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Building
Construction

Aesthetic Architecture



Aesthetic Architecture

—Attractive Buildings Employing State-of-the-Art Materials and Technologies—

by Dr. Eng. Mitsugu Asano, Chairman of JSSC's Committee on the Design, Construction and Manufacture of Aesthetic Architecture (NIKKEN SEKKEI)

Through the investment of great ingenuity in both design and production, diverse performance characteristics have been incorporated into recent architectural spaces, configurations, and designs in order to make structures as aesthetically attractive as possible. Further, hybrid structures consisting of steel and other materials are widely used in these buildings.

The Committee on the Design, Construction and Production of Aesthetic Architecture, established by the Japanese Society of Steel Construction (JSSC), has recently published a report on technologies that promote appealing architecture. The committee's members consist of structural

designers employed by design firms and construction companies. The examples cited in the report were recommended by the member companies and were selected from among recent design projects conducted by those companies. The main object of the report is not a discussion or comparison of these examples. Rather, it is to illuminate the effort involved at the stage of realizing a design concept, to intro-

duce future tasks and developments, and to call attention to the creativity of structural designers. More specifically, the report features technical information and data that are useful in creating aesthetic architectural structures.

The report offers examples of five structural categories that can be made more attractive.

- Improving the attractiveness of an entire frame system
- Improving the attractiveness of roofing (terrace)
- Improving the attractiveness of façades
- Improving the attractiveness of structural elements (members, connections)
- Improving the attractiveness of small-scale structures

The following introduces nine major examples of aesthetic architectural structures that were recently built in Japan.



Kuroshio Arena



National Art Center



Nagoya Dome



Roppongi Hills Arena



Dentsu Building



Mikimoto Ginza 2



Seibu Dome



Marunouchi Oazo's Atrium



International Library of Children's Literature

Kuroshio Arena

—Energetic Roofline, Warm Interior Space, and Seemingly Transparent Façade—

by Hisanori Taniguchi, Shimizu Corporation

Structural Plan

This building is a competitive swimming stadium constructed in Kochi, Shikoku, for the 2002 National Athletic Meet. It has a one-story basement, three stories above ground, and a large roof with a long-side span of 122 m, a short-side span of 98 m, and a trapezoid plane of 32 m. It is equipped with a 50-m pool, an infant pool, a year-round hot-water pool with Jacuzzi, and a training room. The 50-m pool can be converted for use as a gymnasium, thereby making the arena functional for a wide range of uses in addition to swimming, such as other types of sporting competitions and various events.

The roof trusses are unidirectional steel structures to which beams and diagonal members made of laminated Kochi Cedar

are attached in a V-shaped pattern that extends from the bottom of the trusses to the ceiling. This configuration not only calls to mind the Kuroshio Current and the vigor of sport but also gives the interior space a feeling of warmth. The roof trusses are supported on both ends of the large space by space steel columns, and because the walls are formed using Vierendeel trusses, the interior has a feeling of transparency.

Unidirectional Roof Supported by Space Columns

In order to promote the smooth transfer of stress where multiple structural members come together, cast steel members (JIS G5102: SCW480) were adopted for the truss beam cross sections and the column bases.

In particular, due to studies conducted from both design and manufacturing perspectives on the steel castings used for the space column bases, these castings were manufactured in eight different configurations using one set of molds.

Bright, Richly Transparent Space

The walls are composed of three layers: external sashes, support trusses, and movable wooden louvers. Because Vierendeel steel trusses (SM490A) were adopted for the wall support structure, the need for wall braces was eliminated.



Full view of Kuroshio Arena



Hybrid truss composed of steel frames and beam and diagonal members made of laminated Kochi Cedar



50-m pool and space column



Cast steel member adopted for the truss beam cross section



Cast steel member adopted for the space column base



Vierendeel steel truss used for wall

Seibu Dome

—Large Roof Blends Well with Surrounding Environment—

by Satoshi Higuchi, Kajima Corporation

The most distinctive feature of the structural plan for Seibu Dome was the remodeling of the existing open-roofed stadium into a closed dome arena, during two consecutive November-to-March off seasons. To accomplish this, the remodeling was undertaken in two stages. In the first stage, metal roofing consisting mainly of steel frames was built over the seated sections, and in the second stage, membrane roofing was extended above the playing fields.

Outline of Structural Plan

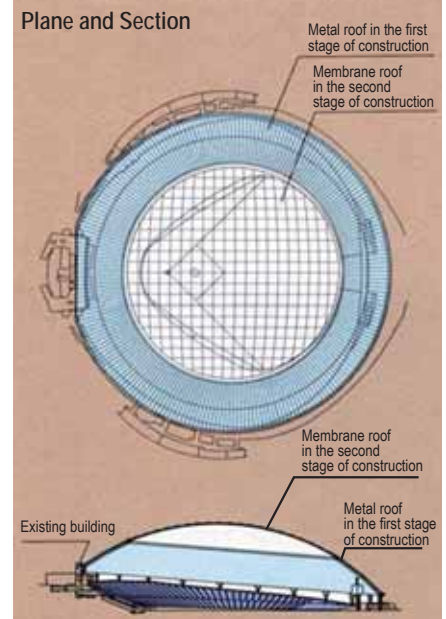
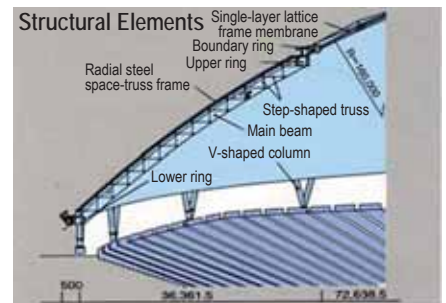
In the planning of the dome, the whole lower ring section was configured to tilt at a

five-degree pitch. The components used for the dome's construction consisted of a steel pipe-structured single-layer lattice frame membrane over the dome's center section, a doughnut-shaped radial steel space-truss frame surrounding the membrane, and 4.5~12 m-high V-shaped columns that support the roof. In order to build the roof structure during two off-season periods, the structural plan allowed for the existing stadium to be used when the first stage of construction was completed.

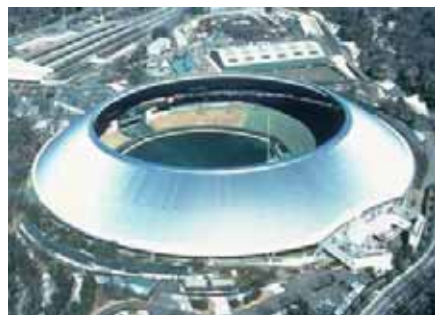
Structural Plan for Membrane Roof

The frame membrane that covers the

dome's center section (145 m in diameter) consists of a single-layer lattice made of steel pipe (558.8 mm in diameter, 14 mm in wall thickness) arranged in 7.5-m grids. Like a globe of the Earth, the single-layer lattice is laid out in a grid of latitudinal and longitudinal lines. In about 300 cross sections where these lines intersect, cast steel fittings were adopted.



Full view of Seibu Dome



Completion of the first stage of construction



Lift up of the roof in the second stage of construction



Cast steel fittings

High-strength bolts were used for flange joining where the metal fittings for the cross sections connect with the steel pipes. The flange surfaces of the metal fittings were machined with appropriate angles to make the fittings' surface, as a whole, closely resemble a sphere.

Construction of Metal and Membrane Roofs

Installation of the metal roofing in the first stage of construction—assembly and installation of steel frames weighing more than 8,000 tons—was implemented more quickly than expected due to the adoption

of the ring-shaped trapping method. Installation of the membrane roofing in the second stage of construction was achieved by assembling the grid frames on the ground and then hoisting the 2,100-ton roof structure into place by means of the lift-up method.

Dentsu Building

—High-rise Building with Asymmetrical Planes, Super Mega-frame System, and Two Kinds of Vibration-damping Devices—

by Masayuki Yamanaka, Obayashi Corporation

Building Outline

In order to provide both functionality and appearance befitting the start of the twenty-first century, three concepts were taken into consideration during construction—100-year service, symbiosis with the environment, and energy savings. To realize these concepts, the motto “low impact and high contact” was emphasized and allowed to influence every stage of design and construction, from planning to completion.

In conformance with the urban planning for SIO-SITE (a comprehensive urban development project), the Dentsu Building provides not only office space but also visitor-intensive superb amenities that integrates commercial and cultural facilities, which thus creates a deep bond with the surrounding community—*high contact*. Also, with its boomerang shape, this high-rise building not only offers scenic beauty and attractive urban landscaping; it also meets the need to minimize such adverse effects on the surrounding area as electrical disruptions and strong tunnel-effect winds—*low impact*.

Structural Outline

In order to realize the major design concept of “100-year serviceability,” a highly functional, highly durable building was targeted that would ensure safety against wind and seismic forces and offer comfortable habitability. In designing a building that is to be serviceable for more than 100 years, it is necessary to assume external forces with

Fig. 1 Appearance of Dentsu Building (left: south side; right: west side)



longer return periods. This is why the seismic design of the Dentsu Building seeks to secure sufficient structural strength by exceeding the Levels 1 and 2 external forces that are commonly adopted.

The aboveground section of the building has a boomerang-shaped plane and measures about 120 m in long-side span, about 41 m in short-side span, and 210.087 m in height. The towering ratio (height-to-width ratio) is about 5.0 in short-side span, compared to 1.7 in long-sides span, thereby giving the building a rather slender profile (Fig. 1). Because of this, a key element of the structural plan was determining how to

control short-side span-direction deformation in which bending deformation is greatest.

