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Tokyo Bay Bridge —Long-span Bridge Employing Advanced Bridge Materials and Technologies—

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Introduction

The Port of Tokyo is representative of all the ports in Japan that handle international trade. Since 1998, it has processed the greatest volume of international marine container cargo in Japan and this volume continues to grow year by year. The coastal area of Tokyo Bay surrounding the Port of Tokyo is home to a high concentration of not only port and harbor logistics functions, but also the nation's major production, commercial, business and urban functions. Owing to all the international trade cargo handled in the area and because of the urban activities conducted in the surrounding metropolitan area, traffic volume is immense. Due to increases in vehicular traffic, road conditions have deteriorated, thereby causing an increase in the lead time required to transport international container cargo from port and harbor facilities to production and consumption sites. This growth in lead time constitutes one of the causes behind the rising domestic cost of logistics in international trade.

In the Port of Tokyo, a strategic plan is currently underway that is designed to enhance smooth inter-city logistics for the transport of international trade cargo in the coastal area. Known as the Tokyo Port Seaside Road, this thoroughfare will extend 8 km and will link Tokyo's Jonanjima in Ota-ku with Wakasu in Koto-ku. The first phase of construction began in July 1993 with a 3.4 km-long underwater tunnel joining Jonanjima with a reclaimed site outside the Central Breakwater; this phase ended in April 2002 when the tunnel was put into service. Currently underway, the second phase of the plan calls for the construction of a 4.6 km-long road that will include the 2.9 km-long Tokyo Bay Bridge (provisional name) linking Wakasu with the reclaimed site inside the Central Breakwater. The road is scheduled for completion in 2010. (Refer to Photo 1 and Fig. 1.)

The following are noteworthy features of the construction site for the Tokyo Bay

Bridge.

- Because the bearing strata are soft, installation of the foundation structure will require greater than normal depth.
- The bridge will have a long span because it will extend over the third fairway of the Port of Tokyo.
- 3) The bridge is subject to restrictions imposed for being within the flight area of the Tokyo International Airport.

In order to meet these restrictions and to secure the required bridge performances, a variety of new bridge design technologies have been incorporated at every turn of the construction. Also, full consideration was



Photo 1 Artist conception of Tokyo Bay Bridge upon completion

Fig. 1 Location of Tokyo Port Bayside Bridge



given to cost reduction, a national policy imposed on public works construction, at every stage from planning and design to construction. As a result, it is not too much to say that every civil engineering technology currently available in Japan is fully implemented in the construction of the Tokyo Bay Bridge.

Introduced below is an outline of the construction of the Tokyo Bay Bridge, which by taking full advantage of advanced civil engineering technologies to overcome a variety of challenging conditions, offers high expectations regarding its role as an important segment of the main logistics thoroughfare for the Port of Tokyo in the 21st century.

Bridge Substructure

• Substructure Outline

Separate structural types have been adopted for the bridge substructure and the foundation: steel pipe sheet piles for the above-water foundation and triple-wall steel pipe piles for the ground foundation because the latter sits on ground reclaimed using waste matter.

The above-water substructure consists of nine piers. The two main piers (MP2 and MP3) that sandwich the third fairway of the Port of Tokyo are solid wall-type piers, and the substructure installed between the side spans uses hollow reinforced-concrete piers.

At the bridge construction site, there is a thick layer of soft alluvial clay (AC2 layer, N value 0), a gravel layer (Dg1 layer) located below A.P. –75 m on the Central Breakwater side that serves as the bearing stratum of the foundations (CP9~MP2), and a sand layer (Ds2 layer) located below A.P. –50 m on the Wakasu side that serves as the bearing stratum of the bridge piers (MP3~WP6). Both bearing strata are located at relatively great depths.

Because of the highly demanding ground conditions under the bridge structure and, further, because the bridge foundation must demonstrate sufficient supporting capacity and stability against design seismic motions throughout the 100-year service life of the bridge, studies were conducted on a variety of structural types as they apply to foundations. As a result, the steel pipe sheet pile foundation was selected as the most suitable structure.

Structural Outline of Bridge Foundation

The following performances are required of the bridge foundation:

- High rigidity of pile foundation structure due to the softness of the ground at the construction site
- 2) High work safety and less environmental burden made possible by reducing soil excavation during construction
- High construction efficiency and cost advantages

Steel pipe sheet pile foundations were adopted as the structural type that meets these requirements with a high degree of satisfaction (Photo 2). Steel pipe with a diameter of 1,500 mm was selected in consideration of the drilling depth, residual stress control and supporting capacity. In order to ensure shear strength of the steel pipe sheet piles during an earthquake,



Photo 2 Steel pipe sheet pile foundation



Photo 3 Interlocking joint for steel pipe sheet pile

interlocking joints were adopted that use striped steel plates in combination with high-strength mortar (Photo 3).

