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Giant H-Shapes (NSGH) for Building Structural Use

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Abstract:

TMCP giant H-shapes for building structural use are a new steel product developed by Nippon Steel in 1994. Marketed with the abbreviation NSGH (New Structural (Nippon Steel) Giant H-Shape), they feature excellent earthquake resistance and weldability, despite the higher strength (325 N/mm² minimum yield strength), than conventional ultra-thick H-shapes. This paper reports on the material properties and performance of TMCP giant H-shapes which provide economic merits through steel weight reduction without reducing the design datum strength (F value) of the steel materials and welds is stipulated in the Building Standards Act. This is made possible by using the H-shapes in columns with thickness exceeding 40 mm. High weldability improves quality.

1. Introduction

NSGH (New Structural (Nippon Steel) Giant H-Shape) is structural use material which was widely used in the 1960s as columns for high-rise buildings. After the problem of its brittle structure at a normal temperature was pointed out in 1969, its use had decreased. Then in the 1990s use increased again with the development of TMCP (thermo-mechanical controlled rolling process) as steelmaking and rolling techniques progressed. Declining material costs, process streamlining and a demand for reducing construction costs such as by simplifying user inspections were also contributing factors.

This report traces the history of giant H-shapes, introduces the mechanical properties of NSGH in the 490 N/mm² class developed by TMCP, and describes the future prospects.

2. History of Giant H-shapes in Japan

Giant H-shapes are the generic term for H-shapes in the H × B = 400 × 400 series and 500 × 500 series (H is the depth of section and B is the width of section), and with over 30 mm of flange thickness (t_f). Sometimes H-shapes with flanges over 70 mm thick are termed ultra-thick H-shapes (ref. **Fig. 1**).

Giant H-shape manufacturing in Japan began with the 32/45 (web thickness / flange thickness) in the H400 × 400 series for the columns of the Nusantra Assembly Hall in Indonesia by Hirohata Steelworks of Fuji Steel in September 1964. Domestically, with the publication of "Guidance for High-Rise Building Structure" in the same year, the construction of high-rise buildings advanced and the Mitsui Kasumigaseki Building (147 m in height) was constructed with about 5,000 tons, mainly 40/60 in the H400 × 400 series in April 1966. In October 1967, ultra-thick H-shapes of 90/125 in the H400 × 400 series, developed by Sakai steelworks of Yawata Steel were used for the World Trade Center (height 417 m) in New York City, putting giant H-shapes in the focus as columns for high-rise buildings.

However, with the discovery of the brittle fracture problem of giant H-shapes at normal temperatures by Kato and Morita[1)] in 1969, economic conditions such as the oil crises, the popularization of Rahmen structure, and the efficient production of box columns, their

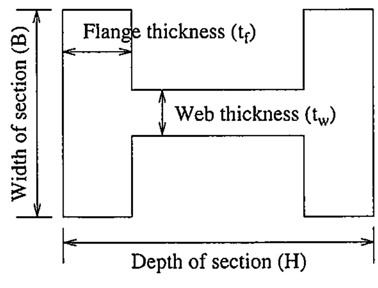

Fig. 1 Dimensions of H-shape

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use as building structural columns subsequently decreased. In the meantime, for another step to making member bigger, H500 × 500 welded appeared around that time. The recent market needs are: the trends of adopting giant H-shapes rolled and of requiring high strength and high weldability with aseismic performance. The former is due to the needs for reducing procurement costs, and construction costs by introducing automatic process lines or simplifying inspections in the construction industry. And the latter derives from an increase in higher buildings, bigger spans, or bigger structures.

To respond to these market changes and user needs, Nippon Steel Corporation developed the high-strength, high-weldability giant H400 × 400 series, featuring aseismic performance, by the TMCP method in September 1994[2]. In February 1997, Nippon Steel aimed at another advancement to the H500 × 500 series and developed for the construction market the New Structural (Nippon Steel) Giant H-Shapes (labeled NSGH hereafter), manufactured by the TMCP method.

