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"HBL‡385 Series," 550 N/mm^2 Class Steel for Building Structures with Good Balance of Excellent Earthquake Resistance and Economic Efficiency†

NAKAGAWA Kei[*1] UEKI Takuya[*2] NANBA Takayuki[*3]

Abstract:

Since the initial approval for "HBL™385," 550 N/mm^2 class steel plate for building structure by the Minister of Land, Infrastructure, Transport and Tourism in 2002, JFE Steel has developed 550 N/mm^2 class building materials and products, such as circular steel tube and cold-press-formed square steel tube, as a pioneer in the industry. This paper explains the outline of "HBL™385 series" including its excellent mechanical properties as a building material and economic advantadge, and provides some findings about its structural design and fire-resistant design.

1. Introduction

JFE Steel's HBL™385 Series[1–4)] realize a low yield ratio and high toughness, while also being a high strength steel with tensile strength of 550 N/mm^2 or higher (yield strength: 385 N/mm^2 or higher), by use of the on-line accelerated cooling system *Super*-OLAC™, which is an advanced "number one" technology of JFE Steel. Taking advantage of these features, high seismic safety can be secured by appropriate design and construction. Adoption of a composition design that considers weldability also enables preheating control in welding on the same level as with 490 N/mm^2 class steels. Because high economic efficiency can be obtained by the reducing the weight of the steel used in structures, which is possible because of the high strength of this steel, and lightening welding control and shortening welding time thanks to its excellent weldability, the HBL™385 Series offers the highest economic efficiency per unit of strength of steel materials of any steel for building structures (comparison with JFE Steel's products). The HBL™385 Series has earned a high evaluation for this advantage, and has been widely adopted, particularly in high-rise buildings. (As of July 2012, cumulative use had reached 95 000 tons.) In 2010, HBL™385 Series received the Contribution Award of the 42nd Ichimura Prizes in Industry.

JFE Steel has also developed use technologies related to the design and construction of the HBL™385 Series, such as structural performance evaluation[5–9)] for composite structures, i.e., concrete filled steel tubular structures (CFT structures) and steel reinforced concrete structures (SRC structures), fire resistance performance evaluation[10)], etc. which have become increasingly important in recent years.

This paper presents an outline of the HBL™385 Series and its structural performance and fire resistance performance.

2. Outline of HBL™385 Series

The standards of the chemical composition and mechanical properties of the HBL™385 Series are

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‡"HBL" is registered trademark in Japan.


[*1] Senior Researcher Deputy Manager,
Civil Engineering Res. Dept.,
Steel Res. Lab.,
JFE Steel


[*2] Senior Researcher Deputy Manager,
Civil Engineering Res. Dept.,
Steel Res. Lab.,
JFE Steel


[*3] Senior Researcher Manager,
Civil Engineering Res. Dept.,
Steel Res. Lab.,
JFE Steel

Table 1 Chemical compositions of HBL^{TM}385 Series

(mass%)

Products	Designation	Thickness (mm)	Chemical compositions C	Si	Mn	P	S	N*	C_{eq}	P_{CM}	f_{HAZ}
Plates	HBL385B-L	12≦t≦19	≦0.20	≦0.55	≦1.60	≦0.030	≦0.015	—	≦0.44	≦0.29	—
	HBL385B	19≦t≦50							≦0.40	≦0.26	
		50<t≦100							≦0.42	≦0.27	
	HBL385C	19≦t≦50				≦0.020	≦0.008		≦0.40	≦0.26	
		50<t≦100							≦0.42	≦0.27	
Cirular tubes	P-385B	19≦t≦50	≦0.20	≦0.55	≦1.60	≦0.030	≦0.015	≦0.006	≦0.40	≦0.26	≦0.58
		50<t≦100							≦0.42	≦0.27	
	P-385C	19≦t≦50				≦0.020	≦0.008		≦0.40	≦0.26	
		50<t≦100							≦0.42	≦0.27	
Square tubes	G385B	19≦t≦50	≦0.20	≦0.55	≦1.60	≦0.030	≦0.015	≦0.006	≦0.40	≦0.26	≦0.58
	G385C					≦0.020	≦0.008				
	G385T		≦0.20	≦0.55	≦1.60	≦0.020	≦0.005	≦0.006	≦0.40	≦0.26	≦0.52
	G385T-Z25										

N*: Total nitrogen Carbon equivalent: C_{eq}=C+Mn/6+Si/24+Ni/40+Cr/5+Mo/4+V/14
Weld crack sensitivity composition: P_{CM}=C+Si/30+Mn/20+Cu/20+Ni/60+Cr/20+Mo/15+V/10+5B
Heat affected zone (HAZ) toughness estimation parameter for metal active gas welding (MAG welding): f_{HAZ}=C+Mn/8+6(P+S)+12N-4Ti (If the chemical composition of Ti≦0.005%, it is regarded as zero.)