Bridge Superstructure

The Tokyo Bay Bridge is being installed in 5 blocks differentiated by location: two land-based approach sections (both ends), two offshore approach sections, and the main bridge section. Of these, the block that will be the largest in scale and require the most difficult construction work is the main bridge section—a three-span continuous truss-box composite structure having a total length of 760 m and a center span of 440 m. All the other land-based and offshore approach sections are multi-span continuous steel slab box girder structures.

Structural Features: Adoption of High-performance Steel for Bridge Construction

A distinctive feature in the construction of this bridge is the use of Bridge High Performance Steel (high-performance steel for bridge construction) to reduce the bridge's total weight as much as possible. Such use is a first in long-span bridge construction in Japan. The Bridge High Performance Steel (BHS) is a high-performance material that was jointly developed in research conducted by the Tokyo Institute of Technology and Japan's major steelmakers. This advanced steel not only has higher strength than conventional steel but also offers excellent weldability and workability. (For more details, refer to BHS on page 5)

Recently, reduced construction expenses, improved durability and lower maintenance costs are being called for in social infrastructure development. To meet these requirements as they apply to bridge construction, there is a growing need for steel products with higher performances; such high-performance steel is being used extensively to enhance weight reduction in the construction of the Tokyo Bay Bridge. In addition, the adoption of weld joining in place of conventional bolt joining to connect steel truss members has brought about many advantages: the realization of a smooth and uniform appearance, the avoidance of coating film deterioration due to the use of bolts and splice plates, and an improvement in coating film durability.

• Structural Features: Weld Joints

As stated above, most of the bridge's structural members are being joined by welding, where the efficient joining method most rarely found in conventional bridge construction has been adopted. Several of these welding methods are introduced below:

-Compact panel point

In the conventional joining method applied to sections where chords and other members that compose the truss are concentrated, the joint structure comprises members that are individually joined via a splice plate. In the current bridge, the conventional method is replaced by a joint structure in which each of the members concentrated at the panel point is directly joined to the others to form a more compact panel point (Fig. 2). In this structure, optimization of the member cross sections is enabled by the direct transfer of stress to each member.

Because the thin crossed axes angle is liable to generate in the compact panel point, advanced welding technology and strict weld control are required in the welding operations.

-Z-shaped joints

In Z-shaped joints, the weld joint section perpendicular to the member axis is shifted each other so that welding is not conducted on identical cross sections of the members to be joined (Fig. 3). This type of joint is a welding technology used for steel railway bridges. As shown in the figure, the Z-shaped joint forms complicated weld lines, and thus requires advanced welding technology for execution.

Shifting of the weld lines in the Z-shaped joint prevents the simultaneous penetration of cracking into the full weld joint section, even in cases when fatigue cracking occurs in the weld joint section. This joint has been adopted from the view-point of securing enhanced safety in weld construction. Meanwhile, as a similar plate weld-joining method, the double-level weld joint has been adopted for steel slabs. With this method, weld lines perpendicular to the member cross section are shifted each other.

-New trough ribs

The recent appearance of fatigue cracking in steel slabs is causing considerable concern in steel bridge construction. In order to avoid fatigue cracking in steel slab-trough rib joining sections, a trough rib with new and unprecedented details has been adopted in Japan (Fig. 4). The new trough rib has a most effective face that has been determined by practical model experiments and FEM analysis.

The Tokyo Bay Bridge is a large-scale structure that aptly symbolizes the future evolution of the Port of Tokyo as a representative of Japan's seaports. The diversity of advanced technologies for structural materials, welding and construction that have been adopted in this bridge are expected to contribute greatly to the devel-

Fig. 2 Compact Panel Point (Image)

opment of still newer technologies for use in building Japan's steel highway bridges.



Conventional panel point

Compact panel point adopted for Tokyo Port Bayside Bridge

Fig. 3 Sequence for Executing Z-shaped Weld Joint







Steel and Bridge Superstructure and Substructure

Bridge High Performance Steel

A new type of high-performance steel for bridge construction—Bridge High Performance Steel (BHS)—has recently been put on the market. Developed to meet emerging needs in steel bridge construction, this steel addresses the demand for reduced weight, improved weldability, and formability in cold bending¹). Three types of steel grades with the designations BHS500, BHS500W, and BHS700W are available.

BHS stands for Bridge High-performance Steel and is specified in the JISF (Japan Iron & Steel Federation) Standards, MDCR 0014-2004. The numbers 500 and 700 after the designation denote the minimum yield strength and the suffix W denotes weathering steel.

