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Technical Review

Nippon Steel & Sumitomo Metal Corporation Construction Products and Technologies for the National Resilience

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Abstract

Japanese government promotes the National Resilience Project in order to create safe and secure people, properties, and economic society, which might be destroyed by terrible natural disasters (e.g. expectative huge earthquakes such as Tokyo epicentral earthquake, floods and landslides caused by heavy rain every year, and eruption disasters caused by increasingly active volcanoes currently). In this report, some Nippon Steel & Sumitomo Metal Corporation construction products and technologies for the National Resilience Project will be introduced and future works will also be described.

1. Governmental Efforts Aimed at Realizing a Stronger Japan

At 2:46 p.m. on March 11, 2011, the M9.0 Great East Japan Earthquake occurred. The epicenter of the quake was beneath the Pacific Ocean offshore from Miyagi Prefecture. The severe shaking recorded a maximum intensity of 7 on the Japanese scale of 0–7 and the subsequent huge tsunami wreaked immeasurable damage to the Pacific coast on the east side of Japan.

The Great East Japan Earthquake caused serious damage, with many lives and enormous assets lost. The death toll was 15 890, the number of missing persons was 2 589, and the number of completely and partially destroyed buildings was approximately 390 000 (as of the end of February 2015). Also, in the affected areas, the public infrastructure, including roads, railways, airports, ports, rivers, the coastline, water supply and sewage treatment facilities, electricity, and gas, incurred catastrophic damage (**Photo 1**), and the resulting cutoff of the supply chain caused the stagnation of economic activities over a wide region.

Based on the lessons learnt from the Great East Japan Earthquake, the government has started to draw up measures aimed at enabling Japan to better withstand natural disasters, maintain and protect human lives and assets, and maintain economic activities in the face of "unforeseen events," and also to prevent the decline of national strength due to natural disasters, and other causes.

Two years after the earthquake, "the Basic Act for National Resilience Contributing to Preventing and Mitigating Disasters for Developing Resilience in the Lives of the Citizenry (Act No. 95, issued on December 11, 2013)" was established, a Minister in charge of Building National Resilience was appointed, and also the National Resilience Promotion Headquarters were established. Subsequently, on June 3, 2014, "the Fundamental Plan for National Resilience" was approved by the cabinet. The actual contents to be implemented were clarified by "the Action Plan for National Resilience 2014" approved by the National Resilience Promotion Headquarters on June 3, 2014. Under the Action Plan for National Resilience, progress control for each fiscal year has been carried out concerning each measure.

For the development of national resilience, it is necessary to take into account regional characteristics. Accordingly, based on the national plan, the formulation of a Fundamental Plan for Regional Resilience [1] is being promoted in 25 cities and wards in 39 prefectures (as of July 17, 2015). Also, in the wake of the Great East Japan Earthquake, each corporation and organization is promoting the formulation of a BCP (Business Continuity Plan) in readiness for a possible disaster.

The Great East Japan Earthquake taught us the necessity of industry, academia, government and the private sector cooperating

Photo 1 Devastated area by the Great East Japan Earthquake

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with each other and devising countermeasures in systems such as evacuation plans and timelines, countermeasures in equipment such as multiplex protection that employs a combination of offshore breakwaters and onshore levees, and multiple protection consisting of a combination of these system and equipment countermeasures, to prevent or mitigate disasters, based on the assumption that "unforeseen events" will certainly occur.

On September 7, 2013, Tokyo was selected as the venue for the 2020 Olympic and Paralympic Games. In this connection, the measures related to the Tokyo 2020 Olympic and Paralympic Games are also clearly stipulated in the Fundamental Plan for National Resilience as part of the items to which particular consideration should be given. The various public infrastructure facilities to be prepared for the Tokyo Games constitute part of the activities aimed at realizing national resilience, and taking the opportunity of the Tokyo Games, it is necessary to promote a greater degree of internationalization and further use of universal design, and also promote the creation of safe urban areas that have robust disaster prevention functions.

Activities aimed at the realization of national resilience and also disaster prevention and reduction must be carried out systematically and continually. At the same time, it is also necessary to resolve various issues such as the issue of financial administration, the decreasing birthrate and aging population, the decline of regional communities, and the obsolescence of the infrastructure (**Photo 2**) that had been built up from the beginning of the period of high economic growth.

It has been predicted that a quake whose epicenter is directly beneath the capital and also one originating beneath the Nankai Trough are liable to occur very soon. In this connection, there are strong demands for new technology and products that can contribute to the realization of national resilience and also the prevention and reduction of disasters. As a steel manufacturer, Nippon Steel & Sumitomo Metal Corporation, making effective use of steel materials as well as various other materials is our mission in order to meet the needs of society and the age by using cost reduction technology that can cope with a limited budget, labor-saving technology that enables us to cope with the reduction of the labor population, technology for reinforcing or renewing the obsolescent infrastructure, and construction technology that contributes to the revitalization of the regional society.

In the following, technical trends in the construction material field regarding recovery from the Great East Japan Earthquake, subsequent reconstruction, future national resilience, and revitalization of the regional society are discussed separately for the civil engineering field and the architecture field.

2. Activities in the Civil Engineering Field

While Nippon Steel & Sumitomo Metal's mainstay construction products used in the civil engineering field are steel pipe piles [2] and steel sheet piles, [3] we are also focusing on fabricated building products for civil engineering use such as segments for shield tunnels. Regarding these civil engineering products, we are actively carrying out research and development of them concerning both materials and application technology as a set, producing a wide range of products and construction methods that allows us to meet the needs of customers.