The major structural features of this unique building with such an asymmetrical plane configuration (Fig. 2) are cited below:

- Adoption of a CFT (concrete-filled steel tube) structure having a concrete strength up to 80 N/mm²
- Use of SA440 fire-resistant steel (80 mm maximum plate thickness) for the inner atrium to realize a steel-frame structure without the need for fire protection (Fig. 5)
- Securing stable energy absorption capacity by expanding the width of the girder

ends

- Securing short-side span horizontal rigidity by use of a super mega-frame system with integrated plane, elevator and structural plans
- Realization of seismic-resistant frames that employ two kinds of dampers, each effective in controlling shear deformation and bending deformation (Figs. 3 and 4)
- Securing habitability by use of a vibration-control device installed at the top of the building

These technologies and methods were adopted to produce a high-rise building with high seismic resistance and were implemented with close attention to quality control.

Fig. 2 Outline of structural plan

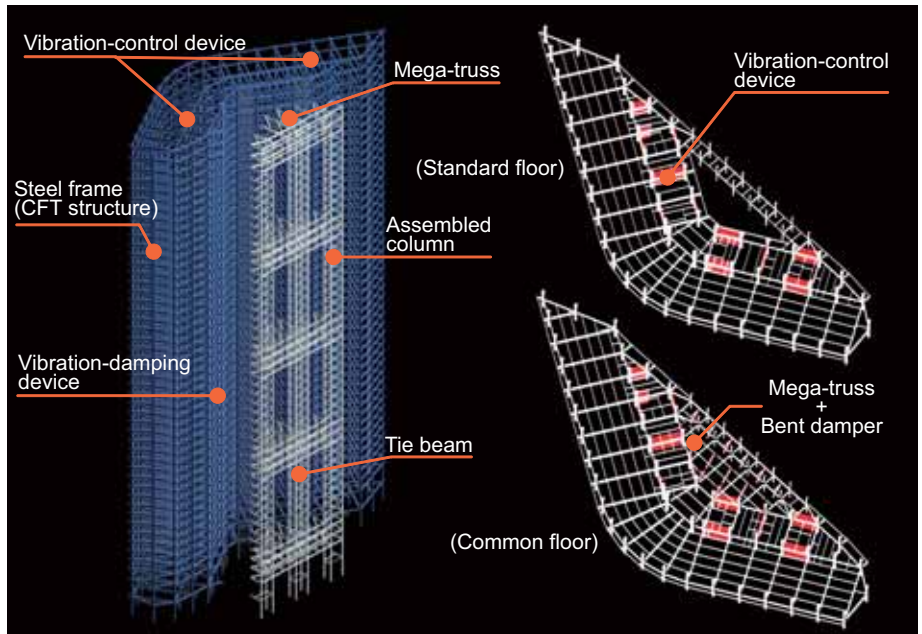


Fig. 3 PYO damper for shear deformation



Fig. 4 Damper for bending deformation



Fig. 5 Inner atrium



Mikimoto Ginza 2

—Façade with Architecturally-designed Window Openings—

by Yasuhiro Hayabe, Taisei Corporation

Structural Plan

This building is composed of tube trusses that wrap around all four rectangular sides (14×17 m each) of the building with the wall structure, which is of composite assemblies made of steel plate and concrete. These walls have irregularly-shaped openings that, according to the architects, “present mobile patterns like those that catch trembling moments.” The Mikimoto Ginza 2 building breaks with the multi-story construction by means of the layered structure approach, frequently adopted for commercial building construction, and the “solid

abstraction throughout the entire building structure” is freely expressed in the building.

In addition, because the surface layers of the walls are steel plate, they present a flat joint-free façade that, in combination with the finish coat, produces a symbolic building that is very strong in spite of its thin outer walls about 200 mm in thickness.

Structural Details of Steel Plate-Concrete Wall

The steel plate-concrete walls are of composite structure with concrete sandwiched

between the two steel plates. The resulting high-strength structure possesses yield strength peculiar to both steel and concrete. The two steel plates are tightly joined by tie bars. Wall details are shown in Table 1.

The reason for making the street-side steel plates 12 mm in thickness and the neighboring site-side steel plates 9 mm was to reduce welding strain occurring in the road-side plate to a minimum and to balance rigidity and strength between the road-side and neighboring site-side plates because of the many openings in the walls.

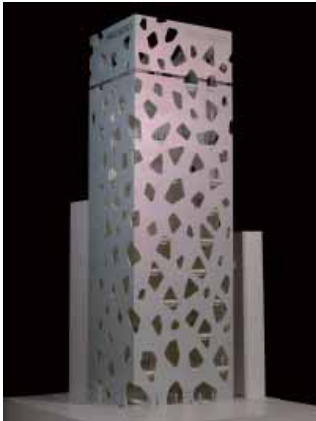
The single-layer steel plate-concrete

wall is divided into 32 unit panels. The size of each unit panel is set at 2.4 m in width × story height (4.5 or 5.0 m). The structure of one of the unit panels is shown in Fig. 1. After the unit panels were manufactured at the shop, they were installed at the site and then filled with concrete after weld-joining.

In order to realize the “flat joint-free façade” envisioned by the architects, minute care was paid during installation.

Table 1 Dimension of Steel Plate and Concrete Composite Walls

Structural section	Designation	Story	Outer plate thickness t_1 (mm)	Inner plate thickness t_2 (mm)	Concrete thickness t_c (mm)	Wall thickness T (mm)	Space between stud bolts B (mm)
South side	SCW4	6~9	12	6	200	218	400 (φ22) 200 (φ13)
West side (Street side)	SCW2	3~5	12	9	200	221	300 (φ22)
	SCW	1~2	12	12	200	224	400 (φ22)
North and east sides (Neighboring-site side)	SCW5	6~9	9	6	200	215	300 (φ19)
	SCW3	1~5	9	9	200	218	300 (φ19)
Rib wall	SCW6	1~9	6	6	200	212	200 (φ13)



Building model (courtesy of Ito Toyoo Architectural Design Office)

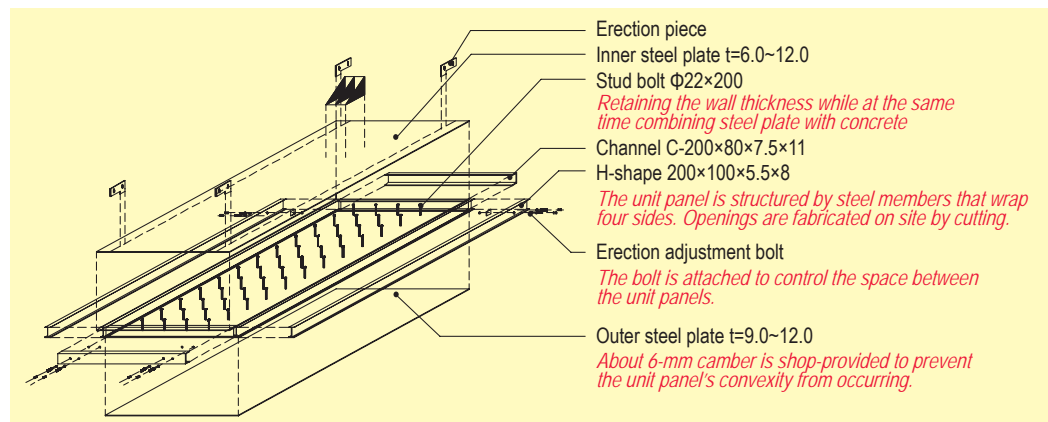


Fig. 1 Structure of Unit Panel



Installation



Appearance



Inside view

Nagoya Dome

—Bright, Open Stadium Employing Single-layer Lattice Trusses—

by Mitsuo Seki, Takenaka Corporation

Building Plan

The Nagoya Dome was designed to symbolize the Tokai area of central Japan and was completed in February 1997 in Nagoya. It is a multi-purpose facility that seats 40,500 fans for baseball games. Because of its location in an urban housing area, the roof was designed as a closed, single-

layer steel-frame lattice dome. At the center of the dome is a 5,000-m² roof of double-walled glass top light that makes the dome bright and produces a feeling of abundant spaciousness. The amount of incoming light is controlled by a retractable rolled screen located beneath the glass top light.

The adoption of a single-layer lattice

roof satisfies not only the height limit imposed by shade regulations but also the need for an interior height of at least 60 m for baseball games. Other advantages are the minimization of air conditioning costs and the cost cutting of a steel-frame roof due to reduced roof thickness and fewer structural members.

Structural Plan

The dome has a concentric circle-shaped plane. The center-to-center diameter between the outermost peripheral columns is 229.6 m and the height is GL+66.9 m at the roof's highest point. The roof has a diameter of 187.2 m and uses mainly steel pipes to form a single-layer steel-frame lattice dome. The roof's geometrical configuration is $L=183.6$ m in center-to-center distance between tension members, the roof height is $H=32.95$ m in member center-to-center distance, and the rise ratio (H/L) is set at 0.179.

The roof lattice consists of isosceles triangular shapes that, being nearly equilateral triangles about 10 m on a side, consist of steel pipes measuring 650 mm in diameter (SM490A). In order to make the members be of uniform strength, the pipe wall thicknesses gradually increase from 19 mm at the center of the dome to 28 mm at the periphery. Steel pipes (SM490B) 900 mm in diameter and 50 mm in wall thickness are used for the tension rings. At junctions

where six lattice pipes meet, each pipe is rigidly weld-joined to a spherical cast steel node.

Roof Design

The following studies were made in designing the single layer-type roof.