3. Development of NSGH

3.1 Production process overview[3]

The TMCP method is a technique which enables the manufacture of steel products with high strength, high toughness and high weldability, ensuring finer steel structure by controlling the rolling temperature or rolling conditions. TMCP is a material control technique widely applied for heavy plate steels.

As for the application of TMCP to H-shapes, in 1980 Nippon Steel developed the centralized cooling technique for the center of the outer flange surface of H-shapes, but controlling forms and residual stress control was the main purpose of cooling control technique of H-shapes in those days in Japan. With a view to material control, TMCP made great progress with the development of the water-cooled TMCP method that combines IMC (inter mill control), one of the hyper beam manufacturing techniques of low yield ratio (yield ratio ≤ 80%) in 1990, and ACC (Accelerated Cooling), water cooling technique applied after rolling.

NSGH was developed with new section process metallurgy integrating this basic technique. The micro-alloying which was put into practice from around 1970 was a response to grain coarsening caused by high temperature and small reduction as a result of shape characteristics and mill load limitation of H-shapes. Oxide metallurgy was developed for the purpose of improving toughness in weld heat-affected zone in the first part of the 1980s. **Fig. 2** shows the manufacturing process outline.

This manufacturing process aims at more uniform material, high strength, high toughness and high weldability. It is a different technical concept than the manufacturing process developed by ARBED Company in 1988, which uses TM-SC (Thermomechanical Treatment with Selective Cooling) in the center of outer flange surface of H-shapes during rolling and QST (Quenching and Self Tempering) of the surface layer of H-shapes by water cooling after rolling, following homogenizing treatment of H-shapes.

3.2 Product characteristics

NSGH manufactured by the TMCP process has the following characteristics. As of 1998, each application for building requires the Minister of Constructions authorization.

(1) With the plate thickness over 40 mm, even at 100 mm, higher value than current steel can be adopted at the time of setting the design standard strength of steel products and welded zones as shown in Building Standards Law in **Table 1**. So a reduction in steel frame weight is possible.

(2) By improving the various performance properties shown in **Table 2**, the quality of the manufactured steel frame can be maintained and increased.

(3) Compared with welding four dimensional box column and

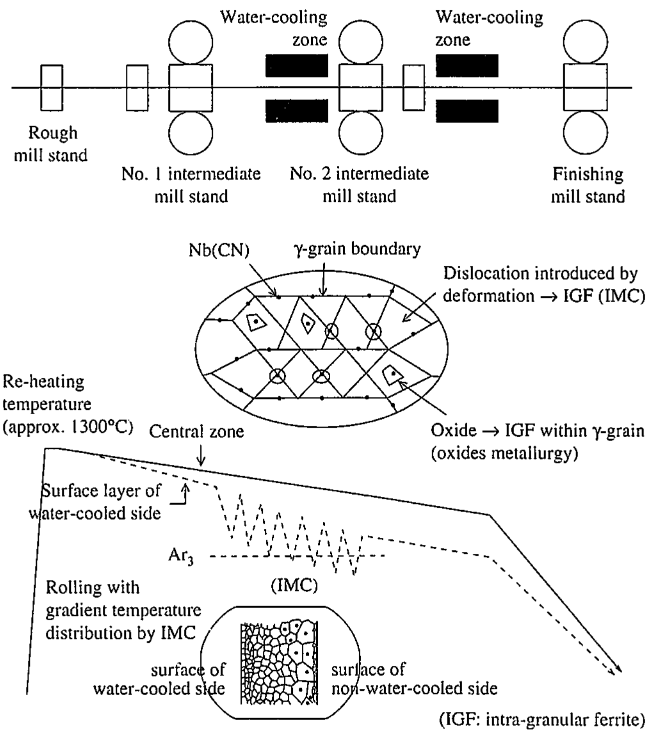

Fig. 2 TMCP process image and temperature hysteresis in flange zone

Table 1 Design standard strength comparison (50 kgf/mm² class steel)