2.1 Preparation of an infrastructure for disaster prevention or reduction

2.1.1 Breakwaters, seawalls, and onshore levees as countermeasures against tsunami

The huge tsunami created by the Great East Japan Earthquake destroyed breakwaters, seawalls, and onshore levees, and caused immeasurable damage to harbors and the hinterland (**Photo 3**).

From the experience of the Great East Japan Earthquake, demands arose for "multiple protection" by combining breakwaters, seawalls, and onshore levees with each other, and also "tenacity" due to each structure strength. The idea behind these measures is to delay the destruction of the structures as far as possible in order to obtain sufficient time to escape, even if an unexpectedly huge tsunami were to arrive and destroy the structures. In order to overcome these new technical issues, we are actively promoting research and development.

Breakwaters are installed at a bay mouth or offshore as the first line of defense against a tsunami. Most of these breakwaters are gravity types consisting of caissons installed on a mound of riprap revetment, etc. Consequently, it has become clear that when such a breakwater is struck by an unexpectedly huge tsunami, the sliding of the caisson and the scouring of the mound could cause the breakwater to be destroyed in a short time. To overcome this issue, we have been promoting the development of a new reinforcing method in which steel pipe piles are installed on the harbor side of the caisson, thus preventing the caisson from sliding and also reducing the effect of scouring of the mound [4], and we have already obtained a clear idea of how to secure tenacity of the breakwater.

An upright type seawall is a second line of defense that protects the hinterland from high tides. Like a caisson, the upright type seawall is also a gravity type, so it incurred catastrophic damage from the large tsunami. In the affected areas where there is apprehensiveness to the effect that ground subsidence would occur, resulting in further damage at high tide, it is considered necessary to take prompt restorative measures. Previously, upright type seawalls consisted mainly of concrete structures made by cast-in-place concrete.

Photo 2 Decrepit infrastructure (damaged bridge)

Photo 3 Devastated breakwaters and tide barrier

However, subsequent to the Great East Japan Earthquake, there has been a shortage of concrete and other materials and also a deficiency of construction laborers markedly in the Tohoku region, so there are demands for new seawalls that can cope with these conditions. By cooperating with the group companies and others, Nippon Steel & Sumitomo Metal developed a line-up of prefabricated type seawalls employing a highly tenacious structure that matches the necessary scale of each seawall based on a method using steel pipe piles as the basic structure that are joined to the precast concrete at the upright part.[5] This method has already been extensively used in restoration work.

An onshore levee, which constitutes a second line of defense, is generally made by earth-filling. For this reason, if a tsunami flows over it, the filling will be eroded, causing the wall to be washed away. In order to overcome this issue, steel sheet piles or steel pipe sheet piles are installed in duplicate on the inner side of the onshore levee to prevent the core of the levee from being destroyed, even if a tsunami were to flow over it. We have developed this “double sheet pile wall”[5] jointly with universities and construction companies. At present, this method is currently being used in the reinforcement work in Kochi Prefecture where it is predicted to be hit by a tsunami that can be generated by earthquakes originating in the Nankai Trough.

Damage to an onshore levee of a compound form is also expected, in which liquefaction due to earthquake causes subsidence of the levee body, which is immediately followed by the strike of a tsunami. In this connection we are also engaged in the development[5] of technology for evaluating such compound damage.

2.1.2 Countermeasures against water damage in river areas and urban areas

It is estimated that damage due to floods and inundation caused by repeating typhoons and concentrated downpours is about 300 billion yen per year.[6] It has also been pointed out that weather is becoming increasingly extreme, and countermeasures to mitigate water damage are important policies.

In upgrading work carried out during the dry season as a countermeasure against flooding of medium and small rivers, steel sheet piles are widely used. Previously, the main type of steel sheet pile used was U-shaped and had a width of 400 mm or 600 mm. In order to reduce the work period and improve workability, we have developed wide hat-shaped steel sheet piles (10H and 25H)[2] having a width of up to 900 mm, and have been making efforts to adopt them in place of U-shaped steel sheet piles. At present, we have a lineup of four types consisting of the above two types with the addition of the even more robust 45H and 50H.[7] Considering the situation in which the applications of hat-shaped steel sheet piles are making inroads into the disaster prevention and other fields, and the needs for improving the durability have also been increasing, we also have commercialized high-strength (SYW430)[7] hat-shaped steel sheet piles.

At the same time, for the restoration work of rivers in narrow urban environments, we developed the Gyropress method™[8], which involves directly cutting the foundations of the existing concrete river wall or the riprap revetment to enable steel pipes to be press-fit into position. In confined spaces in urban areas, needs have arisen to minimize installation space, so we developed a method in which a press fitting machine can be self-propelled over the previous press-fit steel sheet piles or steel pipes with a construction company. This method has been widely used in river restoration work in urban areas.

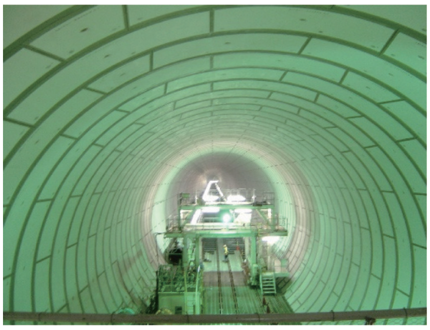

Photo 4 Underground channel (under construction)

As a countermeasure against flood damage in urban areas, in order to cope with the short duration rainfalls that have been increasing from year to year, not only restoration of rivers but also construction of trunk sewers and underground rivers are being actively carried out. In the case of an underground river or underground storage ponds, rainwater is temporarily stored until it stops raining, and is then discharged by a downstream pumping station. As a tensile force acts on tunnel linings when a tunnel fills with water, sometimes conventional reinforced concrete linings (RC segments) cannot withstand such circumstances. In order to cope with these new applications, we developed an “NM segment” and also an “HCCP segment”[9], which are composite structures of steel and concrete and have adequate resistance to tensile force. These products are widely used as tunnel linings subjected to internal water pressure (**Photo 4**).