- Assessment of buckling strength and safety, taking into account unmatched configurations caused by out-of-plane deformation, etc.
- Effect of construction efficiency on the roof trusses
- Shape of and design method for steel pipe joints
- Seismic safety of a large-scale single-layer roof

Because of the three-dimensional concentration of large-diameter steel pipe members on the joints, spherical cast steel nodes (1,450 mm in diameter and 740 mm in height: SCW480) were adopted. All the nodes are identical in shape and have either of two wall thicknesses according

to the stresses applied. Node design was tested by finding the stress bearing ratio of each member through FEM analysis and 1/2-scale model experiments. Further, performance tests and cast steel-SM grade steel weldability tests were carried out using full-scale experimental models.

Construction

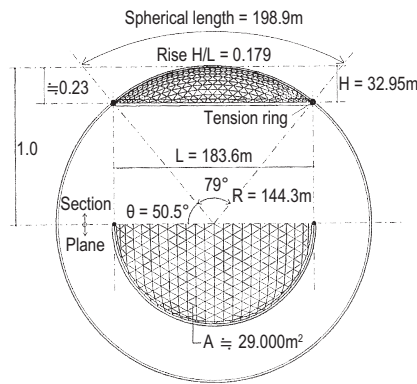
In order to reduce high-elevation work, improve weld quality, secure construction quality and shorten the construction term, a lift-up method was adopted whereby the lower dome structure and the roof could be simultaneously constructed. As a result, only 30 months were needed to complete the Nagoya Dome. The roof, weighing 13,000 tons, was hoisted 23 m upward using jacks.

Source of information

Mutsuo Sahashi: "Space-truss Structures" Vol. 4, May 1995; Edited by Mitsuo Seki, Takanaka Corporation



Appearance



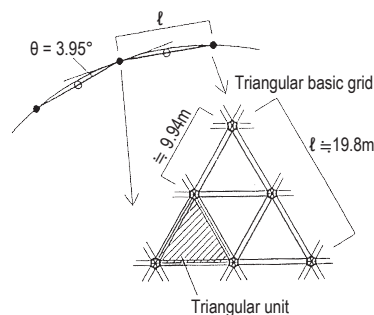
Geometrical Configuration of Roof



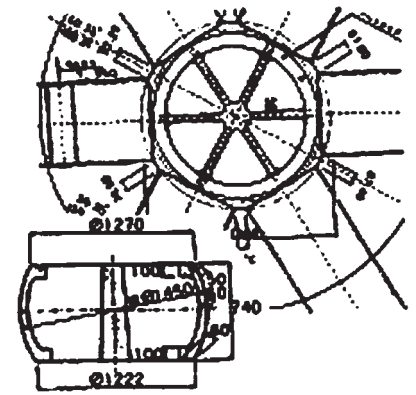
Installation of node section



Inside view



Roof Division Method and Member Arrangement



Node Drawing

Roppongi Hills Arena

—The Roof Serves for Diverse-purpose Event Facilities—

by Takahiro Kido, YAMASHITA SEKKEI INC.

Structural Plan

This structural system consists of an oval ring measuring 54.1 m in length and 41.3 m in width that is supported by six columns, cantilevered truss frames differing in hanging length from 25.7 m to 40.1 m, an external perimeter oval ring that connects



Full view of Roppongi Hills Arena

the truss frames together, beams, and individual tension members for stiffening.

In order to provide efficient support for the wide-span cantilevered beams, the cantilevered truss frames rest on the top plinth of each column and are provided with a backstay cable that is pin-connected to the top of the column in a manner to maintain proper balance.

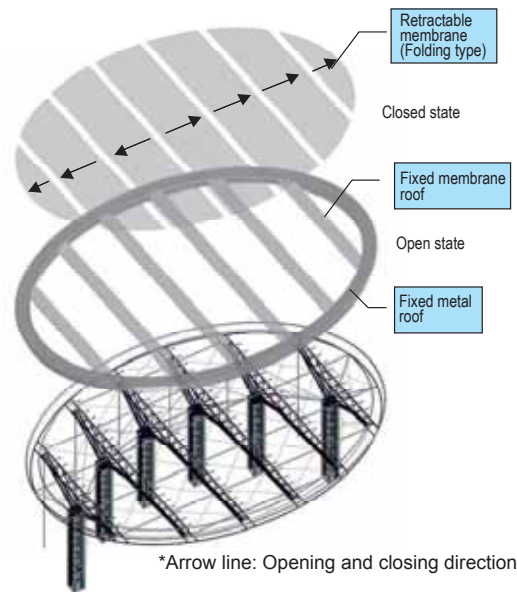
The adoption of this structural system offers the following advantages in terms of structure and construction:

- The elimination of rigid joints for connecting the columns to the cantilevered truss frames allows enormous stress to be transformed via the cantilevered trusses into tensile force in the backstay cables.
- This, in turn, substantially reduces the amount of stress transferred to the columns, thereby enabling a relatively slender column frame.

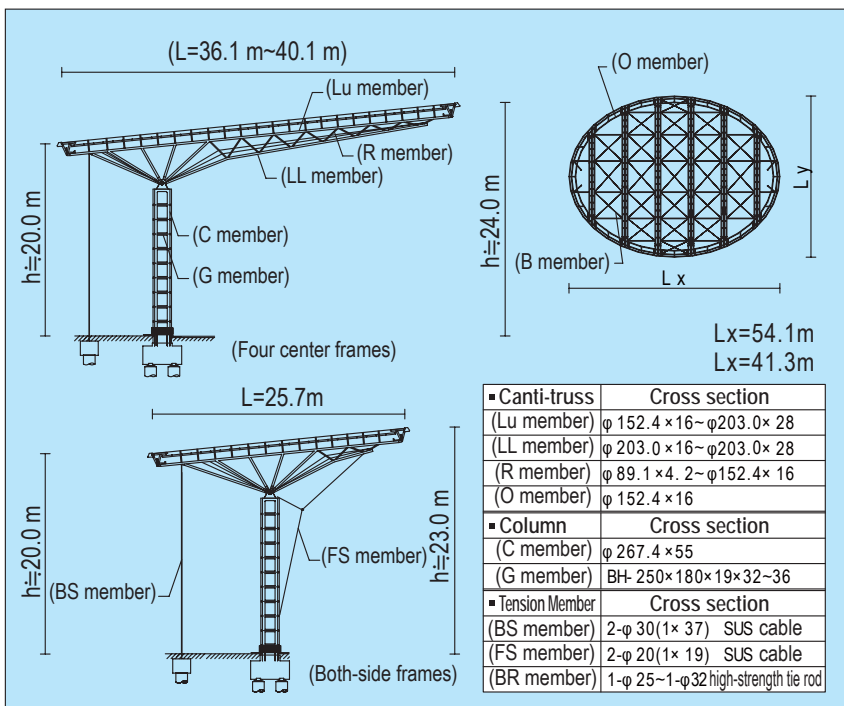
- Level adjustments at the ends of the cantilevered truss frames can easily be made by pulling in the backstay cables.

- The cantilevered truss frames permit structural expression characterized by a dynamic and floating appearance.

Further, in addition to the backstay cables, frontstay cables are provided for two frames on each end of the six cantilevered truss frames. This is intended to secure the soundness of the whole frame construction against unexpected loads. To this end, the initial tension established at the design stage is introduced into both cables.



Roof Structure



Dimensions of Structural Members



Column head-cast steel joint

National Art Center

—Glass Façade with a Three-dimensional Curved Surface Supports the Roof—

by Yasuyoshi Hitomi, NIHON SEKKEI, INC.

Structural Plan

The National Art Center came to completion in 2006 as an art museum used exclusively for exhibitions, without any permanent collections. The building plan consists of a 130-m by 60-m exhibition room and an irregularly shaped 3,000 m² atrium. Considering the possibility that artwork of worldwide value would be on exhibit, the building incorporates base-isolation technology to protect against earthquakes.

Façade Design

The atrium, standing 23 m high, has a glass façade with a three-dimensional curved surface. Its roof is supported by a total of 115 slender columns of flat steel (115 mm × 515 mm) placed at approximately 2-m intervals around the outer periphery of the roof (structural mullion system) and by the

exhibition building. The advantage of minimizing horizontal forces offered by a base-isolation structure allows for a column-free space in the atrium, thereby making possible the transparency of the façade.

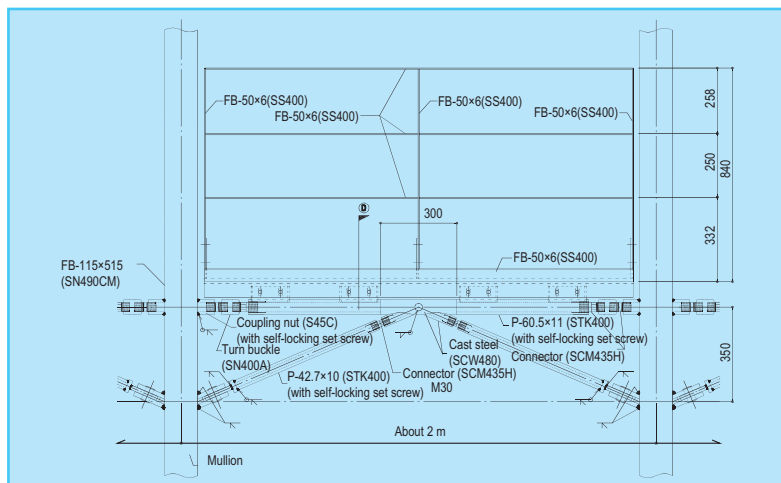
Structural Mullions

For the structural mullions, flat steel pieces were bent in their strong axial direction using cold pressing, and the 3D-truss thus prepared (with different curvatures up to 10.4 m) were weld-joined. Because no specifications are available for steel plate over 100 mm in thickness that is readily bent and suitable for welding, custom-made products equivalent to SN490C materials were adopted.