	NSGH NSGH325B·C	Conventional steel SM490B
Standard strength with over 40 mm in plate thickness (kgf/mm²)	3,300	3,000

Table 2 Comparison of standard specifications and material properties (50 kgf/mm² class steel, $t_f \leq 50$ mm)

Performance item		NSGH NSGH325·C	Conventional steel SM490B
Composition	C (%)	≤0.18	≤0.18
	Si (%)	≤0.55	≤0.55
	Mn (%)	≤1.60	≤1.60
	P (%)	≤0.020	≤0.035
	S (%)	≤0.008	≤0.035
Strength			
	Yield point (N/mm²)	325 - 445	≥295
	Tensile strength (N/mm²)	490 - 610	490 - 610
	Elongation (%)	≥23	≥23
Fracture			
	Yield ratio	≤0.8	Passed over
Reduction of area in plate thickness direction (%)		≥25	Passed over
Absorbed energy at Charpy test (J)		$_vE_{0°C}$≥27	$_vE_{0°C}$≥27
Weldability			
	Carbon equivalent Ceq*1 (%)	≤0.38	Passed over

*1 Ceq = C + Mn/6 + Si/24 + Ni/40 + Cr/5 + Mo/4 + V/14 welded built-up H-shapes columns, NSGH is a prefabricated material which simplifies the welding process. And no closed dimensions simplify beam-to-column connection joint process and quality inspection, bringing about cost reductions in the steel frame processing industry.

3.3 Material performance

This section compares the material properties and weldability[4,5] of NSGH with those of the conventional giant H-shape which was used for the Harumi Tokyo International Trade Center completed in 1972. Also, in light of the brittle fractures in welded connections which were confirmed in the Kobe Earthquake, the structural properties[6,7] of full-size beam-to-column connection by the loaded test are introduced. The partial framing is meant for Rahmen-framed beam-to-column connection joint which consists of NSGH and H-shape beam. **Table 3** shows the size comparison.

Table 3 Size comparison

Specimen	Size ($H \times B \times t_w \times t_f$)	Specification code
NSGH	H498 × 432 × 45 × 70	NSGH325C-SN490C
Conventional steel	H498 × 432 × 45 × 70	SM490B

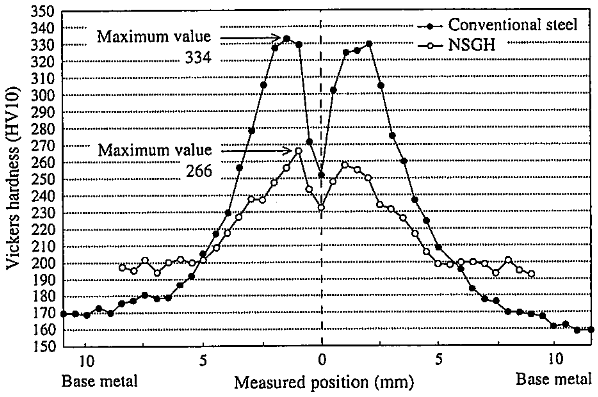

Fig. 3 Maximum hardness test in weld heat-affected zone (test part:1/4B)

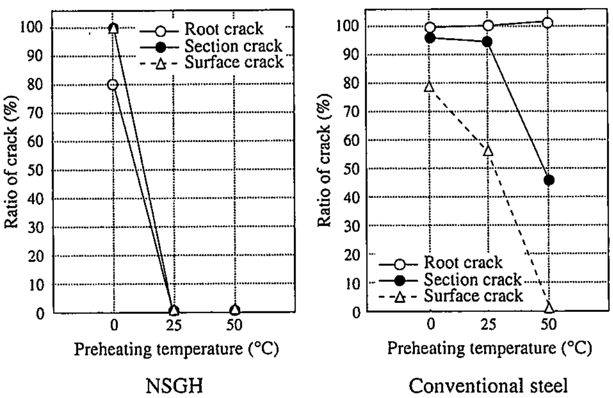

Fig. 4 y-groove weld cracking test (test part: 3/4 B)