2.2 Preparation of a traffic and logistics infrastructure

A traffic and logistics infrastructure is a lifeline for carrying out rescue and first aid in the case of a disaster. Such infrastructure is also required to perform its function for early recovery of the affected areas. In addition, by constructing a network, the disaster areas can be accessed from multiple directions, thereby securing toughness against disasters. However, as represented by the accident in which the ceiling panels dropped off in the Sasago Tunnel, obsolescence of the infrastructure that was built up during and after the high growth period is a significant issue. Despite the above circumstance, a nationwide survey and diagnosis regarding the soundness of the infrastructure has only just started.

As countermeasures against the obsolescence of urban expressways, for the Metropolitan Expressway, which was constructed along with the previous Tokyo Olympics, and the Hanshin Expressway, which was constructed around the same time, large-scale renewal and repair have been planned and are at the implementation stage. The large-scale renewal of the Route No. 1 Haneda Line of the Metropolitan Expressway is the first full-fledged renewal work to be carried out in a confined space in an urban environment, and it is required to be completed in a short period in consideration of the surrounding environment. The work roads for bringing in materials and equipment and also the work construction piers that are to be used as construction stages can be constructed using Metrodeck™ that was also used for the floor slabs of the temporary work roads for carrying out restoration work subsequent to the Great East Japan Earthquake. Metrodeck™, which consists of a combination of checkered H section steel members, is a long-selling product that has been on the market for more than 50 years.

By using NS ECO-PILE™,[3] which is a rotating pile that can be extracted after use as the support structure of a detour (substitute road) used during the work period, it is possible to carry out low-

Photo 5 Steel bridge built of SBHS

impact construction, with little noise and no waste soil. In addition, by using a steel pipe pile mechanical joint,[10] which enables steel pipes to be bonded to each other rapidly on site with high quality, it is possible to expect further reduction of the work period. Furthermore, by using steel pipe sheet piles for the pier foundations of a permanent bridge serving the temporary coffering as well, their high durability enables the foundations to be more compact, and also permits rapid construction work. In this way, construction methods employing steel have considerable merits for the work of renewing obsolescent structures in urban areas.

Also, by using SBHS high yield point steel sheets for bridge construction,[11] which can improve the performance and productivity of steel bridges, for the piers and girders of a permanent bridge, it is possible to construct high quality, durable and long-life bridges (**Photo 5**).

Moreover, fatigue of the concrete floor slabs increases with the rapid increase of traffic volume on the Metropolitan Expressway, which makes it necessary to repair them. In this connection, the replaceable high performance steel floor slab[12] (currently being researched jointly by industry and academia) that facilitates replacement of the floor slabs, also promises to be effective in reducing the dead load on the floor slabs, and is a technology that raises the competitiveness of steel bridges from the viewpoint of LCC.

For the creation of a road network in a large city that is intended to eliminate the missing link such as the Tokyo-Outer Ring Road Expressway, underground tunnel structures that have excellent quake resistance are being used. Here, the Law on Special Majors for the Public Use of the Deep Underground has been fully applied, and construction of a 3-lane road that has an outer diameter of 15.8 m and is to be located at a depth of at least 40 m has started. In urban planning, a zone in which it is permitted to construct a building of 12 m or higher is deemed to be a heavy load zone in which the load of the building needs to be added. When the thickness of the whole tunnel linings is determined from the design condition of this zone, construction could become uneconomical. For this reason, there are demands for a tunnel lining that has the same thickness as that used in an ordinary zone and at the same time has high bearing force. To satisfy these demands, the NM segment[13], which is economical and has high bearing force, is used in this zone.

Regarding railways as well, a rejuvenation plan for the Tokaido Shinkansen has been formulated, and also construction of the Chuo Linear Shinkansen, as a substitute line, has recently started. We are promoting research and development in order to meet new needs for the construction of new lines and also rejuvenation work on existing lines.

It is imperative that the arenas and the traffic infrastructure for the 2020 Olympic and Paralympic Games be constructed over the next five years. In this connection, considering that there are many

Photo 6 Construction of steel diaphragm wall with soil cement

opportunities to use Nippon Steel & Sumitomo Metal's civil engineering products that can realize a short construction period, high quality, and long life, we would like to proactively engage in activities aimed at making technology proposals, and also to provide cooperation. As an example, the construction of a direct link between the Sotetsu and Tokyu lines is being promoted by the Japan Railway Construction, Transport and Technology Agency, aimed at being opened in 2020. A continuous underground wall made of soil-cement and steel,[14] which has high strength enabling its thickness to be reduced, is used, and work for the construction of a large-scale, deep underground Shin-Yokohama Station is being promoted (**Photo 6**).

2.3 Preparation of an industry and energy infrastructure

The shaking of the earth and the subsequent tsunami produced by the Great East Japan Earthquake caused immense damage to many harbor facilities. Also, energy plants on the coast as represented by the Fukushima No. 1 Nuclear Power Plant incurred immeasurable damage. Even as far away from the epicenter as Tokyo Bay where industrial complexes are located, tank fires occurred due to liquefaction and sloshing caused by the extensive shaking of the earth, exerting a serious effect on economic activities.

Regarding Tokyo Bay and the industrial complexes as well, many of the structures were built during the period of high economic growth. Accordingly, in order to maintain Japan's international competitiveness, it is necessary to improve the quake and tsunami resistance of these structures and also “refresh” them. Particularly, as there are apprehensions concerning damage due to a huge earthquake occurring beneath the Nankai Trough, there are increasing demands for prompt action to be taken for harbor facilities and industrial complexes along the Pacific belt.