Characteristics of BHS

The typical characteristic properties of BHS are listed in Table 1. Compared with SM570 and HT780, the conventional steel grades for bridge structural use, BHS demonstrates a high yield strength up to 100 mm in thickness and a high toughness that exceeds 100 J in Charpy absorbed energy, as well as a significantly reduced preheating temperature and high formability in cold bending.

These properties are made available by the use of TMCP (thermo-mechanical control process) to produce fine microstructures, as shown in Fig. 1, with low Pcm values (parameter of crack material), as shown in Fig. 2.

Specifications

JISF specifies BHS in JISF Standards MDCR 0014-2004. Tables 2 and 3 provide the specifications for chemical composition and mechanical properties, respectively. BHS has an extra-low carbon content that improves weldability. Weathering indexes, where V is equal to or greater than 1.0, are specified for weathering steel grades.

Application to Actual Project

Seven thousand tons of BHS have been adopted for use in the construction of the Tokyo Bay Bridge (Fig. 3), one of Japan's most modern bridges (for details, see page 1). Prior to actual application, a full-scale large-size BHS I-girder fabrication test was jointly conducted by the bridge contractors and JISF that proved a 10% reduction in the fabrication period. BHS is expected in the near future to open new fields in the design and construction of steel bridges.

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Reference





Fig. 2 Combined Performances of High Strength and Good Weldability Available through TMCP Application







lable1 Comparison of Typical Characteristic Performances between BHS and Conventional Steel						
	HT570) class	HT780 class			
Steel grade	BHS500 (W)	Conventional	BHS700W	Conventional		
		5101570		H1780		
Min. yield strength (t=50 mm)	500 MPa	430 MPa	700 MPa	685 MPa		
Min. yield strength (t=100 mm)	500 MPa	420 MPa	700 MPa	665 MPa		
Min. Charpy impact energy	100J	47J	100J	47J		
Max. carbon content	0.11	0.18	0.14	0.18		
Max. Pcm	0.20	0.27	0.32	Not specified		
Min. pre-heat temperature	Free	80°C	50°C	100°C		
Max. cold bending radius	7t	-	-	_		

Pcm=C+Mn/20+Si/30+Cu/20+Ni/60+Cr/20+Mo/15+V/10+5B(%)

Table 2 Chemical Composition of BHS

Designation	Thickness		Maximum value (weight %)					Pcm	V	
	(mm)	С	Si	Mn	Р	S	N	Other specified	%	%
								elements		
BHS500	6 -100	0.11	0.55	2.00	0.020	0.006	0.006	-	0.20	-
BHS500W	6 -100	0.11	0.55	2.00	0.020	0.006	0.006	Cu, Cr, Ni	0.20	1.0
BHS700W	6 -100	0.14	0.55	2.00	0.020	0.006	0.006	Cu ,Cr, Ni,	0.30(*1)	1.0
								V, Mo, B	0.32(*2)	

V=1/[(1.0-0.16C)×(1.05-0.05Si)×(1.04-0.016Mn)×(1.0-0.5P)×(1.0+1.9S)×(1.0-0.1Cu)×(1.0-0.12Ni)×(1.0-0.3Mo)×(1.0-1.7Ti)] (*1) Thickness range: 6.0-50.0 mm

(*2) Thickness range: 50.1-100 mm

Table 3 Mechanical Properties and Charpy Absorbed Energy of BHS

	Yield	Tensile	Elongation		Charpy impact test (t ≥12 mm)		
Designation	strength (MPa)	strength (MPa)	Specimen	%	Test temp.	Average energy	Specimen
BHS500 BHS500W	≥500	570/720	t ≤16 mm JIS No5 t >16 mm JIS No5 t >20 mm JIS No4	≥19 ≥26 ≥20	-5°C	≥100J	JIS V Transverse
BHS700W	≥700	780/930	t ≤16 mm JIS No5 t >16 mm JIS No5 t >20 mm JIS No4	≥16 ≥24 ≥16	-40°C	≥100J	JIS V Longitudinal

Steel Pipe Sheet Pile Foundations Employing High Shear-strength Joints

Steel Pipe Sheet Pile Foundations

Steel pipe sheet pile foundations are formed by driving steel pipe piles with interlocking joints into an optional closed configuration (circle, rectangle, ellipse or others), as shown in Fig. 1, and connecting the top of each contiguous pile rigidly to a footing. As a result, this type of foundation offers great horizontal resistance and high vertical bearing capacity. Developed in Japan in 1964, the steel pipe sheet pile foundation was first adopted as a bridge foundation and has since been used in more than 2,000 installations.

When planning the construction of long-span bridges that will impose largescale loads on thick soft ground, there are

cases in which the use of conventional steel pipe sheet pile foundations result in excessively large plane configurations due to restrictions on horizontal displacement. The steel pipe sheet pile interlocking joint employing internally striped steel pipes was developed to remedy this problem because of its higher shear strength relative to conventional joints (Photo 1 and Fig. 2). Steel pipe sheet pile foundations that use these interlocking joints have already been applied in a big-scale construction project. The characteristic features of these high shear-strength joints using striped pipes are introduced below, together with possible future development.