3.3.1 Material properties

Table 4 shows the manufactured chemical composition. In order to improve welding performance, the NSGH component system feature an equal amount of carbon and weld cracking sensitivity composition. **Figs. 3 and 4** show the results of the maximum hardness test in the weld heat-affected zone and y-groove weld cracking test,

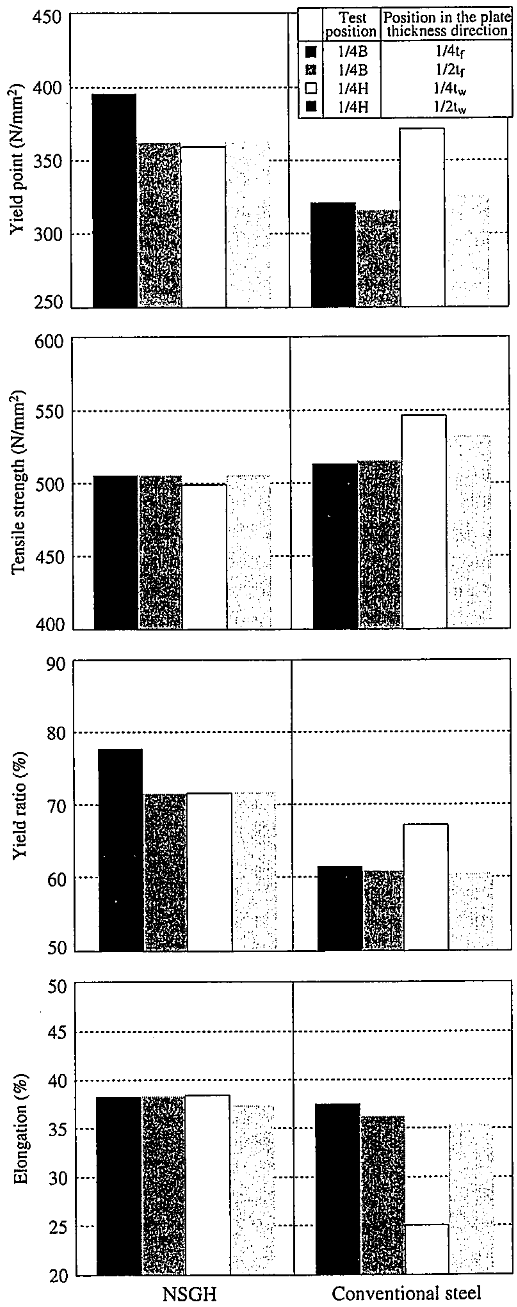

Fig. 5 Tensile test in the rolling direction

Table 4 Chemical composition

(mass %)

	C	Si	Mn	P	S	Ti	V	T-Al	Ceq	Pcm
NSGH	0.10	0.16	1.42	0.008	0.003	0.01	0.07	0.001	0.364	0.206
Conventional steel	0.18	0.46	1.25	0.023	0.016	0.01	0.04	0.020	0.427	0.272

$Ceq = C + Mn/6 + Si/24 + Ni/40 + Cr/5 + Mo/4 + V/14$, $Pcm = C + Mn/20 + Si/30 + Cu/20 + Ni/60 + Cr/20 + Mo/15 + V/10 + 5B$

which are basic properties tests that indicate weldability. Compared with conventional steel, the weldability is remarkably improved.

Fig. 5 shows the strength property in the tensile test results. NSGH has lower component system than conventional steel, but maintains the same level at a given strength. The YR (yield ratio) of NSGH tends to be higher than conventional steel, a level that satisfies the YR regulation (of less than 80%) in the Steel Products for Building Structure (SN Specification) that became part of JIS in June 1994. This YR level assumes adequate aseismic performance.

Fig. 6 and **Table 5** show the results of tensile test of plate thickness direction and the Charpy impact test, indicators the toughness property. NSGH possesses superior anti-lamellar tear property and impact resistance in each part and direction. In particular, the impact property for plate thickness direction which was formerly pointed out in the brittle fracture problem in welded zones has strikingly improved compared with conventional steel.