Table 2 Mechanical properties of HBL^{TM}385 series

Products	Designation	YS (N/mm^2)	TS (N/mm^2)	Typical specimen	Thickness (mm)	El (%)	YR (%)	$_vE_{0°C}$(J)	RA (%)
Plates	HBL385B-L	385–505	550–670	JIS 1A	t<38	≧15	≦80	≧70	—
	HBL385B			JIS 5	t≦50	≧26			
	HBL385C			JIS 4	40<t	≧20			≧25^{*1}(15^{*2})
Circular tubes	P-385B	385–535 (19≦t)	550–700	JIS 12A JIS 12B JIS 4	19≦t≦40	≧19	≦85	≧70	—
	P-385C				40<t≦100	≧21			≧25^{*1}(15^{*2})
Square tubes	G385B	385–505	550–670	JIS 1A	19≦t≦32	≧15	≦80	≧70^{*3}	—
	G385C			JIS 4	32<t≦50	≧20			≧25^{*1}(15^{*2})
	G385T			JIS 1A	19≦t≦32	≧15		≧70^{*4}	—
	G385T-Z25			JIS 4	32<t≦50	≧20			≧25^{*1}(15^{*2})

YS: Yield strength TS: Tensile strength El: Elongation YR: Yield ratio $_vE_{0°C}$: Charpy absorbed energy at 0ºC
RA: Reduction of area in through thickness tensile test ^{*1}Average ^{*2}Each ^{*3}Flat part ^{*4}Flat part and corner part

shown in **Table 1** and **Table 2**, respectively.

As mentioned above, while the products in the HBL^{TM}385 Series are high-strength steels with tensile strength of 550 N/mm^2 or higher, excellent weldability is also secured by providing a carbon equivalent, C_{eq}, and weld crack sensitivity composition, P_{CM}, equal to or lower than those of the 490 N/mm^2 class steel SN490. In circular steel tubes (P-385) and cold-press-formed square steel tubes (G385, G385T), securing the toughness of the heat affected zone (HAZ) is also considered by providing the metal active gas welding (MAG welding) HAZ toughness index f_{HAZ}[11]. At the same time, in these steel tubes, consideration is also given to prevention of strain age hardening due to cold working of the base metal by specifying total nitrogen N* of 0.006% or less. Moreover, from the viewpoint of seismic safety, HBL^{TM}385 plates satisfy both a low yield ratio (80% or less) and high Charpy absorbed energy (70 J or higher at 0°C), and other HBL^{TM}385 Series products also possess mechanical properties conforming to those of plates.

HBL^{TM}385 plates, circular steel tubes, and cold-press-formed square steel tubes are each available in the B type, assuming application to principal building members or welded members, and the C type, which assumes application to members in which thickness direction properties are also required. The C type equivalent of G385T is called G385-Z25. With both the C type and G385-Z25, a reduction of area (RA) provision is added in thickness direction properties tests.

Among HBL^{TM}385 plates, HBL^{TM}385-E is available as a specification supporting large heat input welding, mainly for welded square box-section columns[2].

The features of the 550 N/mm^2 class cold-press-formed square steel tube G385 and the 550 N/mm^2 class high performance cold-press-formed square steel tube G385T are discussed in Section 3.2, together with their structural performance.

3. Structural Performance

3.1 Structural Performance against Local Buckling

The 1980 notification of the Ministry of Construction No. 1791, Article 2 and notification No. 1792, Articles 1 and 3, as revised in 2007, provided width-thickness ratios for carbon steel with specified design strength 205–375 N/mm^2.[12)] However, the treatment of the HBL™385 Series was not clarified since its specified design strength is 385 N/mm^2. Therefore, in order to study the width-thickness ratio rank of the HBL™385 Series, structural performance against local buckling was investigated with the respective cross sections, namely, (1) welded built-up box section, (2) welded built-up H section (BH section), (3) circular tube section, and (4) cold-press-formed square tube section, by performing a stub column compression test using the width-thickness ratio as a parameter.

Figure 1 shows an outline of the test. In accordance with the literature[13)], monotonous loading in the vertical direction was performed so as to apply loading uniformly to the cross section.

Table 3 (a)–(d) show the section sizes of each specimen and the calculated yield load. With sections (1), (3), and (4), the height h of the specimens was planned as 3 times the diameter D, and with section (2), h was 2.5 times the width B.

The calculated yield load N_y of the specimens was obtained by multiplying the cross-sectional area A calculated from the actual measured values by the yield strength σ_y in a tensile test of the steel used in the specimen.

Figure 2 (a)–(d) show the plastic deformation magnification R obtained in the experiment with the results for other steel grades[14–19)]. Plastic deformation magnification R is obtained by subtracting 1 from the ductility factor μ and is defined by the following equation.

$$R = \mu - 1, \mu = \varepsilon_{max}/\varepsilon_y$$

ε_{max} : Compressive strain at maximum proof stress (load capacity) in experiment (Shrinkage of specimen/Initial height)

ε_y : Yield strain (σ_y/E)

σ_y : Yield strength of steel material used in specimen in tensile test (N/mm^2)