Interlocking Joints for Steel Pipe **Sheet Pile Foundations**

Conventional steel pipe sheet pile foundations adopt interlocking joints that are structured by connecting steel pipes that are 165.2 mm in diameter (pipe-pipe or P-P type joint) and filling them with 20 MPa mortar. In the design of such conventional foundations, the interlocking joints are modeled as shear springs, and the shear rigidity and strength of the joints are determined based on the results of tests conducted by the Public Works Research Institute, shown in Fig. 3. The effect of joint shear strength on a steel pipe sheet pile foundation has not yet been clarified; therefore, when assuming the construction of a



Fig. 1 Schematic Diagram of Steel Pipe Sheet Pile Foundation by Temporary Cofferdam Combined Method



Photo 1 High shear-strength striped pipe interlocking joint

large-scale bridge on soft ground, the number of steel pipe sheet piles to be driven is found using the shear strength as a parameter, the results of which are shown in Fig. 4. The figure clearly shows that when shear strength is improved, the plane configuration of a foundation can be made smaller.

Shear Tests of High Shear-strength Striped Pipe Joints

In order to understand the shear charac-

teristics of striped pipe joints, push-down shear tests were carried out. In the tests, the loading test device shown in Fig. 5 was used, and the load was applied to the support in the middle of the test specimen.

The interlocking pipes used were internally striped steel pipes with a diameter of 165.2 mm and a plate thickness of 11 mm; the strength of the mortar was set at 40 MPa, twice that of conventional mortar. The identical test method was applied to three specimens.

Fig. 6 shows the relationship between the shear strength and the relative slip displacement of the specimens. The average shear strength of the three test specimens with interlocking joints formed using striped pipes was 1,640 kN/m.





Fig. 3 Test Results concerning Shear Strength of Conventional Pipe Joints



Fig. 4 Relationship between Shear Strength of Joints and Number of Steel Pipe Sheet Piles



Fig. 6 Example of Relationship between Shear Strength and Relative Slip Displacement





Fig. 7 Example of Judgment of Yield

Fig. 5 Loading Test Device



Design Shear Characteristic Values of High Shear-strength Striped Pipe Joints

Shear Strength

The shear strength of the striped pipe joints was determined as follows. The yield point was found by first determining the relationship between the shear strength and the relative slip displacement (Fig. 7) and then incorporating into this value a safety factor of 1.25, the same level for conventional interlocking joints. The yield point thus found was set as the shear strength during a level-2 earthquake. The shear strength during regular service was determined by incorporating a safety factor of 2.0 into the shear strength during a level-2 earthquake, as in the case of conventional joints; the shear strength during a level-1 earthquake was determined by incorporating a safety factor of 1.5 into the shear strength during a level-2 earthquake.

• Shear Rigidity

The shear rigidity for conventional joints is found from the shear strength at a relative slip displacement of about 0.1 mm where the surface adhesion of the mortar is severed. However, in the case of striped pipe joints, because of the higher shear-resisting capacity between striped joint pipes and mortar, the shear strength steadily grows even after surface adhesion is severed. Consequently, it was decided that the shear rigidity of high shear-strength joints is to be found from slip displacement that is equivalent to shear strength during a level-2 earthquake, which was determined above.

Summary of Design Shear Characteristic Values

Table 1 shows the shear strength and the shear rigidity that are applied in the design, and Fig. 8 summarizes the relationship between the shear strength and the slip displacement using envelope curves. As shown in the figure, the design shear

Table 1 Shear Characteristic Values Used in Design

	Shear strength (kN/m)	Shear rigidity (kN/m²)
During level-2 earthquake	1,150	
During level-1 earthquake	767	630,000
Regular service	575	



Fig. 8 Design Shear Characteristic Values of High Shear-strength Striped Pipe Joints

strength of striped pipe joints shows a 5-fold increase over conventional joints. As shown in Fig. 8, as regards the spring model of joints, a nonlinear spring of the bi-linear type was adopted for level-2 earthquakes, and a linear model with the identical shear rigidity was adopted for regular service and level-1 earthquakes; further, the upper limit was provided for the shear strength in both cases.

Steel Pipe Sheet Pile Foundations Employing High Shear-strength Striped Pipe Joints

Fig. 9 shows the results of a trial design for a steel pipe sheet pile foundation using both high shear-strength striped pipe joints and conventional pipe joints.