The structural mullion frame is stiffened against buckling at a pitch of about

3 m by horizontal tie truss beams. Taking into consideration the deformation tracking properties of sashes, criteria for the story drift were established at 1/120 or under.

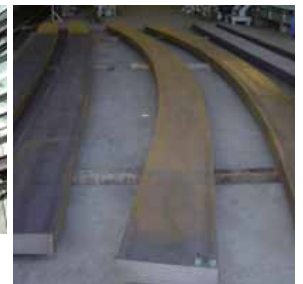
Time-history response analysis at the time of a large earthquake reveals that the maximum horizontal acceleration generated would be 286 cm/s² and the maximum vertical acceleration would be 581 cm/s², or about one third that of an ordinary seismic-resistant structure. Based on this, the allowable stress design to ensure safety was implemented on the assumption of a horizontal quake of 0.3G and a vertical quake of 0.6G.



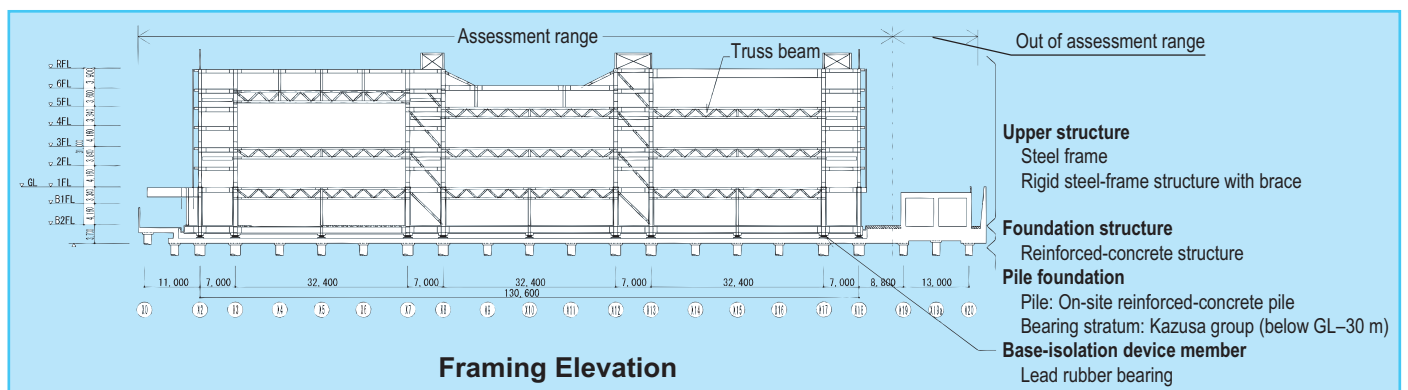
Full view of National Art Center



Glass façade with a three-dimensional curved surface



Slender column of flat steel



Framing Elevation

Marunouchi Oazo's Atrium

—A Column-free Expanse Created by Balanced Cantilever Framing System—

by Ichiro Ogawa and Tamotsu Ito, Mitsubishi Jisho Sekkei Inc.

Overall Structural Plan

Located at the center of the Marunouchi Oazo complex is the shop and restaurant building, which contains an atrium that rises 40 m or more in height and defines a space that clearly distinguishes the complex as a whole. The atrium roof measures approximately 20 m×25 m and is somewhat fan shaped. The roof of the 7-layer atrium has a finish of glass top light. Exterior curtain walls for five layers from third to seventh stories (height: about 30 m) are hung from the top of the roof.

Balanced Cantilever Framing System

For framing the atrium roof, eight plane

trusses protrude, like a frame built using the balanced cantilevered method, that crisscross a ship-shaped truss composed of four steel pipes on the upper and lower sides. In order to secure bilateral balance in a perpendicular direction, a spiral rope and a tie rod are attached to the end of each arm of the cantilever truss to prevent rotation.

The use of curtain walls hung from the roof frame using flat bars eliminates the need for column-like perpendicular members for façade walls. For wind beams, unit trusses are adopted as light members; they consist of cross-shaped hot-extruded steel as chord members and a combination of steel bars and ball joints as diagonal members.

Truss End Details

Since four steel pipes meet at each end of the ship-shaped truss—a representative form of the roof frame, the joints are made compact by the use of steel castings. The cast steel section is shaped so that one end is integrated with the boxed column and the other end rests on the column top plate.

The cast steel pipe corresponds in grade to SN490C (328.0 in diameter×45 mm), and the attached steel pipe conforms to STKN490B (318.5 in diameter×28 mm). Shop welding was used to connect the cast steel pipe and steel pipe, while field welding was used only for connecting parts of the steel pipe.



Photo: Kawasumi Architectural Photograph Office

Outside view of atrium

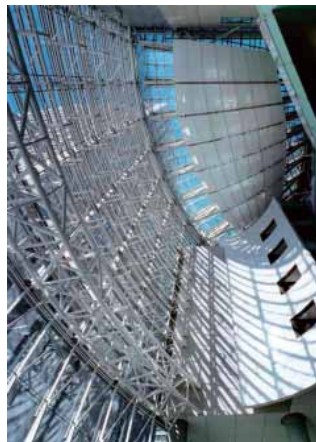
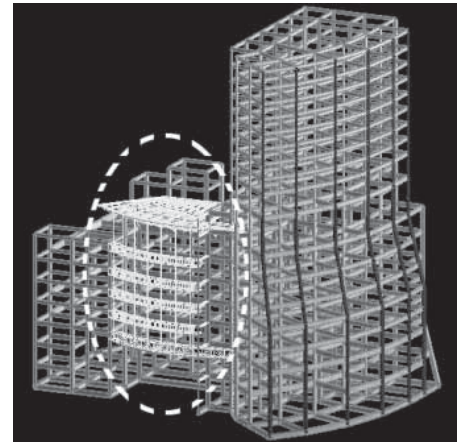
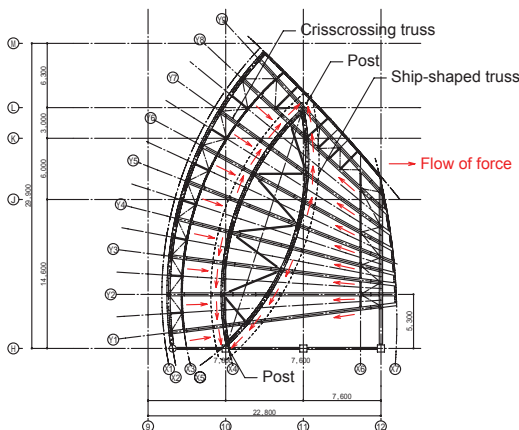


Photo: Kawasumi Architectural Photograph Office

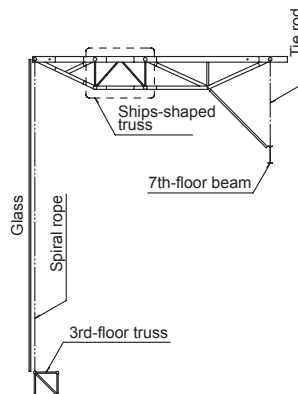
Inside view of atrium



Perspective view of entire building frame



Roof Framing Plan



Truss Framing Elevation



Edge of ship-shaped truss

International Library of Children's Literature

—Solid Posts Combining a Bright and Transparent Atrium with Sashes—

by Hiroshi Yamamoto, NIKKEN SEKKEI

Structural Design

It has been discussed how an old masonry and brick building, designated as an historical asset of the Tokyo Metropolitan Government, is gaining new life as a library of children's literature. In order to affect the reutilization of this building, a base-isolated retrofitting method was adopted that not only preserves the conventional interior/exterior structural design but will also ensure its structural safety.

In renovating the building as a new international library of children's literature, it was necessary to provide information/air-conditioning/disaster-prevention systems and a site for exchanges between people and goods. To meet this need, a service entrance composed of a glass enclosure was added that passes between two core shafts of reinforced concrete and along the exist-

ing building.

Glass Design

In contrast to the conventional exterior walls with their rich design detail and impression of weightiness, efforts were made to avoid the use of design detail in the materials of the glass enclosures forming the added corridor and entrance hall. Care was also taken to secure the visibility of the façade of the original building. The flat bars used as support posts for the exterior glass were reinforced using prestressed concrete (PC) bars, which also serve as the support structure for the floor.

Fire-resistant (FR) steel with no added fire protection was adopted for the flat bars comprising the major structural members, and the structural safety of the building during fire was verified. The safety

required for the new building was achieved by providing the PC bars with sufficient tension force to remain viable at the maximum assumed fire temperature.

Structural Details

FR steel flat bars with no added fire protection, measuring 50×180 mm, were used as posts for the glass enclosures on the 1st, 2nd and 3rd floors. An initial-stage tension force of 2.6~3.8 tf was introduced into PC bars that were 9.2 and 11 mm in diameter. FR steel flat bar posts were also arranged at 900-mm intervals in the entrance hall, cafeteria, and 3rd-floor lounge. For these sections too, PC bars were adopted as the reinforcing members.

Photo: The Japan Architects Co., Ltd.