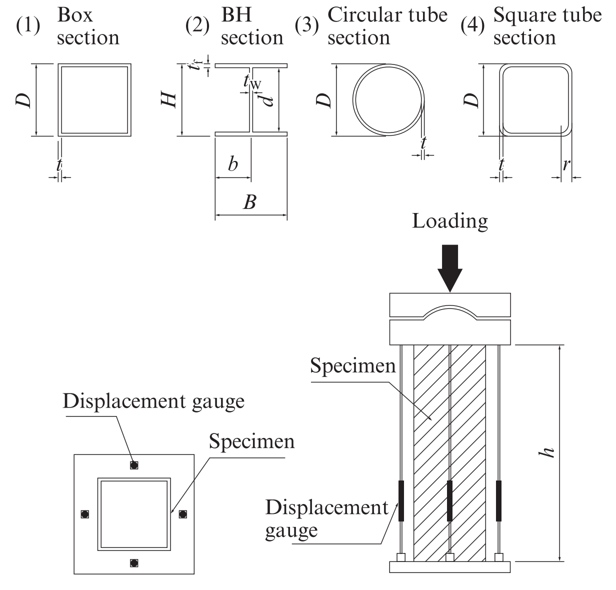


Fig. 1 Overview of stub-column test

Table 3 Section size and calculated yield load

(a) Stub-column of box section

	D (mm)	t (mm)	D/t	h (mm)	A (mm^2)	N_y (kN)
BOX-FAB	308.6	11.7	26.4	929	13 900	5 640
BOX-FBC	346.3	12.0	28.9	1 041	16 100	6 520
BOX-FCD	374.9	10.0	37.5	1 126	14 600	5 850

(b) Stub-column of BH section

	H (mm)	B (mm)	t_w (mm)	t_f (mm)	b/t_f	d/t_w	h (mm)	A (mm^2)	N_y (kN)
BH-FA	464.2	281.7	19.3	19.2	7.3	22.1	692	19 000	8 660
BH-FAB	444.1	282.1	11.9	19.3	7.3	34.1	692	15 700	6 910
BH-FBC	436.7	327.1	19.2	19.3	8.5	20.7	801	20 300	9 220

(c) Stub-column of circular tube section

	D (mm)	t (mm)	D/t	h (mm)	A (mm^2)	N_y (kN)
P-FC	599.4	11.7	51.5	1 800	21 500	8 370
P-FBC	629.4	15.6	40.3	1 890	30 100	11 600
P-FAB	599.1	18.7	32.1	1 800	34 000	13 100
P-FA12	268.5	11.6	23.2	810	9 350	4 050
P-FA19	426.9	18.6	22.9	1 284	23 900	9 630

(d) Stub-column of square tube section

	D (mm)	t (mm)	D/t	r (mm)	h (mm)	A (mm^2)	N_y (kN)
G-FA-1	349.7	19.3	18.1	68.8	1 050	23 600	10 300
G-FA-2	350.5	19.2	18.3	70.0	1 050	23 500	10 100
G-FAB-1	449.8	19.3	23.4	68.7	1 351	31 200	13 800

D: Width of cross-section t: Thickness of cross-section
H: Height of BH section B: Width of BH section
t_w: Web thickness of BH section t_f: Flange thickness of BH section
h: Hight of stub-column $b=B/2$ $d=H-2t_f$
r: Outer diameter of corner of square tube section
A: Cross-sectional area N_y: Calculated yield load