The trial design in Fig. 9 is for a largescale bridge built on a thick layer of extremely soft ground. In this case, when a steel pipe sheet foundation employing conventional joints was adopted, the plane dimension of the foundation was deter-

Fig. 9 Comparative Case Study between Conventional Pipe Joint and High Shear-strength Striped Pipe Joint

Joint	Conventional pipe joint	High shear-strength striped pipe joint
Plane configuration (mm)	60000000000000000000000000000000000000	COOCCOOCCOOCCOOCCOOCCOOCCOOCCOOCCOOCCO
Number of steel pipe sheet piles	175	106

mined by the displacement. When a foundation employing striped pipe joints was adopted, the number of steel pipe sheet piles to be used could be reduced, and at the same time a considerably small plane dimension for the foundation could be realized, as can be seen in Fig. 9.

These trial designs demonstrate that the use of striped pipe interlocking joints allows for reductions not only in foundation dimensions but also in construction cost, depending on the ground and loading conditions.

Future Development

The steel pipe sheet pile foundation employing high shear-strength interlocking joints is particularly advantageous when planning the construction of largescale foundations on thick layers of soft ground. This type of foundation does not always present a similar advantage under every application condition, because the dimension can be reduced depending on the design condition. But, the foundation is expected to serve as the most suitable foundation structure in urban areas where construction sites are limited in space or neighboring construction is required. Further, studies are underway regarding their application in new foundation structures, such as integrated foundation-bridge pier structures that use protruding-type steel pipe sheet pile foundations.

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Energy Balance Seismic Design —Application of Seismic Design Based on Energy Balance in Steel Construction—

The "Seismic Design Method based on Energy Balance" (hereinafter referred to as the energy method), a notification of the Ministry of Land, Infrastructure and Transport, was promulgated on June 28, 2005¹⁾ and was enforced on September 1, 2005. While conventional seismic design methods adopt as criteria such intuitively understood physical quantities as strength and deformation, the energy method adopts energy, a physical amount that is more universal.

Specifically, this design method rationally examines a building's seismic resistance by comparing energy input caused by seismic motion with the energy that the structure can absorb^{2), 3)}. The energy method is particularly effective when used in steel-frame buildings, because the energy absorption capacity has been quantitatively measured through an abundant accumulation of structural experimental results. Another advantage offered by this method is that it allows for the appropriate use of hysteretic dampers that positively absorb seismic energy.

Outline of the Energy Method

The flow of structural calculations in the energy method is shown Fig. 1. Structural calculations encircled with dotted lines are the same as those used in the conventional seismic design method, and those shown in the grey zone are structural calculations peculiar to the energy method.

• Significance of the terms (Section A in Fig. 1)

In the energy method, when the seismic resistance of a frame structure equipped with hysteretic dampers is assessed, the structure is divided into two sections main frame and damper section—with assessments being made of each, as shown in Fig. 2. The main frame is defined as that composed of common columns and beams, and the damper section as that composed of the energy-absorbing members and their supporting members. The types of dampers in common use are shown in Fig. 3.

Fig. 1 Flow of Structural Calculations



Examination of rarely-occurring moderate earthquakes (Section B in Fig. 1)

Examination of the energy balance in rare earthquakes (moderate earthquakes) follows the flow in Fig. 4. The amount of energy working on a building structure due to an earthquake, *Ed*, is calculated using the following equation. The seismic resistance is confirmed by ascertaining that this value does not surpass the amount of energy, *We*, that can be absorbed before the building structure reaches the limit beyond which damage is caused.

$$Ed = \frac{1}{2}M \cdot Vd^2 \tag{1}$$

Where:

- *M:* Total mass of the aboveground section of the structure
- *Vd:* Velocity conversion value for energy working on the structure due to an earthquake (during moderate earthquake)

In a moderate earthquake, the main frame should of course remain in the range where it is safe from damage, but the damper section is allowed to plasticize.

Next, it is necessary to confirm that the inter-story drift angle during a moderate earthquake does not surpass the criteria so that the interior/exterior members, building equipment, etc. incur no damage. Further, in cases when dampers are used, it is necessary to confirm the residual story drift after the earthquake.

Examination of the rarest

earthquakes (Section C in Fig. 1) Examination of the energy balance of the most rarely-occurring earthquakes (large earthquakes) is made according to the flow in Fig. 5. The amount of energy working on a building structure due to an earthquake is calculated using Equation (1). By taking this value and subtracting from it the amount of energy, *We*, that can be accumulated before the building structure reaches the limit beyond which it suffers damage, as shown in Equation (2), we can calculate the amount of energy, *Es*, that the building structure must absorb during a large earthquake to finally cause plastic distortion in

Fig. 2 Difference between Main Frame and Damper Section



Fig. 3 Type of Damper



Fig. 4 Examination on Rarely-occurring Earthquake



the main frame.