There are methods of increasing the seismic resistance of harbor facilities such as the RS Plus™ method,[15] which increases the supporting force for steel pipe piles installed in the sea, and the submerged strut method[15] in which steel pipe piles are combined with diagonal braces to construct a pier. Both of these methods are in wide use.

When the ground liquefies due to seismic motion, the weight of the structures on it cause subsidence and also fluidity in the lateral direction, resulting in considerable damage to these structures. As technology for suppressing liquefaction of the ground, there is a hi-drain pile (**Photo 7**) method in which water drainage members are applied to steel pipes and steel sheet piles in order to promote the dissipation of excessive void water pressure in the earth. In addition, research is also being promoted concerning a method in which steel

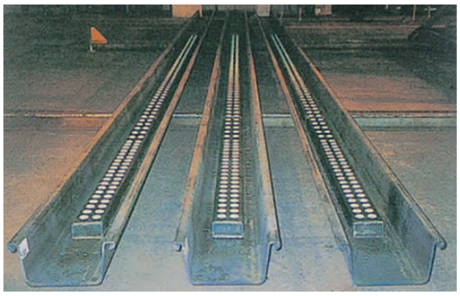

Photo 7 Hi-drain piles (steel sheet piles)

pipe piles and steel sheet piles are installed in the vicinity of important structures in order to minimize deformation and fluidity of the ground.

Along with the shutdown of the nuclear power plants after the occurrence of the earthquake, the capacity of thermal power plants in various regions was increased and also power plants that had been idle were put back into service. However, obsolescence of existing thermal power stations located in coastal areas has become an issue for the future. Concerning coal-fired thermal power plants, studies are being carried out with a view to increasing the capacity of disposal sites for coal ash, which constitutes waste material, and we are proposing the use of a highly water-impermeable double sheet pile water insulation structure and also NS-BOX consisting of a combination of straight sheet piles and box-shaped section steel.

2.4 Future prospects

As described above, many disasters occur in Japan and it is necessary to make prompt efforts to realize a more resilient Japan. At the same time, there are increasing demands to overcome financial issues as well as the decreasing birthrate and aging population, which are considered to take a long time to overcome.

In this situation, Nippon Steel & Sumitomo Metal must contribute to disaster prevention and mitigation in order to make Japan a resilient country from the aspect of the use of steel. In addition, it is necessary to make great efforts to overcome the issues confronting Japan by striving to reduce the construction costs and construction period, and to realize energy saving.

From now on as well, it is necessary to continue research and development from the aspects of both materials and application technology, and also to further upgrade our analysis, evaluation, and design technology, as well as also our manufacturing and fabricating technology. There are also demands to proactively integrate Nippon Steel & Sumitomo Metal technologies with various other technologies such as construction technology and precast concrete technology, aiming at the creation of groundbreaking technology from a fresh viewpoint.

For example, as it was described about our efforts to realize an upright type seawall, if various companies share their technology with each other, we can also offer new products that meet new needs. Also, as in the case of the Combi Gyro method [16], which uses steel pipe piles in combination with hat-shape sheet piles, we can also create new products by combining new materials with new technology.

In addition, ICT (Information and Communication Technology) is continuing to make rapid progress. In the civil engineering field, it is considered that in the near future demands will arise for coherent quality control over the range extending from planning, through design and construction, to maintenance management, using CIM (Construction Information Modeling). On the manufacturing side, it is considered that full-fledged adoption of CIM (Computer Integrated Manufacturing) will be carried out. These two CIMs could be considered as a new energy saving technology that is capable of realizing high-quality and long-life structures.

In the future, it will be necessary to accurately grasp the demands of society and the needs of customers while positively incorporating new technology as described above, and also to meet these sophisticated and multifarious needs through new steel technology and products.

3. Efforts in the Building and Housing Engineering Field

3.1 Resilient steel structures that largely contribute to business continuity

The risk of a huge earthquake whose epicenter is beneath the Nankai Trough or of an earthquake occurring directly beneath the metropolitan area is high, and in this connection attention is being focused on the resilience of structures. The import of the Building Standards Law is to prevent structures from collapsing and also to protect human life in the extremely rare event of a major earthquake. However, it is not limited to these reasons alone. It is also intended to further increase resilience and also to ensure that the structures can continue to be used after a large earthquake has occurred. Particularly, in the case of important structures, such as public structures that are used as disaster prevention centers, or ultra high-rise buildings, seismic design force that exceeds the level stipulated by the Building Standards Law is set, and structural design for increasing the safety of the structure is being actively conducted.

Building owners are also demanding progressively sophisticated specifications for their buildings. In addition to the verticalization, larger span, and higher stories of buildings, the increasing diversity of architectural design resulting from the mounting complexity of applications and the pursuit of aesthetics are causing the increasingly severe demands being placed on the performance of the building structures. In the midst of this situation, the primary structural members and their cross-sectional area are becoming progressively large as a matter of course. With the aim of reducing the amount of steel used and also reducing the amount of fabrication and welding work, attention is being focused on the use of high-strength steel. [17]

The first high-strength steel exceeding the framework of conventional structural materials used for construction was SA440 the high performance 590 N/mm^2 steel plate for building structures, [18] which was commercialized in 1996 after being developed as part of the project of new materials and application technologies including structural design and welding methods, under a Comprehensive Project on New & Advanced Materials administered by the Ministry of Construction called "Development on Techniques of Effective Use of New Metallic Materials for Building Structures," which was commenced in 1988. The use of SA440 is based on the assumption that the plastic design is applied, so a steel material standard that matches the concepts of SN steel (JIS G 3136), including low yield ratio and narrow yield point range, has been adopted.