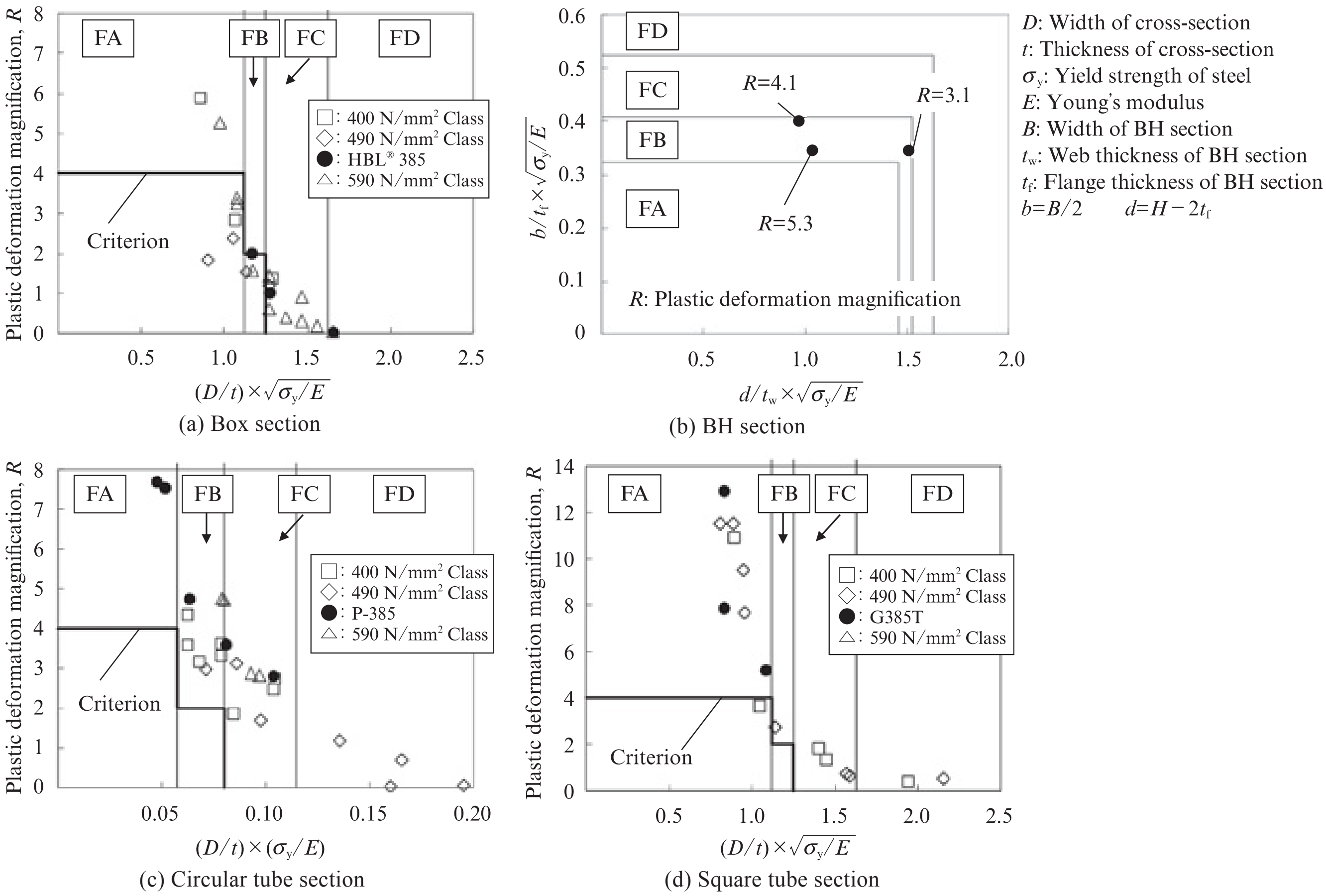


Fig. 2 Results of stub-column test (Plastic deformation magnification)

E : Young's modulus (= 205 000 N/mm^2)

In Fig. 2, specimens of different strength classes are compared by arranging the specimens by the equivalent width-thickness ratio, which is obtained by multiplying $(\sigma_y/E)^{1/2}$ by the width-thickness ratio D/t (in case of the circular tube section, by multiplying σ_y/E by the diameter-thickness ratio D/t). With all the sections, the HBL™385 Series have plastic deformation magnification similar to that of the existing 400 N/mm^2 to 590 N/mm^2 class steels, and also achieves the plastic deformation magnification for the width-thickness ratio rank corresponding (with necessary modifications) to that in the above-mentioned Ministerial notifications. As the target values of plastic deformation magnification, the values here were "4 for FA (P-I-1), 2 for FB (P-I-2), and 0 for FC (P-II)," which are established by width-thickness ratio rank, in "Recommendations for Limit State Design of Steel Structures[20]."

In addition to the results of the stub-column test described above, bending experiments with a welded built-up box section and the beam of a welded built-up BH section confirmed that HBL™385 has structural performance on the same level as SN490, etc. in terms of buckling resistance performance, clarifying the appropriateness of corresponding application of the above-mentioned notifications when setting width-thickness ratios. A lateral buckling test was also performed[21] to examine the spacing of stiffening to prevent lateral buckling of the beam in BH sections, and design equations were then constructed based on the viewpoint in various recommendations and standards.

After organizing this various knowledge, JFE Steel obtained a Performance Evaluation (BCJ Evaluation ST0179-03) of the design provisions for the HBL™385 Series from the Building Center of Japan.

3.2 Structural Performance of High Performance Cold-Press-Formed Square Steel Tube G385T

JFE Steel and Seikei Steel Column Corp. commercialized a jointly-developed 550 N/mm^2 class cold-press-formed square steel tube for building structural use, G385, in 2004 and also commercialized a high performance 550 N/mm^2 class cold-press-formed square steel tube for building structural use, G385T, in 2012.

As shown in Tables 1 and 2, in G385T, toughness of 70 J or higher is specified not only in the flat parts of the cross section, but also in the corner parts. In the chemical composition, the contents of P and S, which reduce the toughness of the base material, are limited to lower levels than in G385, and consideration is also given to

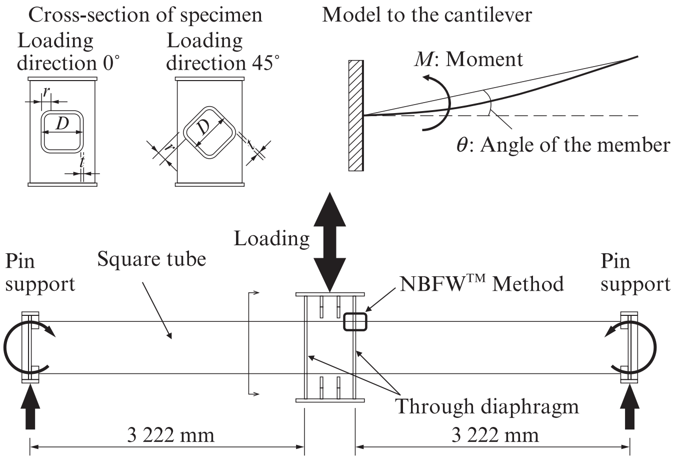


Fig. 3 Overview of G385T bending test

Table 4 Bending specimens of G385T

	D (mm)	t (mm)	D/t	r (mm)	LD (°)	M_p (kN·m)	θ_p (rad)
T1	450	19	23.7	66.5	45	1 993	0.011 4
T2	500	32	15.6	112	45	3 786	0.010 6
T3	500	32	15.6	112	45	3 729	0.010 5
T4	400	32	12.5	112	45	2 288	0.013 8
T5	500	32	15.6	112	0	4 194	0.011 8
T6	500	32	15.6	112	45	4 045	0.011 4
T7	600	32	18.8	112	45	6 115	0.009 3