$$Es = \frac{1}{2}M \cdot Vs^2 - We \tag{2}$$

Where

Vs: Velocity conversion value for energy working on the structure due to an

earthquake (during large earthquake) We: Amount of energy that can be absorbed before the building structure reaches the limit beyond which damage occurs Although *Es* can be absorbed by distributing it to each story of the building,



how the energy is to be allotted to each story depends on the type of framing and other characteristic features of the building. In the current notification, the equations used in the research thus far made^{2),} ³⁾ are adopted. In cases when the story has a damper, the required amount of energy absorption allotted to each story, E_{si} , is further adjusted according to the strength ratio of the main frame to the damper section, as shown in Equation (3). However, two additional energies work on damper sections: the energy absorbed by plasticization of the damper section alone when the main frame is in a state of plastic response (second item on the right side of the equation), and the energy calculated assuming that only the damper section is already undergoing plasticization due to being struck by several moderate earthquakes prior to being subjected to a large earthquake (third item on the right side).

Main frame:

$$E_{Sfi} = E_{Si} \frac{Q_{fui}}{Q_{ui}}$$

Damper section:

$$E_{Sdi} = E_{Si} \frac{Q_{dui}}{Q_{ui}} + {}_2E_{dpi} + \beta {}_1E_{dpi}$$
⁽³⁾

Where

 $Q_{\rm uv}$: Retained horizontal strength

- Q_{fui} : Retained horizontal strength of main frame
- Q_{dui} . Retained horizontal strength of damper section

The seismic resistance during a large earthquake can be confirmed by ascertain-



Fig. 6 Accumulated Plastic Deformation Capacity Retained by

Fig. 7 Accumulated Plastic Deformation Capacity Retained by Energy-absorbing Member



Fig. 8 Elevation and Standard Floor Plane





Table 1 Building Outline

Application	Office
Structural type	Steel-frame structure
Building area	1071m ²
Total floor area	8778m²
No. of story	8 stories above ground, 1 penthouse
Height	Eaves height: 33.3 m; maximum height: 39.1 m
Standard floor height	4.1 m

Table 2 Structural Outline

ing that the required amount of energy absorption, found in Equation (3), is less than the amount of energy absorbed by both the main frame and the damper section.

Examples of the retained amount of energy absorption (*Ed*), obtained based on structural experiments using steel members (H-shape beams) and energy absorption members (buckling-restraint braces), are shown in Figs. 6 and 7. The energy absorption amount of both members is shown in terms of a dimensionless value called accumulated plastic deformation magnification *(η)*.

Outline of Trial Designs

In order to examine the applicability of the energy method, a trial design using this method was conducted for a steel-frame office building (8 stories above ground) of the center core type, shown in Table 1 and Fig. 8. Table 2 shows the structural outline of the building. As shown in Figs. 9 and 10, buckling-restraint bracing dampers employing low-yield point steel (LY100) are arranged as axial members in both the Y and X directions of the building core.

Type of structure	Steel-frame structure
Framing type	X-direction: Moment-resistant frame structure with brace-type damper section Y-direction: Moment-resistant frame structure with brace-type damper section
Column, beam, damper	Column: Cold-formed square steel tube Girder: Rolled H-shape Brace-type damper: Hysteretic damper (buckling-restraint brace)
Column-beam joint	Connection: Column-penetration type Column joint: On-site welding Beam joint: Friction joining by use of high-strength bolt F10T
Floor type	Deck plate of form-mound concrete slab
Non-bearing wall	Exterior wall: ALC panel Interior wall: Light steel bucking board covering

Fig. 9 Framing Elevation, Column Position Drawing



Fig. 10 Framing Elevation



X-direction framing elevation



Y-direction framing elevation

Fig. 11 shows a comparison between the required value of accumulated plastic deformation magnification, as calculated using the energy method and the retained accumulated plastic deformation magnification of the main frame and damper section, based on structural experimental results. As seen in the figure, the required value for both the main frame and damper section is lower than the retained value. In particular, appropriate arrangement of the buckling-restraint bracing dampers allows the main frame to suffer only extremely light damage and to remain nearly within its elastic range.

In order to examine the applicability of the energy method, a time-history seismic response analysis was made to compare the analytical results with the forecasted value of the energy method. The maximum story drift is shown in Fig. 12, and a comparison between the response analytical results for accumulated plastic energy and the forecasted value in the energy method is shown in Fig. 13. Very safe results were obtained regarding the accumulated plastic energy of the main frame, and it has been found that, with regard to other energies as well, the forecasted values of the energy method

Fig. 12 Comparison of Maximum

Story Drift between Timehistory Response Analytical Results and Forecasted

Values of Energy Method 9 8 7 6 Story 5 4 3 2 ON IN 0 20 40 60 80 Story drift (X-direction) • : Energy method ○ : HACHINOHE △ : TOHOKU : JMA KOBE

favorably correspond to the response analytical results.