3.3.2 Weldability

Since NSGH is utilized primarily for columns in high-rise buildings, the main welding joints are butt joints between two columns and T-shaped joints between beam and column shown in **Fig. 7**. The material properties of these welding joints are structurally vital elements. To confirm the material properties of these welding joints, a butt weld between two columns was done under the conditions in **Table 6** and the results of a tensile test and a Charpy impact test in a welded zone are shown in **Tables 7 and 8**. The data for conventional steel are taken from actual structures (the welding conditions are unknown). Each test value of NSGH keeps a given strength and toughness of the material.

3.3.3 Structural performance

Fig. 8 shows the specimen dimensions for the loaded test using a full-size beam-to-column connection and **Table 9** shows the item of each test specimen. **Figs. 9 and 10** show the relationship of shear–displacement of the beam ends and **Table 10** shows the maximum proof strength and magnification of cumulative plastic deformation. The maximum proof strength is more than 1.6 times the panel yield proof strength. And the adequate rise in proof strength is seen up to the full plastic proof strength level of the column. And the magnification of cumulative plastic deformation, based on the deformation

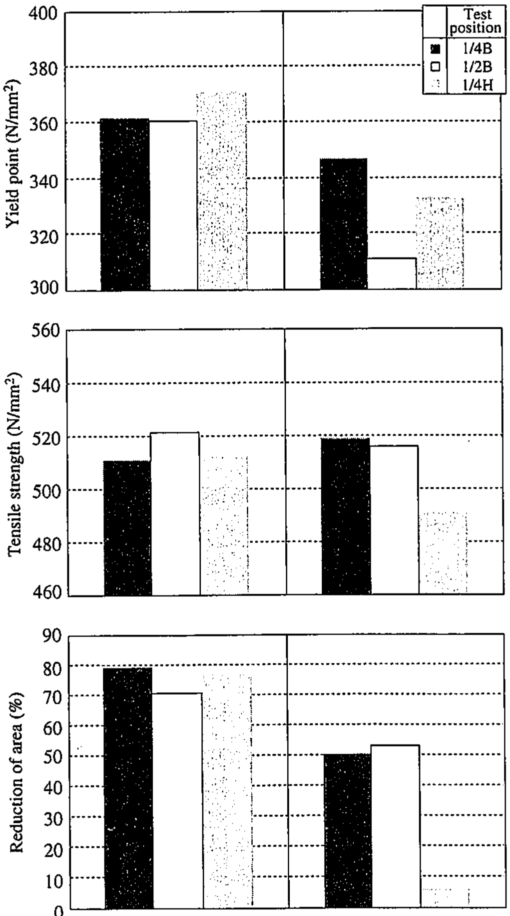

Fig. 6 Tensile test in plate thickness direction

Table 5 Charpy impact test

Specimen	Test direction	Test position	Position in the direction of plate thickness	$_vE_{0°C}$ Absorbed energy (J)	$_vE_{0°C}$ Ratio of brittle fracture (%)
NSGH	Rolling direction	1/4B	$1/4t_f$	298	8
			$1/2t_f$	307	10
		1/2B	$1/4t_f$	246	18
			$1/2t_f$	223	40
		1/4H	$1/4t_w$	326	0
			$1/2t_w$	183	47
	Plate thickness direction	1/4B	$1/2t_f$	141	52
		1/2B	$1/2t_f$	103	65
Conventional steel	Rolling direction	1/4B	$1/4t_f$	62	92
			$1/2t_f$	34	97
		1/2B	$1/4t_f$	114	72
			$1/2t_f$	107	73
		1/4H	$1/4t_w$	17	100
			$1/2t_w$	15	100
	Plate thickness direction	1/4B	$1/2t_f$	15	100
		1/2B	$1/2t_f$	17	100