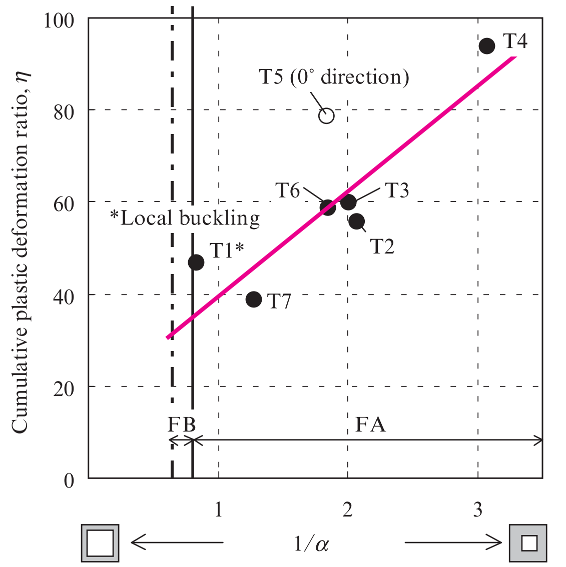
D: Width of cross-section t: Thickness of cross-section
r: Outer diameter of corner of square tube section
LD: Loading direction M_p: Calculated full plastic moment
θ_p: Calculated rotation angle at M_p

securing the toughness of the heat affected zone more strictly, by limiting the MAG welding HAZ toughness index f_{HAZ} to a low level.

Figure 3 shows an overview of the G385T bending test. The specimen was prepared by welding 2 through diaphragms in the central loading part of a G385T steel tube, and a 3-point bending test was performed by gradually increased cyclic loading under peak-to-peak alternate incremental loading with the two ends as pin supports.

Table 4 shows the list of bending test specimens. The width-thickness ratio, D/t, of the cross-section of the column and the loading direction (0°, 45°) were used as parameters. The same conditions were applied with specimens T2, T3, and T6 in order to examine the variation in results when using multiple specimens. The NBFW™ welding method was applied with all specimens (NBFW: Non-Brittle Fracture Welding). NBFW™ is a construction method in which brittle fracture is avoided by welding a through diaphragm in the column[19, 22].

Figure 4 shows the results of the bending test of G385T. The cumulative plastic deformation ratio (cumu-



α : Equivalent width-thickness ratio=$(\sigma_y/E)(D/t)^2$
σ_y : Yield strength of column on flat part E : Young's modulus
D : Width of column t : Thickness of column

Fig. 4 Result of G385T bending test

lative ductility) η, which is an index of seismic safety, is shown on the vertical axis. The cumulative plastic deformation ratio, η is calculated by the following equation[13].

$$\eta = \Sigma W / (M_p \cdot \theta_p)$$

ΣW : Energy absorbed by plastic hinge of specimen (kJ)
M_p : Full plastic moment of column (kN·m)
θ_p : Angle of rotation at full plastic moment of column (rad)

The horizontal axis in Fig. 4 shows the width-thickness ratio, D/t, arranged by the equivalent width-thickness ratio, α, in which D/t is standardized by the yield strength, σ_y, obtained in a tensile test of the skin plate of the flat part of the column.

Because the strength of specimen T1 decreased due to local buckling, the data for that specimen were arranged with the point in time when strength (proof stress) decreased 5% from maximum strength as the ultimate state. In all the other specimens, ductile fractures which initiated from the toe of the diaphragm weld bead grew to the column base metal side and fracture occurred after large plastic deformation. This is the assumed fracture mode in the NBFW™ method, namely, "Prevention of fracture in the weld (HAZ) enables the base metal of the steel tube to demonstrate its performance to the maximum extent."

Based on various studies, including the content described above, a design method evaluation (BCJ Evaluation ST0205-01) was received from The Building Center of Japan, allowing omission of supplementary design items such as the strength decrease required in BCP325, etc. (2007 notification of the Ministry of Land, Infrastructure, Transport and Tourism No. 594, Article 4.3, b, 2 and specification provisions provided in the 1980 notification of the Ministry of Construction No. 1791, Article 2.3, a) by applying the NBFW™ method to the 550 N/mm^2 class cold-press-formed square steel tube for building structural use, G385T.

3.3 Structural Performance as Composite Structures

Concrete filled steel tubes (hereinafter, CFT) have the advantage that excellent deformation performance and fire resistance performance can be obtained by an effect in which the steel tube confines the concrete (confinement effect) while the concrete provides buckling stiffening for the steel tube. Concrete filled steel tubes have been applied widely in recent years, centering on high-rise buildings.