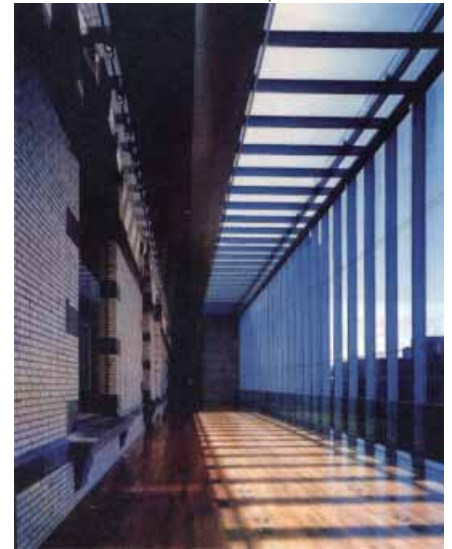
Front view

Photo: The Japan Architects Co., Ltd.



Court-side view

Photo: The Japan Architects Co., Ltd.

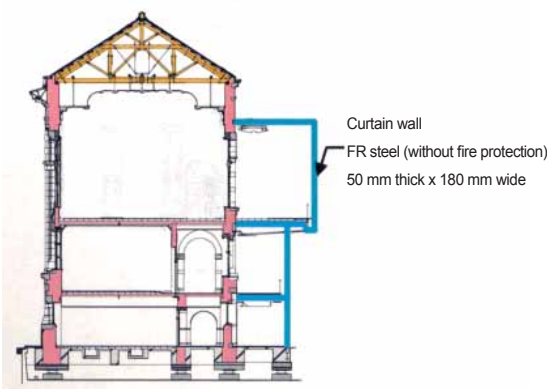


Third-floor lounge

Photo: The Japan Architects Co., Ltd.



Glass cafeteria



Sectional Drawing of Curtain Wall



FR steel post and PC bar

Steel Products for Aesthetic Architecture

Fire-resistant Steel

Fire-resistant (FR) steel has greater high-temperature strength than conventional steel. Because FR steel products conform to the room-temperature specifications of steel products used in building structures, any design work or construction that employs FR steel products can be performed in a manner identical to conventional steel products. A comparison of the high-temperature strength of FR steel and conventional steel is shown in Fig. 1.

The temperature at which the yield point falls to 2/3 the specified room-temperature strength (325 N/mm²) is approximately 350°C for conventional steel, but is in the neighborhood of 600°C for FR steel. Two-thirds the specified room-temperature strength corresponds to the allowable stress for sustained load. During a fire, sufficient strength is required to support the self-weight of a building, that is, the allowable stress for sustained load. To meet this demand, FR steel guarantees a high yield point of 600°C, which is more than 2/3 the specified value at room temperature (F value). The grades and mechanical properties of FR steel are shown in Table 1.

The available products and sizes of FR steel are: plates with thicknesses of 6 mm to 100 mm and H-shapes with flange thicknesses up to 40 mm. The two basic strength levels are: 235 N/mm² (Grade 35) and 325 N/mm² (Grade 50). For plate thicknesses greater than 40 mm, FR steel plates are available that have been manufactured using TMCP (thermo-mechanical control process) and that feature no reduction in the specified value at room temperature, F value (specified design strength).

Fig. 1 Comparison of High-temperature Strength of FR Steel and Conventional Steel

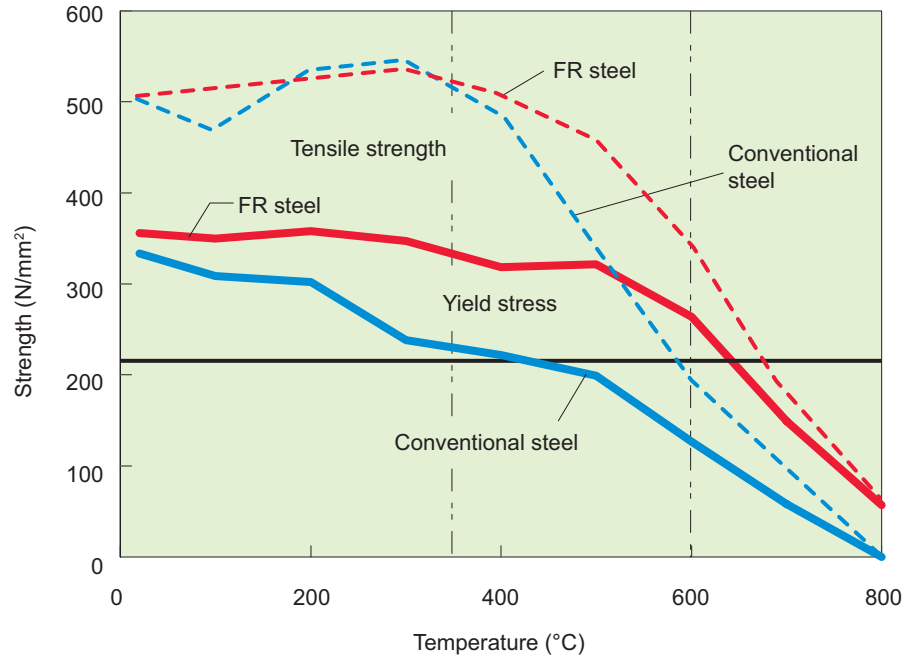


Table 1 Grade and Mechanical Properties of FR Steel

Symbol of grade	Yield strength		Tensile strength (N/mm ²)	YR (%)	Elongation		
	Thickness (mm)	(N/mm ²)			Thickness (mm)	Test piece	(%)
SM400A-FR	6 ≤ t ≤ 16	245 ≤	400 ~ 510	-	t ≤ 16	No.1A	18 ≤
	16 < t ≤ 40	235 ≤			16 < t ≤ 50	No.1A	22 ≤
	40 < t ≤ 100	215 ≤			40 < t	No.4	24 ≤
SN400B-FR	6 ≤ t < 12	235 ≤	400 ~ 510	-	6 ≤ t ≤ 16	No.1A	18 ≤
	12 ≤ t ≤ 40	235 ~ 355			16 < t ≤ 50	No.1A	22 ≤
	40 < t ≤ 100	215 ~ 335			40 < t ≤ 100	No.4	24 ≤
SN400C-FR	16 < t ≤ 40	235 ~ 355	400 ~ 510	≤ 80	t = 16	No.1A	18 ≤
	40 < t ≤ 100	215 ~ 335			16 < t ≤ 50	No.1A	22 ≤
SM490A-FR	6 ≤ t ≤ 16	325 ≤	490 ~ 610	-	t ≤ 16	No.1A	17 ≤
	16 < t ≤ 40	315 ≤			16 < t ≤ 50	No.1A	21 ≤
	40 < t ≤ 100	295 ≤			40 < t ≤ 100	No.4	23 ≤
SN490B-FR	6 ≤ t < 12	325 ≤	490 ~ 610	-	6 ≤ t ≤ 16	No.1A	17 ≤
	12 ≤ t ≤ 40	325 ~ 445			16 < t ≤ 50	No.1A	21 ≤
	40 < t ≤ 100	295 ~ 415			40 < t ≤ 100	No.4	23 ≤
SN490C-FR	16 ≤ t ≤ 40	325 ~ 445	490 ~ 610	≤ 80	t = 16	No.1A	17 ≤
	40 < t ≤ 100	295 ~ 415			16 < t ≤ 50	No.1A	21 ≤
TMCP325B,C-FR	40 < t ≤ 75	325 ~ 445	490 ~ 610	≤ 80	40 < t ≤ 50	No.1A	19 ≤
	75 < t ≤ 100	325 ~ 445			40 ≤ t	No.4	23 ≤
TMCP355B,C-FR	40 < t ≤ 75	355 ~ 475	520 ~ 640	≤ 80	40 < t ≤ 50	No.1A	19 ≤
	75 < t ≤ 100	355 ~ 475			40 ≤ t	No.4	21 ≤

*H-Shape: Thickness of flange is under 40mm
YR=Yield strength/Tensile strength

Steel Castings

Castings are classified into two kinds according to chemical composition: cast iron and cast steel. While the carbon content of iron castings somewhat exceeds 2%, that of steel castings is around 0.2%, which approximates the carbon content specified for ordinary rolled steel products. Because of this, in steel building construction, casting components for steel structures that require welding are generally steel castings.

Further, castings are sometimes classified into two different kinds according to the production method: steel castings for welded structures (JIS G5102) and centrifugal casting steel pipes for welded structures (JIS G5201). The Building Standard Law of Japan specifies the materials that can be used for building structures and SCW480 grade steel castings are often used, which has similar specifications to those of ordinary rolled steel (Table 1).

Production Processes

The production processes for both iron castings and steel castings are nearly the same. They include the lost-wax method in which a sand mold is prepared by affixing sand to a wax mold, and a method whereby a wood mold is embedded in sand that is then hardened with resins or by decompression. Of these, the furan-resin casting method is introduced below.

First, the casting method and casting plan (Fig. 1) are devised based on the production drawing, which is redrawn to the design drawing to allow for shrinkage of the casting materials. Should the casting plan is not appropriate, defects such as shrinkage cavities will occur in the product. To avoid critical problems such as this, risers and runners are arranged in a proper manner taking into account the past experience and through solidification simulation analysis. Although it is not unusual to produce a product yield for castings of about 40%, the measures mentioned above are mandatory in order to avoid the occurrence of inner defects.

Next, as shrinkage occurs during casting, a pattern is manufactured taking into account the shrinkage allowance. In cases when the pattern is repeatedly used in the same configuration, wood and other materials capable of withstanding repeated use are used to manufacture the pattern, while formed polystyrene is sometimes introduced for the pattern when the configuration for each product is not same.