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("Outline of Trial Designs" introduced above was prepared by extracting part of research results of the Working Group to Prepare Application Manuals for Energy Balance-based Seismic Designs for Steelframe Buildings, chaired by Group Chief Okada, former Building Research Institute, Japanese Society of Steel Construction.)

Fig. 11 Comparison between Required and Retained Accumulated Plastic Deformation Magnifications



Accumulated plastic deformation magnification Accumulated plastic deformation magnification

Main frame

Damper section

 $\ensuremath{\bigcirc}$: Required accumulated plastic deformation magnification (X)

Required accumulated plastic deformation magnification (Y)

- \square : Retained accumulated plastic deformation magnification (X)
- Retained accumulated plastic deformation magnification (Y)

Fig. 13 Comparison of Accumulated Plastic Energy between Time-history Response Analytical Results and Forecasted Values of Energy Method



Japanese Society of Steel Construction

JSSC Symposium 2006 on Structural Steel Construction

The Japanese Society of Steel Construction (JSSC) has held an annual Symposium on Structural Steel Construction since 2004. The major aim of this symposium is to show the comprehensive and functional interrelationships between the operational results of JSSC's various committees and to provide a venue for the exchange of information and ideas between JSSC members and others involved in steel construction.

JSSC Symposium 2006 on Structural Steel Construction was held on November 16 and 17, 2006 in Tokyo and was cosponsored by the Japan Iron and Steel Federation, Building Research Institute, Architectural Institute of Japan, Japan Society of Civil Engineers, National Institute for Materials Science, and other organizations. Among the major events of the 2006 symposium were five sessions, special lectures, an academy session, and a poster session.

Held concurrently with the symposium were two other meetings: the Symposium on Iron and Steel Materials and Steel Construction (a scientific exchange meeting) and the Japan-China Technical Exchange Meeting on Steel Construction. More than 400 persons took part in the JSSC symposium, which was utilized as a site for exchange between researchers and engineers involved in steel construction.

Major Programs of the 2006 Symposium

Special Session 1

Featured were reports on future developments and directions in



A scene at the Special Session

steel-structure maintenance, monitoring technologies, and inspection/diagnosis technologies, all of which are a growing concern for steel construction in Japan. Also presented was an outline of the 2006 IABSE (International Association for Bridge and Structural Engineering) international conference in Copenhagen regarding maintenance, repair, reinforcement, inspection technology, monitoring, and maintenance management.



Memento presentation from China Steel Construction Society to Japanese Society of Steel Construction



"Excellent Report" citations at the Academy Session

Special Session 2

"R&D on Buildings with New Structural Systems Employing Innovative Steel Structural Materials" is a research project that has been underway since 2004. An outline of research projects planned for 2006 to 2008 was presented by the participating organizations: JSSC, Japan Iron and Steel Federation, National Institute for Land and Infrastructure Management, and Association of New Urban Housing Technologies.

Special Session 3

Reports were presented on the achievements of research conducted by the Forum on 21st-century Structures. In 2006, the Forum implemented 3rd-phase research projects in a number of areas; of these projects, interim reports were delivered on the following four themes: research on the seismic reinforcement of existing buildings by the use of steel dampers, defining the potential for and the development of steel-structure buildings using steel sheet members, a proposal for reusable flat slab structures using tapered steel tubes, and research on an expansion structural system and damage-control structures.

• Engineering Session 1

Reports were made on trends and revisions of JSSC's standards, including specifications, manuals and guidelines. It was reported that revisions to the welding bevel standards were based on the ISO's original draft. The floor slab steel U-shape standards were revised so that large-size U-shapes can be applied in order to meet the need for reduced labor and greater durability in steel bridges. It was also reported that the revisions to the fatigue design guidelines reflect improvements in fatigue strength technology.

• Engineering Session 2

A lecture entitled "Next-generation Hybrid Structures: Recent Technical Trends and Future Development" was given on composite and mixed structural systems that combine different kinds of structural materials in bridge and building construction, concretesteel hybrid structures, and wood-, glass- or FRP-steel hybrid structures. Panel discussions on hybrid structures were also held.

• Joint Symposium of JSSC and the Iron and Steel Institute of Japan

This symposium, entitled "Structural Steel: Development and Technical Review," featured discussions by lecturers and panelists on a wide range of themes—the latest developments in structural steel products and examples of their application in the fields of not only building construction and civil engineering, but also shipbuilding and storage tanks.

• Japan-China Technical Exchange Meeting on Steel Construction

Two days of meetings were held on "Recent Circumstances in Steel Construction in Japan and China" and "New Structural Technology: Hybrid Structures." Special and keynote lectures were delivered by university professors from both Japan and China.