Figure 5 shows an overview of the shear bending test under constant axial force of a CFT column using G385[7]. The specified compressive force is applied to the CFT column specimen by an oil hydraulic jack attached in the vertical (axial) direction, and shear bending is then applied cyclically by peak-to-peak alternate loading by a second jack attached in the horizontal direction.

Table 5 shows the list of CFT specimens. The compression strength of the concrete filling is approximately 60 N/mm^2. The concrete is placed by the direct casting method. The experimental parameters were the width-thickness ratio (D/t) of the steel tube and the axial force ratio ($n = N/N_0$, N: Vertical axial force, N_0: Compressive strength at center). **Figure 6** shows an example of the bending moment (M)-story drift (θ_{SD}) relationship obtained from this experiment in the case of specimen G3. Here, the influence of the P-Δ effect is considered in the evaluation of the bending moment in the experiment. Strength did not decrease suddenly under the cyclic incremental loading, and the original axial strength was maintained until the end of loading.

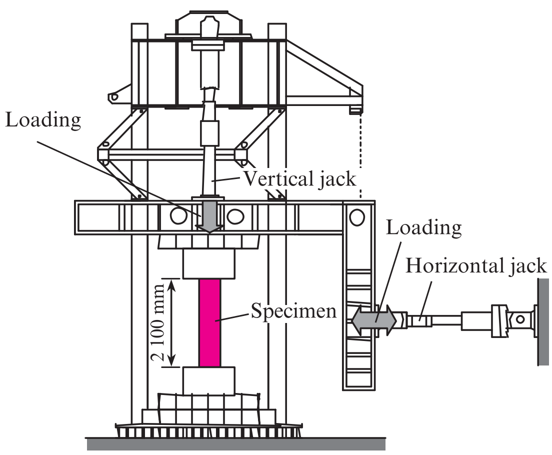


Fig. 5 Overview of shear bending test under constant axial force

Figure 7 shows the result of the shearing bending test under constant axial force. At each width-thickness ratio, the experimental maximum bending moment ($_{test}M_u$) was divided by the value ($_{anh}M_u$) calculated by an evaluation formula in the literature[23]. As all the plots are positioned near 1 on the vertical axis, it can be understood that the maximum bending moment of CFT columns using G385 generally corresponds to that given by the evaluation formula in the literature[23]. For comparison, the results of past research[9, 24] were also plotted in Fig. 7. The results of the CFT columns using G385

Table 5 Specimens of CFT

	D (mm)	t (mm)	D/t	$_S\sigma_y$ (N/mm^2)	$_S\sigma_u$ (N/mm^2)	$_S$YR (%)	$_C\sigma_B$ (N/mm^2)	n (=N/N_0)
G1	350	12	29.2	395	542	73	63.8	0.4
G2	350	12	29.2				65.9	0.6
G3	450	12	37.5				68.1	0.4

D: Width of cross-section t: Thickness of cross-section
$_S\sigma_y$: Yield strength of steel $_S\sigma_u$: Tensile strength of steel
$_S$YR: Yield ratio of steel $_C\sigma_B$: Compression strength of concrete
n: Axial force ratio N: Axial force
N_0: Compressive strength at the center

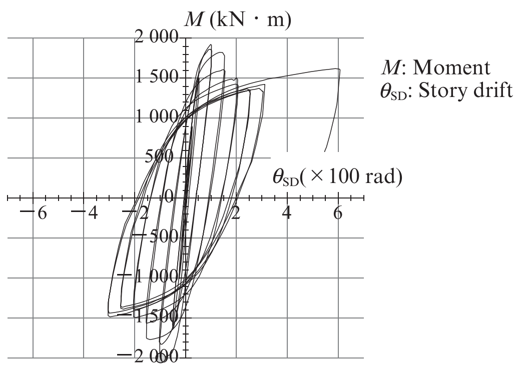


Fig. 6 Bending moment–story drift relationship (Specimen G3)

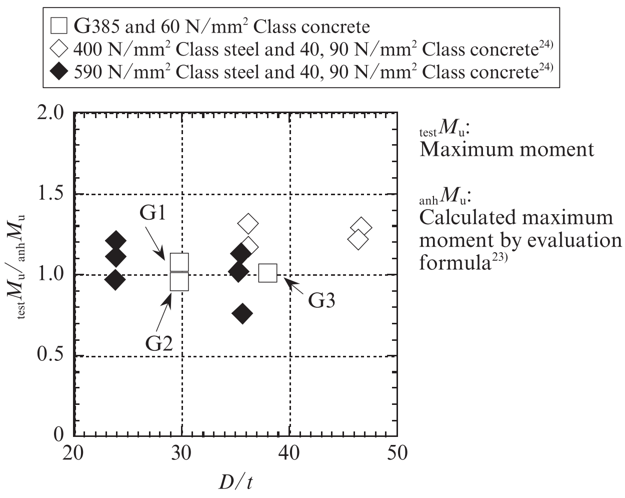


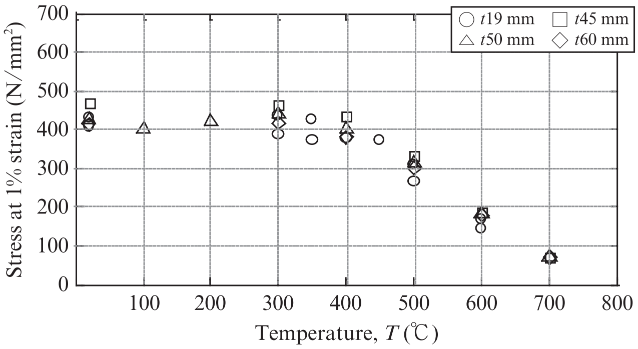
Fig. 7 Result of shear bending test under constant axial force