Patterns manufactured in this way are embedded in sand to which the binder is added and the sand hardens within approximately 10 minutes. Generally, sand molds are prepared in two sections—upper and lower molds—so that the wooden pattern can be easily removed. After hardening of the upper and lower sand molds, the wooden pattern is taken out of the sand. The upper and lower sand molds are repaired for minor nicks and provided with sand burning-preventive measures, and are joined in preparation for pouring of the molten steel.

In producing steel castings, molten metal, which is made from steel scrap using electric arc furnace, is used. After being poured from the pouring cup, the molten metal is also supplied from risers because it suffers liquid shrinkage. After the molten metal cools down in the sand mold and the mold is removed, casting with runner and riser etc.

is obtained. After these gating systems are taken off and heat treatment is conducted, the castings are trimmed with grinder and machined, which are then shipped to users. (Refer to Fig. 2)

Applications

The major application of castings is in large-size industrial machinery parts and shipbuilding, with only a few percent being used in building structures. Because of this, only a few foundry companies position steel castings for building structures as a major product line. Nevertheless, as can be seen from their use in the joints of structural and finishing members of Sun Dome Fukui (see Photos 1 and 2), steel castings often function as structural materials for the joint components in space-frame structures and serve an important role in “aesthetic architecture.”

Fig. 1 Example of Casting Plan

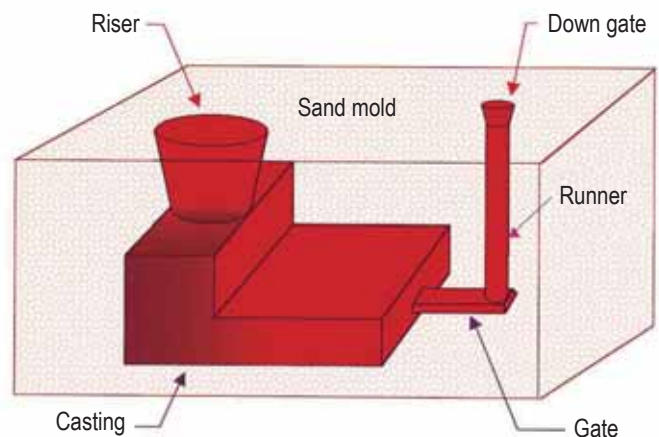


Table 1 Mechanical Properties of SCW480, Steel Castings for Welded Structures (JIS G5102)

Grade	Yield point (N/mm ²)	Tensile strength (N/mm ²)	Elongation (%)	Charpy impact test value at 0°C (J)
SCW480	275≤	480≤	23≤	27≤

Fig. 2 Production Process for Steel Castings

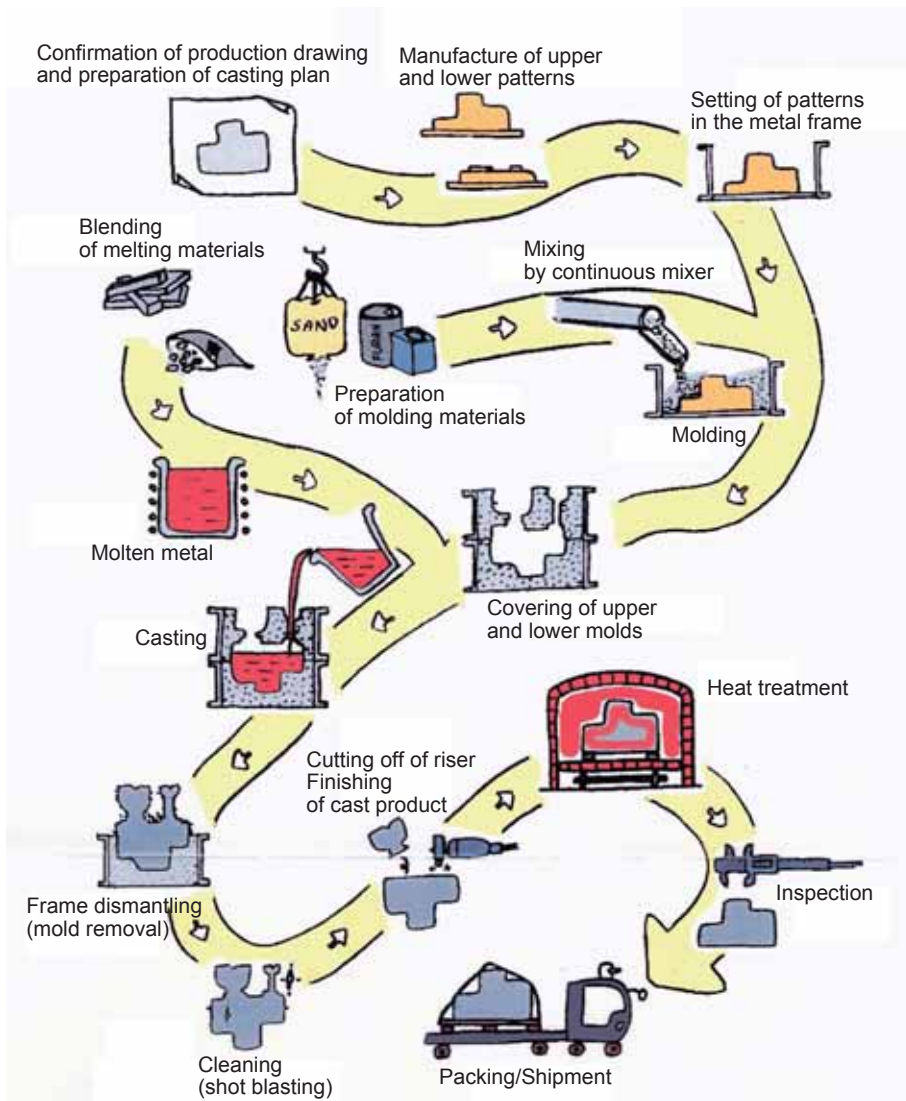


Photo 1 Inside view of Sun Dome Fukui



Photo 2 Expanded inside view (the cross-shaped sections are composed of steel castings)

Hot-extruded Steel Shapes

The extrusion of nonferrous metals such as copper was conducted in the 19th century. However, the practical extrusion of steel was difficult to implement because lubricants capable of withstanding high temperatures were unavailable. Then, in 1941, the French company Ugine successfully extruded steel using glass as the lubricant. Since then, the hot-extrusion process has made remarkable developmental strides as a method for producing stainless steel and special-alloy pipe and tubes and specially-shaped steel shapes. (See Photos 1 and 2 and Fig. 1)

This method has been used in Japan

since the installation of a hot-extrusion machine in 1960, mainly to manufacture stainless steel seamless pipe and tubes and hot-extruded steel shapes. In particular, the manufacture of hot-extruded steel shapes in Japan has relied solely on this machine. The hot-extruded steel shapes produced in Japan meet diverse needs, and the related



Photo 1 Hot-extrusion machine



Photo 2 Hot-extruded products

production technologies have been accumulating for many years now.

Production Process and Available Dimensions

The outline of a production process that uses a hot-extrusion machine is shown in

Fig. 2. Billets that have been reheated to around 1,200°C are inserted into the container; then, steel shapes that have been processed into deformed products are extruded from the front die caliber using water pressure. Hollow steel shapes are made available by the use of mandrels.

The die alone determines shape configuration (the die plus mandrel when producing hollow products). In contrast to the rolling process, the hot-extrusion process does not require the preparation of many rolls. The most outstanding feature of the hot-extrusion process lies in the small-

Fig. 1 Sectional Configurations of Hot-extruded Steel Shapes



lot production of items having specially-designed configurations.

The grades of steel available for hot extrusion include not only carbon steel and alloy steel but also difficult-to-process stainless steel. Regarding sectional dimensions, it is necessary to limit the product diameter to a maximum of 215 mm, while the available length of each shape depends on its cross section, up to a maximum of 11 m (Table 1). By fully utilizing these dimensional features, steel shapes are supplied monthly in about 500 configurations (averaging 2 tons/lot) that meet customer-tailored design requirements, not standard configurations.

Applications

Hot-extruded steel shapes are used in diverse fields—for example, forklift masts, parts for machine tools, and joints for steel sheet and pipe piles. In addition, these shapes are being increasingly used as both decorative and structural members in building construction, establishing many application records in such distinctive buildings as art galleries, museums and other cultural facilities.

