resisting earthquakes of seismic intensity 7, and which can be reused and recycled.

It may be said that the direction of research and development mentioned above is one in which the development in Phase III of new steels with improved performances—greater strength, better weldability, lower yield point, superior fire resistance—will be combined successfully.

**Photo 1 Nippon Television Network Corporation Tower using buckling restrained brace**

Concerning the development of new building materials in the future, it is that there will be calls for developing hybrids of steel and other materials, rather than single-function steels, and proposing optimum combinations of materials for frameworks with the major emphasis on the “appropriate material in the appropriate place”.


### References

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