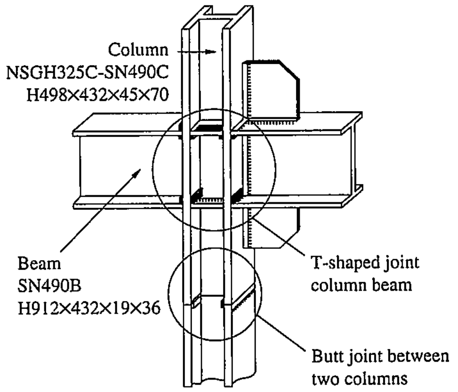

Fig. 7 Column-to-beam connection of giant H-shape column

Table 6 Welding conditions

Test specimen	Welded position	Assumed welding place	Groove form	Welding condition: Method	Flux	Pass number	Story temperature (°C)	Heat input (J/cm)
Column-column	Flange	Sideways at site	9 mm 25°	CO_2 Semi-automatic	YM-26 1.2mmφ	70	250	17,000

Table 7 Tensile test of welded joint

Test specimen	NSGH		Conventional steel	
Item / Test position	Tensile strength (N/mm^2)	Fracture position	Tensile strength (N/mm^2)	Fracture position
1/4B	562	HAZ	446	HAZ

HAZ: Heat-affected zone

Table 8 Impact test of weld joint

Unit: J

Test specimen	NSGH				Conventional steel			
Direction	Rolling direction		Plate thickness direction		Rolling direction		Plate thickness direction	
Position	Bond	HAZ	Bond	HAZ	Bond	HAZ	Bond	HAZ
1/4B ($1/2t_f$)	198	183	60	115	41	209	50	34
	(38)	(28)	(48)	(57)	(82)	(18)	(75)	(92)
1/2B ($1/2t_f$)	168	213	104	95	64	204	48	37
	(25)	(20)	(22)	(25)	(47)	(22)	(78)	(100)

Note: ( ) Represents ratio of brittle fracture (%), Test temperature: 0°C

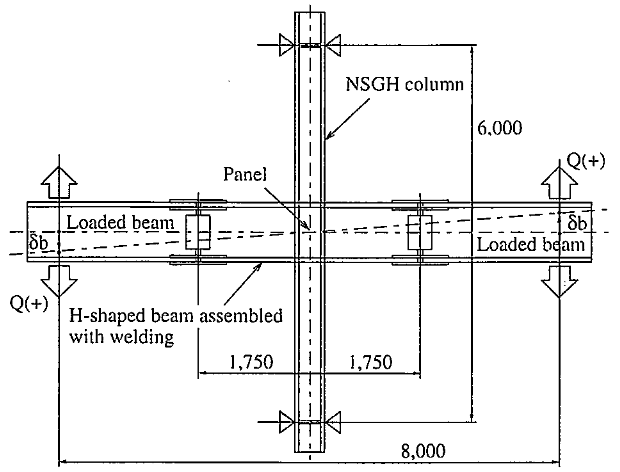

Fig. 8 Test specimen and test method

Table 9 Test specimen list

Specimen No.	Dimensions of test specimen			Column/beam/panel proof strength					
	Giant H-shape column [NSGH325C] $H \times B \times t_w \times t_f$ (mm)	H-shape beam [SM490B] $H \times B \times t_w \times t_f$ (mm)	Panel doubler [SM490B] Plate thickness (mm) × number of piece	Column/beam/panel proof strength ratio			Full plastic proof strength (t_f)		
				Column/beam	Panel/beam	Panel/column	Column	Beam	Panel
1	498 × 432 × 45 × 70	900 × 300 × 25 × 40	16 × 2	0.971	0.587	0.604	154.8	159.4	93.5
2		900 × 350 × 25 × 60	28 × 2	0.677	0.521	0.770	154.8	228.6	119.2