Academy Session

The 14th Annual Lecture Meeting on Steel-structure Papers was held as an Academy Session of the JSSC Symposium 2006 on Structural Steel Construction. It targeted researchers, engineers, and university students involved in steel construction and consisted of 119 lectures presented in 20 sessions. "Excellent Report" citations were presented.

Poster Session

Presentations on research in steel construction and new steel structural technologies, using posters etc., were offered mainly by universities for this year's session, in addition to corporate members of JSSC.

JSSC Symposium 2007 on Structural Steel Construction is scheduled for November 15 and 16, 2007.



A scene at the Academy Session



Poster Session

China-Japan Opinion Exchange Meeting on Steel Construction

The China-Japan Opinion Exchange Meeting on Steel Construction (a gathering for the exchange of ideas on steel construction by those involved in steel construction in China and Japan) was held on November 18, 2006 in Tokyo. The meeting was sponsored by the Committee on Overseas Market Promotion, the Japan Iron and Steel Federation (JISF).

Total participants in the meeting numbered 37, and active discussions were developed there. Among the participants were:

—Japanese side

- Ph.D., Yuhshi Fukumoto, Professor Emeritus of Osaka University and Nagoya University (who acted as Chairman)
- Ph.D., Hanbin Ge, Associate Professor, Nagoya University
- 14 participants from JISF: members of the Committee on Overseas Market Promotion and the chief and members of the Working Group on Steel Bridge Technology & Promotion, Research Group on Steel for Bridges

-Chinese side

 21 participants from the China Steel Construction Society, who had participated in the Japan-China Technical Exchange Meeting on Steel Construction held by the Japanese Society of Steel Construction on November 16 and 17 in Tokyo (delegation chief: Cheng Zhiguang, Vice Chairman of the China Steel Construction Society)

The meeting opened with a greeting by Chairman Fukumoto and an explanation of the meeting's objectives by Chairman



Participants in the China-Japan Opinion Exchange Meeting on Steel Construction

Takeshi Katayama of the Committee on Overseas Market Promotion. After this, presentations were made in each of three fields: steel buildings, civil engineering steel structures, and steel bridges. Question and answer sessions followed.

The meeting concluded successfully with closing remarks by Chairman Fukumoto and a greeting by Vice Chairman Cheng Zhiguang who then presented a memento to Chairman Takeshi Katayama.

Major Q&A in the Meeting

An outline of the meeting's Q&A follows.

• Steel Buildings

Presentations were made by Toshitsugu Inosako (vice chairman of the Committee on Overseas Market Promotion) who discussed the current state of steel building construction in Japan in a presentation titled "High-performance Steel Products and Application Technologies" and by members of the Chinese side who discussed current applications of high-performance steel products in China. The following Q&A session focused primarily on methods to guarantee the performance of Z-direction characteristic properties of steel products in Japan, on welding criteria for seismic-resistant steel products, and on the need for intumescent coatings when applying fire-resistant steel in space-truss structures.



Memento presentation from Cheng Zhiguang, Vice Chairman of CSCS to Takeshi Katayama, Chairman, Committee on Overseas Market Promotion of JISF

• Civil Engineering Steel Structures

The current state of civil engineering steel structures in Japan was introduced by Chairman Katayama, as was an explanation by the Chinese members outlining the state of bridge construction in China and the strength of the high-performance steel products applied. The following Q&A primarily focused on the application of corrugated steel sheets in bridge construction in Japan and on the thickness and Z-direction properties of the corrugated steel sheets used in constructing the Second Tokyo-Nagoya Expressway.

• Steel Bridges

A presentation titled "Promoting the Application of Weathering Steel Bridges in Japan" was given by Masashi Kato, Dr. Eng. and a member of the Working Group on Steel Bridge Technology & Promotion, Research Group on Steel for Bridges. The Q&A focused mainly on the concepts governing the maintenance control of steel bridges in Japan where the world's most prominent suspension and cable-stayed bridges are in service.



Ph.D., Hanbin Ge, Associate Professor of Nagoya University, Ph.D., Yuhshi Fukumoto, Professor Emeritus of Osaka University and Toshitsugu Inosako, Vice Chairman, Committee on Overseas Market Promotion of JISF (fourth, third and second, respectively, from right)



Gathering for the exchange of ideas



Tokyo Bay Bridge	I
Steel and Bridge Superstructure and Substructure Bridge High Performance Steel Steel Pipe Sheet Pile Foundations Employing High Shear- strength Joints-	5
Energy Balance Seismic Design1)
JSSC Symposium 2006 on Structural Steel Construction————————————————————————————————————	5 8



COVER

Tokyo Bay Bridge is being built employing the latest bridge steel material and engineering technologies (see pages 1 to 4).

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