Fig. 2 Extrusion of Hot-extruded Steel Shapes

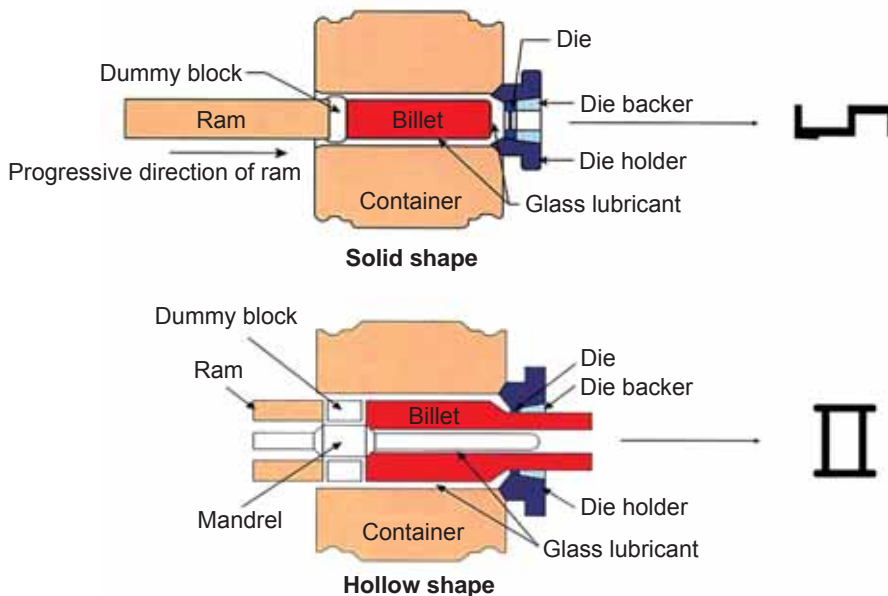
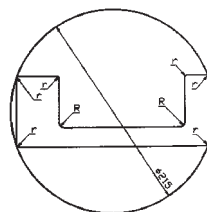


Table 1 Available Sizes for Hot-extruded Steel Shapes

Circumscribed circle (diameter)	215 mm (8 inches)
Thickness	6 mm (0.2 inches)
Corner (r)	2 mm (0.08 inches)
Corner (R)	5 mm (0.2 inches)
Minimum area (S _{min})	300 mm ²
Maximum area (S _{max})	6,000 mm ²
Length	1~11 m (3.2~36 feet)
Maximum weight	260 kg/p (574 lbs/p)

S_{max} is available up to 12,000 mm², when product is as-extruded or not corrected.



Steel-structure Harbor Facilities in Asia (Two-part Series: 2)

Port and Harbor Development and ODA

by Norihiko Ibuki
General Manager, Overseas Project Department
Japan Port Consultants, LTD.

Outline of Port and Harbor Projects Funded with ODA

Official development assistance (ODA) has been inaugurated as aid provided by governments or government organizations to developing countries to assist in economic development and welfare improvement. ODA is divided into two categories according to the type of capital flow: bilateral aid is provided through direct assistance, and multilateral assistance is implemented through international organizations.

Bilateral assistance includes grant aid, technical cooperation and loan aid (Japanese yen loans). In Japan, most grant aid and technical cooperation are implemented by the Japan International Cooperation Agency (JICA), a non-profit organization established by Japan's Ministry of Foreign Affairs. In addition, most loan aid is provided through the Overseas Economic Cooperation Operations of the Japan Bank for International Cooperation.

Multilateral assistance includes capital participation and donations to international organizations. Capital participation and donations to international development organizations are implemented mainly by the Ministry of Finance, while donations and other allotments to various organizations of the United Nations are controlled mainly by the Ministry of Foreign Affairs.

Meanwhile, at a cabinet meeting held on March 10, 2006, a new law was drafted — “Law Concerning the Promotion of Administrative Reform for Realizing a

Simple and Efficient Government.” In compliance with this law, the Japan Bank for International Cooperation is to be integrated into a “new financial organization” in fiscal 2008, and the bank's overseas economic cooperation operations are to be ceded to JICA. As a result, the organizations responsible for the administration of grant aid and loan aid will be unified.

Because of their great scale, port and harbor development projects are mostly implemented under yen-denominated loan conditions. But for development projects such as these that are mainly targeted for LLDC (Least among Less Developed Countries), implementation is under grant aid conditions, albeit for small amounts, taking into account the difficult financial condition of the LLDC.

According to surveys conducted on ODA-based port and harbor developments for the last five years (1999~2003) in the field of transportation, these projects accounted for 36~38% of all ODA projects in terms of project number. Meanwhile, all government yen loans, excluding deferred debt, for the same five years amounted to ¥3,550 billion, of which loans in the transportation area accounted for about 21%, or ¥750 billion. Of this 21%, loans for port and harbor development accounted for about 9%, or ¥67.5 billion yen.

Application of Steel Structures

Introduced below is a description of how steel products have been used for port and

harbor development projects involving Japan Port Consultants, LTD. (JPC).

• Development Project for Semarang Port in Indonesia

In the development project for Semarang Port located on the northern coast of central Java, Indonesia, steel structures were adopted for the breakwaters and piers. The breakwater is designed to support a continuous steel sheet pile wall using oblique steel pipe piles. In breakwater construction, gravity-type composite breakwaters are widely adopted that use heavy concrete structures, such as caissons and rubble-type sloping breakwaters constructed by piling up rubbles.

However, at the Semarang Port construction site, the soft seabed posed many hurdles to construction. These included the need for ground improvements to accommodate heavy gravity-type structures; difficulty in securing the vast amounts of good-quality sand needed to replace the weak stratum; and construction cost increases related to mixing cement into the weak stratum. To overcome these hurdles, steel structure construction was selected.

• Development Project for Kupang Port in Indonesia

At Kupang Port located in West Timor, Indonesia, an island that sits in front of the port serves as a breakwater, protecting the port from sea waves. Because vast investments are required to build breakwaters,

most conventional ports have evolved from river ports. However, in order to accommodate the trend toward greater ship size due to growing social modernization, it has become necessary to secure the requisite water depth for ports. Because islands form isolated channels with the appropriate water depth and provide calm sea areas, there are many cases in which ports and harbors in developing countries are located in such geographically blessed sites.

Kupang Port is located in such a channel site, where the sloping terrain of the seabed is steep and drops precipitously in front of the pier. Because of this, a steel pipe-pile structure that is easily adaptable to rugged seabed surfaces has been chosen to replace the gravity-type pier as the pier structure. (See Fig. 1)

● Development Project for Bitung Port in Indonesia

Bitung Port in north Sulawesi, Indonesia, is located at a channel site, like the Kupang Port. Because of the steep slope of the seabed in front of the pier, a steel pipe-pile

pier structure has been adopted for the pier structure. (See Fig. 2)

● Development Project for Colombo Port in Sri Lanka

The development project for Colombo Port, Sri Lanka, involves the construction of container berth and terminal in the port surrounded by existing breakwaters. Because the seabed in front of the pier is comparatively flat and the foundation layer is located in shallow water, a caisson-type gravity structure was adopted for the pier. Steel pipe piles were used for the foundation piles of the land-based container crane. (See Fig. 3)

Japanese ODA and Future Port and Harbor Development

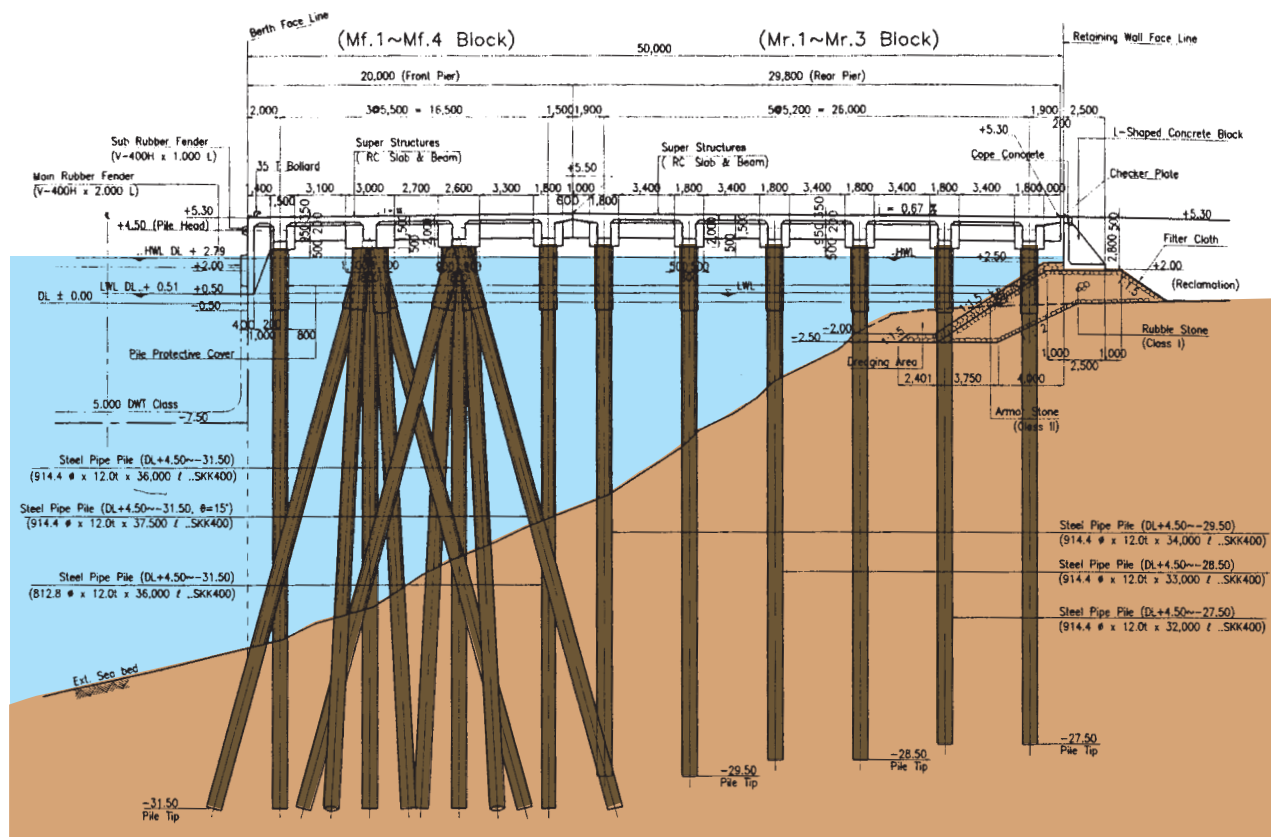
Japanese ODA has hitherto been provided mainly in support of the developing countries of Asia. This will remain unchanged because of the important political and economic relations between Japan and Asia. Meanwhile, then-Japanese Prime Minister J. Koizumi stated in 2005 that Japanese

ODA for Africa will double in the next three years. He frequently stressed Japan's aid doctrine in political speeches and at summit meetings—"In order to support the efforts of African countries to achieve sustainable self-reliance, the Japanese government will provide the support that these countries truly require."