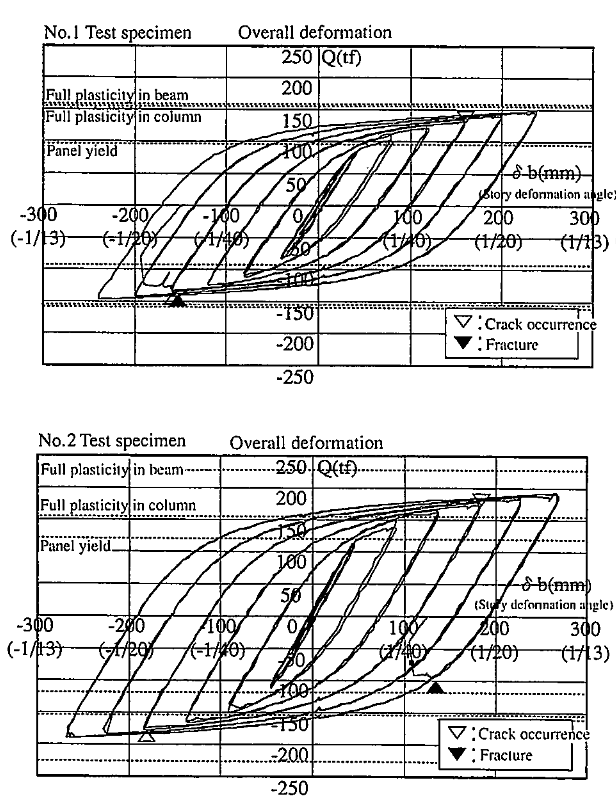

Fig. 9 Relationship between beam-end shearing force (Q) and beam-end displacement (δ_b)

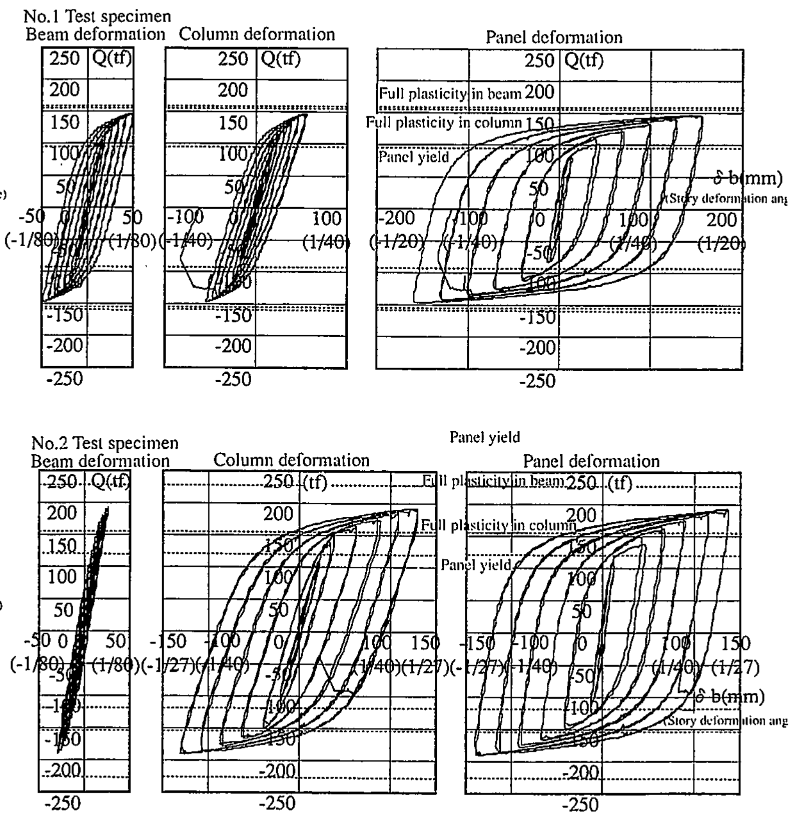

Fig. 10 Relationship between beam-end shearing force (Q) and displacement (δ_b) (beam-column-panel components)

Table 10 Test result

Test specimen No.	Experiment results	
	Maximum proof strength (Increase ratio) Q_{max}(tonf)	Magnification of cumulative plastic deformation (ηf)
1	150.2 (1.61)*	30.8 (51.0)*
2	195.8 (1.64)*	41.6 (54.0)*

*( ) Represents the values based on the deformations at the time of panel yield

at the full plastic proof strength of the column shows a big value of around 30 to 40. This shows that NSGH is more than fully equipped with the proof strength and plastic deformation performance required of steel for building structures.