are distributed in the same range as those of CFT columns using conventional 400 and 590 N/mm^2 class steels, showing that the G385 CFT columns have structural performance on the same level as CFT columns of those steels.

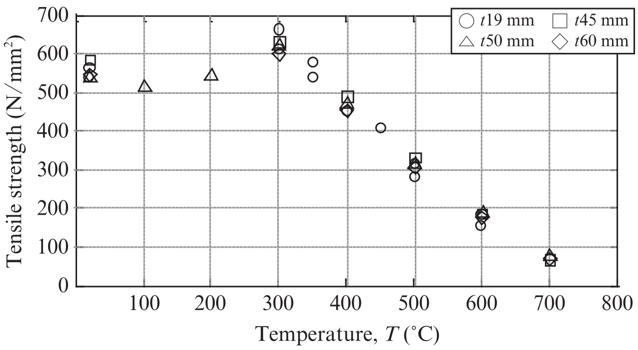
4. Fire Resistance Performance

In the revision of Japan's Building Standards Act in June 2000, the concept of "performance-based design" was also incorporated in fire resistance design. As a result of this, it is now possible to adopt various materials and structural work methods in fire resistance design by satisfying performance requirements[25].

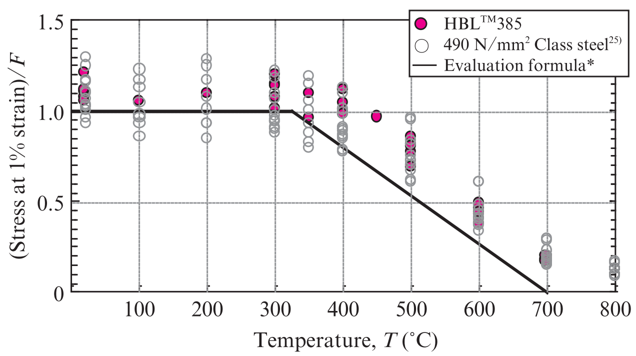
This chapter introduces the results[10] of an elevated temperature tensile test of HBL™385, which form the basic data for resistance performance evaluations.



(a) Stress at 1% strain



(b) Tensile strength



*Notification of the Ministry of Construction

(c) Comparison of stress at 1% strain

Fig. 8 Results of high-temperature tensile test

The elevated temperature tensile test was performed based on JIS G 0567 "Method of elevated temperature tensile test for steels and heat-resisting alloys" with II-10 type test pieces (JIS: Japanese Industrial Standards). The steel used was the same grade HBL™385 (specified design strength F = 385 N/mm^2) in all cases. One charge each was performed with the plate thicknesses of 60 mm, 50 mm, and 45 mm, and two charges were performed with the thickness of 19 mm, for a total of five charges.

The test results (average of two test specimens) are shown in **Fig. 8** (a) and (b). The horizontal axis in these figures is the test temperature T, and the vertical axis is (a) Stress at 1% strain and (b) Tensile strength.

Figure 8 (c) shows a comparison of the results of a test with 490 N/mm^2 class steel (F = 325 N/mm^2) for which results of this test are shown in the literature[25] and the elevated temperature strength evaluation formula for steel materials in the 2000 notification of the Ministry of Construction No. 1433. The vertical axis shows Stress at 1% strain standardized by specified design strength F, and the horizontal axis shows the test temperature T. From Fig. 8(c), it can be confirmed that HBL™385 has high temperature strength properties similar to those of the conventional 490 N/mm^2.

In addition to the elevated temperature tensile test, JFE Steel has also performed fire resistance tests under load for fireproof coated CFT in the HBL™385 Series[10].

5. Conclusion

This paper has presented an outline of the HBL™385 Series, which was developed by JFE Steel using state-of-the-art technology, and has described the features of HBL™385 products as high strength steel materials which provide a combination of low yield ratio, high toughness, and excellent weldability. Tests have confirmed that structural members utilizing these features amply satisfy performance requirements corresponding to the part and shape where the materials are used, and various design provisions have been clarified. At present, the HBL™385 Series products are widely used as steel materials for building structures which secure the seismic safety of those structures while also realizing improved economic efficiency.

All these results were achieved by responding promptly to the needs of society for building design and construction methods as a pioneer in the development of 550 N/mm^2 class steels.

With safer buildings now demanded following the Great East Japan Earthquake of March 2011, JFE Steel, together with its customers, will continue to contribute to safe and secure town-building.