Subsequently, as a result of the Kobe Earthquake coupled with the development of various energy absorbing devices, the damage control design method that minimizes damage to the primary structural members in the event of a powerful earthquake has entered the limelight. In the Collaborative Project by Cabinet and Ministries named "Development of New Building Systems Using Innovative Structural Materials," which was commenced in 2004, the slogan "No Damage to the Primary Structural Members in the Event of a

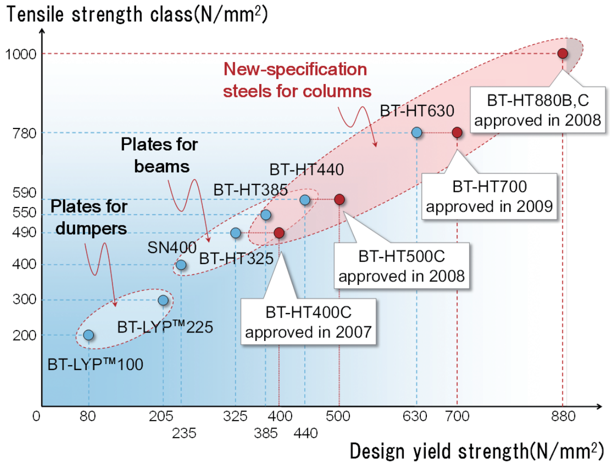

Fig. 1 Nippon Steel & Sumitomo Metal's steel plates used for building structures

Intensity 7 Class Earthquake" (intensity 7: on the Japanese scale) was created, and the steel material developed under the project was H-SA700 (780 N/mm^2 ultra-high strength steel plates).[19] The extent of the elastic region of H-SA700 is skillfully utilized mainly in combination with energy absorbing devices to form a main framework aimed at maintaining elasticity, as a base isolation structure and a vibration control structure. As the new material has thus been developed based on the assumption of use in elastic design, its yield point has been increased, and also the yield ratio, which was viewed with importance until now, has been greatly alleviated.

Nippon Steel & Sumitomo Metal has utilized its thermal machining control (TMCP) technology and HTUFF™ technology[20] to develop the BT-HT series lineup, which are high tensile steel plates intended for building construction, while responding to the demands for improved welding work efficiency and also increased resilience of welded joints. In addition to the conventional low yield ratio type steel materials "BT-HT325, 385, and 440 (= SA440), and 630", we also have a full lineup of high yield point steel materials[21, 22] "BT-HT400, 500, 700 (= H-SA700), and 880" for elastic design with alleviated yield ratio, thus enabling us to cope with various design needs (**Fig. 1**). We are also employing these technologies in the manufacture of cold-press-formed square steel tubes and circular steel tubes. Our circular steel tubes have already been used in various structures including the TOKYO SKYTREE.

In this series, BT-HT880 is a top world-class strength steel material intended for building construction. An example of such an application is Nippon Steel & Sumitomo Metal's Amagasaki Research and Development Center (**Photo 8**). To flexibly cope with future research and changes in the organization, the building has a large 133 m×23 m column-less space for use as an office, and also uses BT-HT880 and vibration damping braces to form a vibration control structure. Built-up H-shapes made of BT-HT880 are used as the 1st floor columns to enlarge the elastic limit displacement, and then damping braces are concentrated on the 1st floor to absorb most of the seismic energy. In this way, the behavior of the beam and column members remains within the elastic limit even at the time of the Kobe Earthquake.[23]

Full-fledged use of ultra-high strength steel of 780 N/mm^2-tensile strength class or above is just getting underway. However, the spread of applications of this steel is hampered by severe welding conditions such as preheating and post-heating to prevent welding

Photo 8 Nippon Steel & Sumitomo Metal Amagasaki Research and Development Center

metal from cracking, and also heat input and interpass temperature to ensure that the welding metal has adequate strength. In the future, we would like to contribute to the rationalization of welding of high-strength steel while preparing related application technologies such as the development of new welding materials and also the use of undermatched welded joints[24, 25] concerning which advanced research has been recently conducted.

3.2 Contribution to high labor productivity and reduction of work period

In urban areas centered on Tokyo, large-scale redevelopment projects are being conducted in earnest, and there is a rush to construct ultra high-rise buildings. From a nationwide viewpoint as well, the construction of large, low-rise buildings such as distribution warehouses and commercial facilities is increasing, and many public buildings are becoming due for renewal. Particularly, plans to rebuild local government offices, which constitute the primary promotion body for regional revitalization, are being announced one after the other. Based on this situation, the lack of laborers and increasing construction costs are accelerating, resulting in bids being rejected or delayed, which in turn delays the overall building project. The lack of laborers is a long-term issue accompanied by aging of the population, and improvement of labor productivity and reduction of the work period are structural issues in the construction industry.

In contrast to the construction of a reinforced concrete structure that is labor-intensive and requires a large number of on-site workers such as shuttering workers and rebar workers, the construction of a steel structure can directly contribute to reduction of the work period and labor costs. Consequently, for buildings that were previously made exclusively of reinforced concrete structures, steel structures are also the target of a comparative study during the planning of rebuilding. Here, a description is given of the trends in the development of steel products and application technologies that are conducive to labor saving and reduction of the work period that are issues being tackled by Nippon Steel & Sumitomo Metal.

First, regarding beam members that consist mainly of H-shapes, we are making unflagging efforts to substantiate our product lineup and also to develop various design methods and construction methods for NSHYPER BEAM™, which are widely used in a variety of buildings from low-to-medium rise to ultra high-rise buildings. NSHYPER BEAM™ comes in a wide range of sizes that are unavailable in the conventional H-shapes of JIS G 3192, and are more price competitive than built-up H-shapes, thus realizing rationalization of structural design and efficiency of construction work.