4. Conclusion

As mentioned so far, the performance of NSGH is remarkably better than the old giant H-shapes and satisfies the requirements for building structure use, namely aseismic performance and high weldability. Since February 1997 when another advancement was made to the H500 × 500 series (ref. to **Photo 1**), beginning with NSGH for Dojima Abanza (ref. to **Photo 2**), nearly 10,000 tons have been used throughout Japan in one year.

NSGH needs no lowering the design strength from actual one of F values which are designated by Building Standards Law (Notice No. 1906 by Ministry of Construction). At present, governmental evaluation and authorization are needed for each application. It requires general authorization and more strength (such as 60 kgf/mm^2 class steel) aiming at further cost reduction, in order to expand the demand.

Acknowledgments

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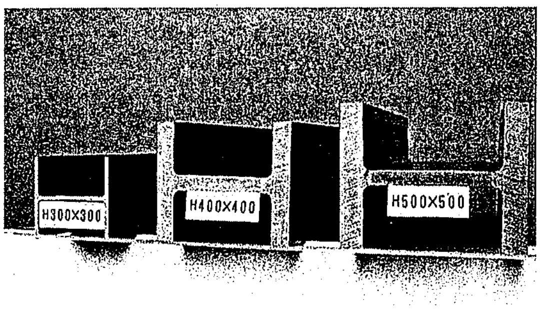

Photo 1 NSGH series (H400 × 400, H500 × 500)

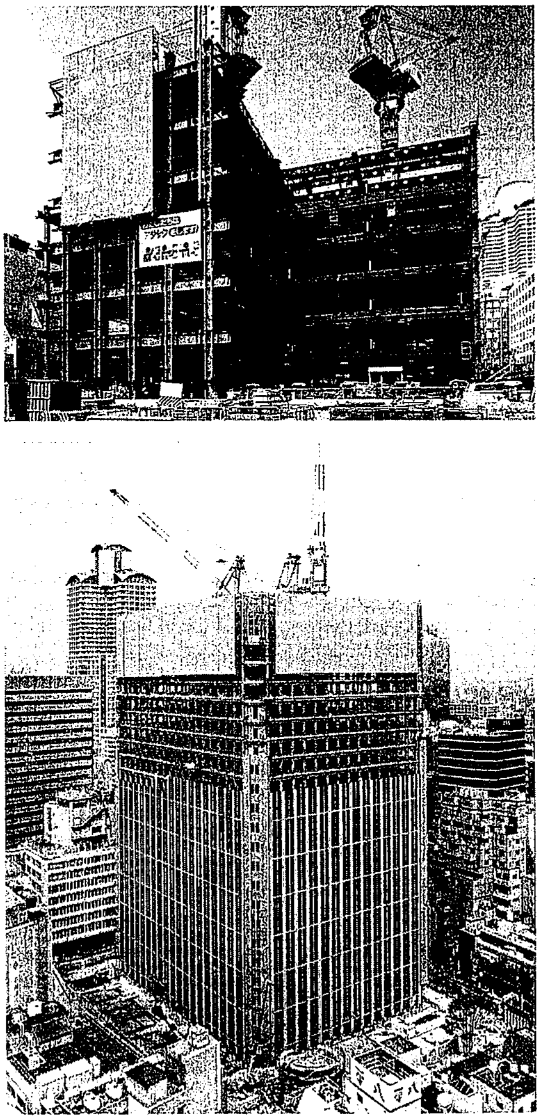

Photo 2 NSGH 500 × 500 series erection work example (Dojima Abanza/Osaka start of construction May 1996, scheduled completion February 1999)