In the sub-Saharan area of Africa south of the Sahara Desert, there are many LLDC with difficult financial situations; these countries will primarily receive grant aid support. However, LLDC with improving financial conditions can expect to receive yen loans for their port and harbor development projects.

As stated above, in most cases where steel is used in the construction of port and harbor facilities, steel structures suitable for the topographical, soil and other natural conditions of the port site will be adopted. In addition, there are cases where steel structures allow for a narrower work site than gravity-type structures and where they reduce the use of heavy construction machinery in building port and harbor

Fig. 1 Standard Section of the Pier at Kupang Port



facilities. Also, in developing countries where it is difficult to procure adequate construction machinery, steel structures offer the added advantage of requiring fewer machines for construction.

In the construction of port and harbor

facilities in developing countries, it will be necessary to select structural types that are appropriate for the specific conditions of these countries and areas. It will also be necessary to contribute to the economic development of these countries and at

the same time to transfer to them Japan's excellent technologies and know-how. It is thought that the demand for steel structures in port and harbor development projects will continue to expand in the future.

Fig. 2 Standard Section of the Pier at Bitung Port

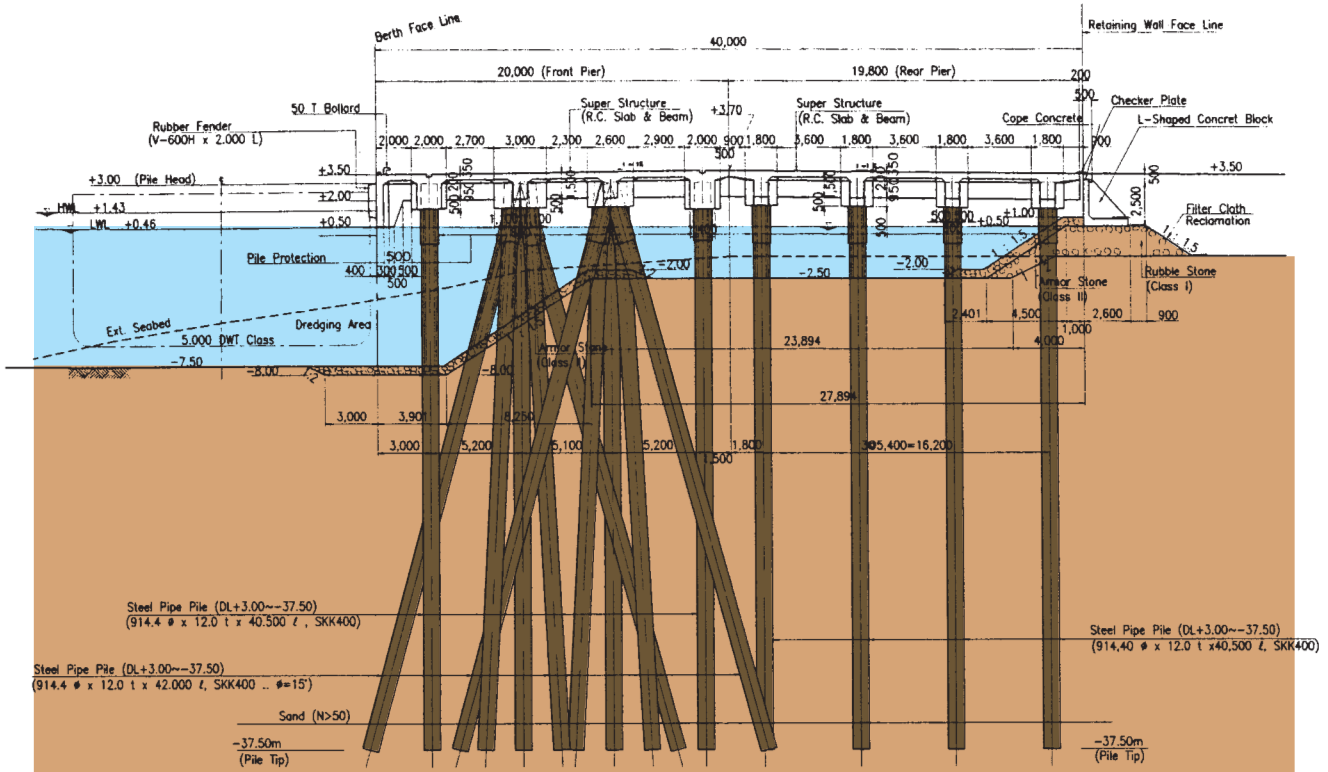
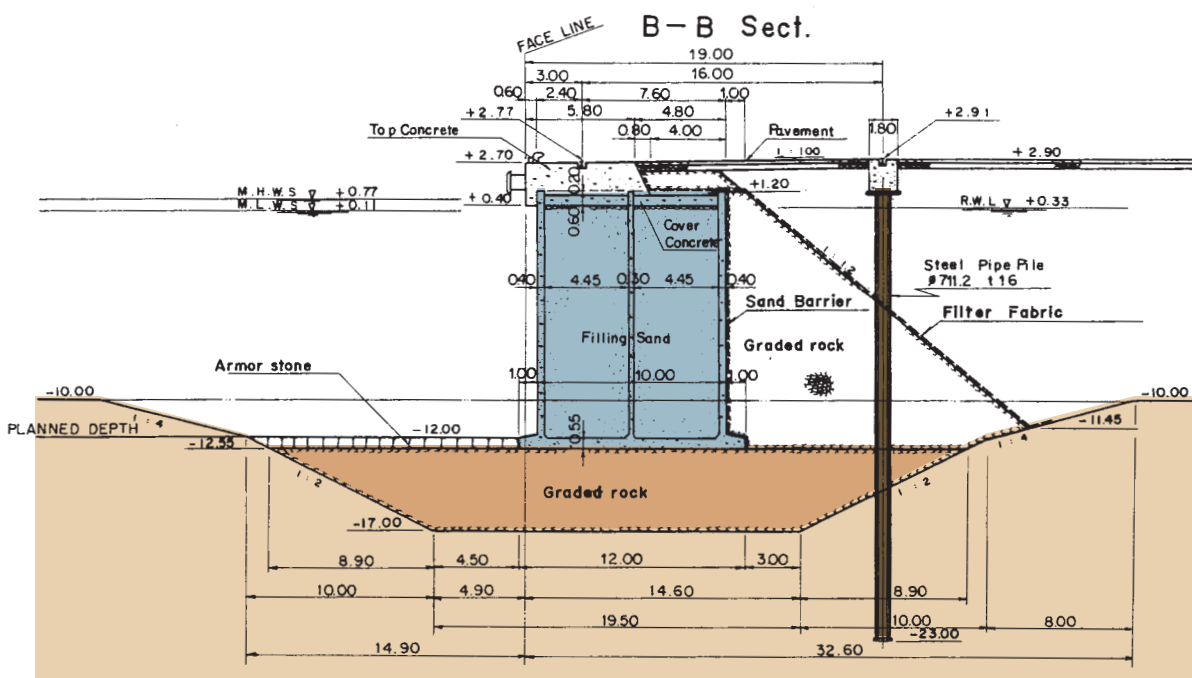


Fig. 3 Standard Section of the Pier at Colombo Port



JSSC Special Prize

Awarded for Accomplishments in Research on the Redundancy of High-rise Steel Buildings

On November 16, 2006, the Japanese Society of Steel Construction (JSSC) presented the JSSC Special Prize to the Committee to Study the Redundancy of High-rise Steel Buildings (chaired by Prof. Akira Wada, Tokyo Institute of Technology). This award was presented for research conducted jointly with U.S. counterparts on guidelines for collapse control design and for the subsequent publication of *Guidelines for Collapse Control Design*.

The destruction of the World Trade Center buildings on September 11, 2001, due to progressive collapse attracted wide attention and caused societal concern about the safety of steel buildings. To meet this concern, the JSSC quickly established in June 2002 the Committee to Study the Redundancy of High-rise Steel Buildings with a mandate to design a method that could control progressive collapse in steel buildings.

The proposed research was promoted in collaboration with the Council on Tall Buildings and Urban Habitat (CTBUH) of the U.S. In September 2005, these two organizations jointly published *Guidelines for Collapse Control Design*, which presents the world's first practical design guidelines for controlling progressive collapse in steel buildings. *Guidelines* was published not only for Japanese users but for overseas users as well.

The research conducted thus far has contributed to the sound development of steel building construction technologies both in Japan and abroad. The JSSC holds these accomplishments in high regard and, because of this, presented the current award.

Guidelines for Collapse Control Design, available in a three-part series—Design, Research and High-performance Steel Products for Building Construction—is covered in detail in issue No. 12 of *Steel Construction Today & Tomorrow*.



Prof. A. Wada (left) receives the JSSC Special Prize

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COVER

Typical aesthetic architecture and steel members used—*left above*: National Art Center (for details, see page 9); *left below*: column head-cast steel joint (page 8); *right above*: Mikimoto Ginza 2 (page 5), and *right below*: lounge structure using uncoated FR steel (page 11)

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