Nippon Steel & Sumitomo Metal has newly added "NSYP345," which can increase the design standard strength by 20 N/mm^2 compared to the conventional steel standard (SN490B), to the lineup. At the same time, we developed two new design and construction methods that extract the optimum performance from a slender web and narrow width flanges which have excellent weight efficiency, which are the features of NSHYPER BEAM™. One method is reinforcement of the beam-end web using stiffeners. It is called a “design and construction method for steel beams with stiffened slender web,”[26] and exhibits excellent deformation performance while realizing weight reduction. The other method, called the “innovative lateral torsional buckling design method for composite steel beams,” takes into account the constraint effectiveness due to the floor slabs on the beams, thus enabling the lateral braces preventing the beams from lateral torsional buckling to be omitted. By combining these methods with NSYP345, it is possible to pursue reduction of the weight of steel compared to conventional H-shapes. We are steadily increasing our record of use of these methods, mainly in distribution warehouses (**Photo 9**).

Regarding materials used for column members mainly consisting of steel plates, in order to improve the productivity of steel frame members that have been made increasingly larger and thicker, it is becoming increasingly necessary to carry out high performance welding work. Generally, during the fabrication of a welded built-up box column that is widely used in ultra high-rise buildings, electroslag welding and multi-electrode submerged arc welding are used, and the heat input reaches 50 to 100 kJ/cm. If welding employing such a high heat input were to be conducted on conventional steel, the microstructure of the heat-affected zone (HAZ) would become coarsened, causing the resilience to deteriorate. This in turn would increase the risk of brittle failure.[20, 27] In order to simultaneously satisfy the needs for the high welding productivity and securing welded joint quality , Nippon Steel & Sumitomo Metal developed the high HAZ resilience technology with fine microstructure imparted by fine particles, called HTUFF™, and has applied it to the BT-HT series of high tension steel plates intended for building construction. Recently, we have developed the “BT-HT440-SP,” which is a 590 N/mm^2 class low-temperature-preheating type TMCP steel plate. This material enables the preheating process, which was previously necessary to prevent cracking of the weld, to be omitted. It is currently available on the market.

Also, in the pursuit of higher efficiency by means of welding robots, there are an increasing number of examples in which welded built-up box columns are being replaced by high performance cold-press-formed square steel tubes. This trend was accelerated[28] as a result of the standardization of BCP325T by the Japan Iron and Steel Federation, which can be designed under the same conditions as those of a welded built-up box, as a column product that has a higher performance than that of the BCP325 general cold-press-formed square steel tube. However, when BCP325T is used in the construction work of major buildings like ultra high-rise buildings, complicated multi-layer lamination is necessary for welding the columns and the diaphragms, in order to guarantee structural performance. For this reason, it was desirable to reduce the amount of labor for the welding work and also the operation control. In the case of the 490 N/mm^2 class and 550 N/mm^2 class TMCP type cold-press-formed square steel tubes “BCHT325BTF, CTF and BCHT-385BTF, CTF” commercialized by Nippon Steel & Sumitomo Metal, we greatly improved the resilience of HAZ, resulting in a structural performance exceeding that of the BCP325T and also rendering the abovementioned complicated welding unnecessary.

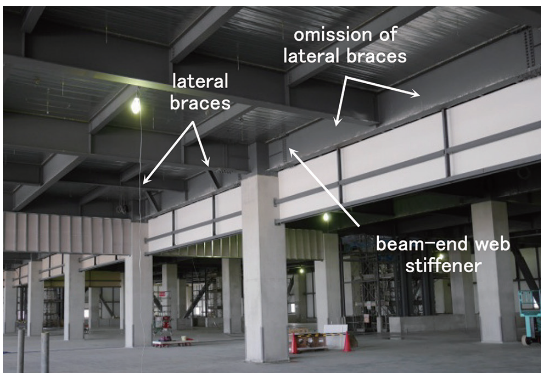

Photo 9 Application of new design and construction methods using NSHYPER BEAM™

3.3 Future public buildings using steel structures

Public buildings such as government buildings (city halls), schools and hospitals, perform a symbolic role in the regional community as centers for welfare, education and medical care, and also function as disaster prevention centers or evacuation places in the event of a disaster. Such buildings that were constructed during the 1960s and the 1970s have become increasingly derelict, and moreover as they were designed according to old quake-resistant standards, there is increasing apprehension concerning their structural safety, and thus there are increasing demands to rebuild them. Previously, there were many cases in which these public buildings were constructed using reinforced concrete structures. However, because of the scarcity of workers and rising construction costs in recent years, there is a shift away from reinforced concrete structures, which require much labor, to the use of steel structures, as shown in **Table 1**.[29]

The form desired of a public building is also changing. For example, in the case of the construction of a school, due to the falling birth rate and limited availability of public finance among other reasons, there is an increasing tendency to consider the possibility of amalgamation with other public facilities, as well as to examine the building from the design stage to see if it can cope with changes in the purpose of use in the future (**Photo 10**[30]). When constructing a government building or a hospital, in addition to the necessity of increasing the size of the space intended for an office and a laboratory, there have arisen demands for a building plan that can flexibly cope with changes or additional functions in the future.

In 2014, the Japan Iron and Steel Federation established the “Committee for Promoting the Use of Steel Structures for Public Buildings”, and is currently developing activities aimed at establishing the effectiveuse of steel structures in the field of construction of public buildings. In order to disseminate the use of steel structures, we have prepared a pamphlet entitled “Advanced Public Buildings Supported by Steel” (**Photo 11**), and while collaborating with the

Table 1 Share by structure type in floor space of newly built public buildings (CY2011 → 2014)[29]

	Steel structure (S)	Reinforced concrete structure (RC)	Steel framed reinforced concrete structure (SRC)
Schools	26 → 35%	61 → 53%	10 → 8%
Hospitals	25 → 37%	61 → 49%	11 → 9%
City halls	35 → 40%	45 → 42%	13 → 12%

Photo 10 Shiseikan Elementary School in Sapporo [30)]

Photo 11 Promotional brochure for advanced public buildings by utilizing steel structure (The Japan Iron and Steel Federation, Japan Steel Fabricators Association)

Japan Steel Fabricators Association, we are holding workshops on a nationwide scale aimed at the building owner (central government, regional public organization), the designer, and the building contractor.

Among these activities, we emphasize the following as the features and advantages of a steel structure.

(i) Coping with combined use and changes: Large span frames that create large spaces with few columns have structural advantages when used to construct a building. In addition, they can cope flexibly with the need to use the same facility for different applications, and also with changes in the layout in the future. As the use of a steel structure is a dry construction method, the frame can be combined with various finishing materials including wood, glass, metal and stone to produce a highly aesthetic architectural expression, and also is highly compatible with renovation work such as expansion or modification.

(ii) Reduced work period and costs: Steel frame members are produced in a factory, so they are of stable quality, and enable the amount of on-site work and also the work period to be reduced. Although the unit price of steel frame members is higher than that of rebars and cement for a reinforced concrete building, the total cost of a steel frame building is expected to be cheaper. In addition, because the on-site work period is short, noise and dust are also reduced, thus reducing the burden on nearby residents.

(iii) Preparedness for disasters: It is essential that a public building that functions as a disaster prevention center in the event of a disaster be resilient and permit business continuity. Nippon Steel & Sumitomo Metal responds to changes in regulations and design methods. Particularly, in order to improve the seismic resistance of a steel structure, we have developed a large variety of steel materials and construction methods, and placed them on the market. These steel materials and construction methods are also highly effective when designing a structure to withstand tsunami. [31)]

The disadvantages of a steel structure compared to a reinforced concrete structure are thought to be its environmental performance including sound insulation, vibration damping, and heat insulation. In order to quantitatively evaluate a steel structure in respect of the above parameters, the Japan Iron and Steel Federation commissioned the Japanese Society of Steel Construction to conduct the evaluation, and in 2014 it established the "Technical Committee for Investigation and Research on Public Buildings Utilizing Steel Structures" (Chairman: Seichi Fukao, Professor Emeritus, Tokyo Metropolitan University), and commenced research activities. They intend to measure the environmental performance of public facilities constructed using steel members, and, while accumulating the measurement data, the committee will clarify that the details of floor/wall and finishing materials, and for the tie-in with those members are the dominant factor in the determination of the abovementioned environmental performance, rather than the type of building frame structures.

One can say that the same applies to durability as well. Although the statutory lifetime of a steel structure is set shorter than that of a reinforced concrete structure, there is no difference in actual fact. By implementing appropriate measures to optimize the details at flashing (weatherproofing), for example, there is virtually no progression of corrosion of general internal steel members, and the durability of a steel frame building is considered to be more or less semi-permanent. [32)]

A designer who has been involved for many years with reinforced concrete structures actually finds it difficult to design the details for a steel frame building. For this reason, the abovementioned technical committee is planning to create design guidelines that summarize points to keep in mind and recommended details, in addition to examples of trial design of steel structure public facilities, the results of cost and work period validation, and the results of measuring and analyzing the performance of the various environment items.

3.4 Strengthening the ability to make proposals for solutions in the housing field

The number of new housing starts in the Ministry of Land, Infrastructure and Transport's Statistical Survey of Construction Starts has started to increase slightly, buoyed partly by various government policies, from the reduced demand that was a reaction to the last-minute surge in demand prior to the increase in the consumption tax, which was seen in FY 2014. In the midst of this situation, there was a steady demand for multi-story housings (3-stories or more) intended to be built on confined land in urban areas, health facilities to cope with the increase in senior citizens, and also for rebuilding derelict apartment houses, company housing, and dormitories that were constructed during the period of high economic growth. Looking at the trends of the recent demand for the construction of housings, the following can be seen.

(i) "Quake resistance" for increasing the ability to continue using a building in the event of a large earthquake

(ii) "Durability" that enables building structures to be used by several generations of people

(iii) "Variability" that enables a building to be easily modified according to changes in lifestyle

Photo 12 3-story restoration public housing in Kamaishi, Iwate (NS-SUPER-FRAME™)

(iv)“Energy saving” to reduce running costs

The above items match the authorization standards for so-called “long-life, quality housing.”

In the housing field as well, lack of workers is a serious problem, and the needs for improvement of labor productivity and also reduction of the work period are high. The number of public housing restorations after the Great East Japan Earthquake built so far (as of June 2015) is still only about 36% of the planned number, but here too the reduced work period and reduced costs realized by using steel structures are highly appraised. All of the public housing restorations constructed at the Kaminakashima public restoration estate in Kamaishi City during the 1st construction period (54 households) and 2nd construction period (156 households) were constructed using steel structures. Of these public housings , 5-story buildings and 8-story buildings were constructed using the Outer Frame™ (CFH Frame System) developed by Takenaka Corporation, and 3-story buildings were constructed using NS-SUPER-FRAME™[33] developed by Nippon Steel & Sumitomo Metal (**Photo 12**). The NS-SUPER-FRAME™ is a light-gauge steel framed housing method that was independently developed and nurtured by Nippon Steel & Sumitomo Metal. Recently, we have added a 4-story housing method to our lineup, and in the future it is anticipated that it will find increasing application for apartment houses, company housing, and health facilities for senior citizens.

Amid the predicted medium- to long-term decrease in the number of new housings constructed, the housing manufacturers are likely to shift to the construction of dwellings possessing more discriminating quality in order to meet the above demands, and also to develop fierce competition while increasing added value. In light of this background, taking the opportunity of management integration conducted in 2012, the year in which Nippon Steel & Sumitomo Metal was founded, we have become able to use two showcase products, namely the SuperDyma™ high corrosion resistance plated steel sheet, which was developed by the former Nippon Steel Corporation and the SMart BEAM™ welded light-gauge H section steel, which was developed by the former Sumitomo Metal Industries, together with our powerful application technologies in the housing field, to prepare a one-stop system that can meet the demands of a variety of customers.

SuperDyma™ is highly appraised for its excellent corrosion resistance and forming ability. It is used not only in the NS-SUPER-FRAME™, but also as the base material for various light-gauge shaped steel for housing applications. We are developing proposal activities for SuperDyma™ aiming at the housing manufacturers and others, while utilizing our measurement and evaluation technologies for noise, vibration, and heat, and also analysis technologies, such as “Katachi Solution”,[34] which is cross-section optimization technology fostered during the development process of light-gauge steel framed houses. Also, the SMart BEAM™ has a solid reputation for its size flexibility that enables it to rapidly meet design needs, its economic design due to its thin cross-section that cannot be realized by hot-rolled H-shapes and its high dimensional accuracy that leads to reduced forming costs. It is used mainly as a beam member for steel frame prefabricated houses (**Fig. 2**).

Fig. 2 Application of SMart BEAM™

Recently, Nippon Steel & Sumitomo Metal placed on the market a new product called SD-SMartBEAM™, which is a combination of SuperDyma™ and SMart BEAM™. We will propose and promote it as a replacement for conventional post-galvanized or painted H-shapes.

We are also aggressively developing proposal activities aimed at partial use of these steel products for use as materials that have not been conducted until now, e.g., materials for house foundations and the primary structural members of wooden houses. Examples of this are the steel foundation Hi-MS Method using SuperDyma™, which we developed jointly with Makes Corporation, a unit type foundation rebar manufacturing company, and also the SMart BEAM Construction Method for long-span beam members for wooden houses, which we developed jointly with Tatsumi Corporation, a manufacturer of architectural hardware. We are making full use of both the SuperDyma™ and SMart BEAM™ products together with our application technologies that we have fostered until now, and from now on we intend to promote development in collaboration with the customer, while making detailed and attractive proposals.

3.5 Future prospects

As seen in Abeno Harukas and also the recently announced the Tokiwabashi District Redevelopment Project under which an ultra high-rise building having a maximum height of 390 m is to be constructed, buildings are becoming increasingly high and large. Amid this trend, the structural safety of buildings is being rigorously debated, and we have entered an age in which the resilience and business continuity of a building are evaluated as asset values. At present, the ideal structural design based on the assumption of increasing seismic design force is being enthusiastically discussed along with the improvement of technology for predicting long-period seismic motion due to a huge subduction zone earthquake, and also pulse-type seismic motion due to an inland earthquake.[35] Researches are also being actively conducted for evaluation methods on the limit performance of steel members that are subjected to a large deformation response or to a repetitive response occurring multiple times, due to the occurrence of such an earthquake, and also the behavior of a steel structure up to the point of collapse after exceeding the maximum load capacity.[36] These researches are aiming to construct a rational design setup by clarifying the limit state of building structures.

While observing the trend of these researches, we will prepare high performance steel for building structures and also application technologies so that we can flexibly meet the increasingly severe and diverse design needs. A design method described in this paper, in which the high-strength steel material is combined with vibration damping and base isolation technology, and damage control is made the target while a lucid collapsing mechanism is assigned to the building frame, will probably become an effective solution for realizing a building that is resilient and also assists business continuity.[37]

On the other hand, the increase of labor productivity to offset the reduction of the worker population due to the decreasing birthrate and aging population rate is an urgent issue for the building industry. Concerning steel structures, steel materials and construction methods that contribute to greater efficiency of the assembly and connection of steel members and also contribute to reduced consumption of steel are being demanded. As a prerequisite for carefully investigating high productivity and efficiency, it is desirable to clarify the required performance of the steel members from the viewpoint of structural safety of buildings. In addition to the above researches, various kinds of research conducted under the initiative of the Japan Iron and Steel Federation, namely (i) elucidation of fatigue characteristics of high performance steel members that are subjected to long-period seismic motion,[38, 39] (ii) clarification of the required performance for eliminating brittle fracture of welded joints,[40] (iii) development of application technologies for undermatched welded joints,[24, 25] and (iv) development of rational design methods against buckling of steel members.[41, 42] These researches will probably enable the behavior of steel members exposed to a massive earthquake, and also the required strength and deformation capacity of the members, to be gradually clarified. It is necessary to link our initiatives with these research items, and to tackle the improvement of labor productivity and reduction of the work period while balancing the required structural performance with economic rationality in a high dimension.

The construction industry in Japan, which will hold the 2020 Olympic and Paralympic Games, is booming. However, we will make efforts to ensure that even after the current virtuous cycle has run its course, steel construction will continue to remain in the spotlight. Not only domestic markets, but also overseas markets centered on developing countries in which it is assumed that demands in the infrastructure field will increase are considered important for creating new demands in building products. Although there are differences in vernacular characteristics concerning design forces, building production systems and the like, the necessity of ensuring robustness of buildings and cost reduction through the pursuit of high productivity is a universal one. We shall aim at realizing product discrimination by globally exporting our high-end products and also our sophisticated application technologies fostered in Japan. From now on as well, we shall endeavor to timely meet the needs of the construction industry by promoting the development of steel materials and application technologies, and evolve rational and economic solutions that bring out the features and advantages of steel structures.

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