The authors wish to take this opportunity to express their sincere appreciation to all those concerned in the laboratory at Fukuyama University, beginning with Prof. Koichi Minami, for their great assistance in performing the cyclic shear bending test of CFT.

References

1) Hayashi, Kenji; Fujisawa, Seiji; Nakagawa, Ichiro. High Performance 550 MPa Class High Strength Steel Plates for Buildings. JFE Technical Report. 2005, no. 5, p. 53–59.
2) Suzuki, Shinichi; Ichimiya, Katsuyuki; Akita, Toshikazu. High Tensile Strength Steel Plates with Excellent HAZ Toughness for Shipbuilding. JFE Technical Report. 2005, no. 5, p. 24–29.
3) Sueishi, Nobuyuki; Arakawa, Takekazu; Ohmori, Akio; Matui, Tokumi. High Strength and Heavy Wall Thickness Steel Pipes for Building Structures. JFE Technical Report. 2009, no. 14, p. 9–15.
4) Nakagawa, Kei; Kamura, Hisaya; Hirano, Osamu; Fujisawa, Kazuyoshi; Murakami, Yukio. Experimental study on deformation capacity of 550N/mm^2 class cold press formed square steel pipes. Summaries of Technical Papers of Annual Meeting (AIJ). C-1, Japan, 2008, p. 549–550.
5) Fujisawa, Seiji; Fujisawa, Kazuyoshi; Nanba, Takayuki. The Structural Performance of a SRC Column Fabricated by High-Strength Steel of 550 N/mm^2 Grade for Building Frames. JFE Giho. 2005, no. 10, p. 41–50.
6) Ueki, Takuya et al. Deformation Capacity of CFT using 550N/mm^2 Press Column. Summaries of Technical Papers of Annual Meeting (AIJ). C-1, Japan, 2008, p. 1119–1120.
7) Kinoshita, Tomohiro; Nanba, Takayuki; Ueki, Takuya; Murakami, Yukio; Kamura, Hisaya; Shima, Kunio; Minami, Koichi. Experimental Study on Structural Performance of Concrete Filled Tubes (CFT) using High Strength Steel Pipe Part I. Summaries of Technical Papers of Annual Meeting (AIJ). C-1, Japan, 2009, p. 1213–1214.
8) Kamura, Hisaya; Nanba, Takayuki; Kinoshita, Tomohiro; Ueki, Takuya; Murakami, Yukio; Minami, Koichi. Experimental Study on Structural Performance of Concrete Filled Tubes (CFT) Using High Strength Steel Pipe Part II. Summaries of Technical Papers of Annual Meeting (AIJ). C-1, Japan, 2009, p. 1215–1216.
9) Nanba, Takayuki; Kamura, Hisaya; Kinoshita, Tomohiro; Murakami, Yukio; Fujii, Toshiki; Minami, Koichi. Experimental Study on Structural Performance of Concrete Filled Tubes Using High Strength Steel Pipe Part 3. Summaries of Technical Papers of Annual Meeting (AIJ). C-1, Japan, 2011, p. 1183–1184.
10) Murakami, Yukio; Kinoshita, Tomohiro; Sakamoto, Yoshihito; I, Hidehiro; Suzuki, Takao. Properties of 550N/mm^2 Class Steel at Elevated Temperature. Summaries of Technical Papers of Annual Meeting (AIJ). Fire protection, Japan, 2012, p. 271–272.
11) Furuya, Hitoshi et al. Effect of Chemical Compositions on the HAZ Toughness and Its Formulation under Simulated Column-Beam Connection Welding of Structural Steel for Building. Kou Kouzou Rombunshuu. Japan, 2001, vol. 8, no. 32, p. 17–32.
12) BCJ et al. "2007 Nenban kenchikubutsu no kouzoukankei gijutsukijun kaisetsusho." (Japanese)
13) Building Research Institute. Kozai Kurabu. Kyodokenkyu Koukouzoukenchikubutsu no kouzouseinouhyouka shikenhou ni kansuru kenkyu iinkai houkokusho. 2002-04. (Japanese)
14) Kido, Yuuta; Yamada, Satoshi; Kuwamura, Hitoshi; Akiyama, Hiroshi;Kadono, Akio. Stub-column test focused on material properties: part 1, 2. Summaries of Technical Papers of Annual Meeting (AIJ). C, Japan, 1992, p. 1245–1248.
15) Inoue, Teturo; Kuwamura, Hitoshi; Buckling Behavior of Box Section Stub-column of High-Strength Steel with Low Yield Ratio Whose Mechanical Property in Tension has Prastic Flow. Summaries of Technical Papers of Annual Meeting (AIJ). C, Japan, 1990, p. 1359–1360.
16) Kato, Ben; Akiyama, Hiroshi; Suzuki, Hiroyuki. Inelastic Local Buckling of Steel Circular Tubes under Pure Compression. Transactions of the Architectural Institute of Japan (204). 1973, p. 9–17.
17) Kamba, Teruyasu. Stub Column Test of High-strength CRS Steel Column with Small Diameter-to-Thickness Ratio. Journal of structural and construction engineering (507). 1998, p. 123–129.
18) Nakashima, Takashi; Minoda, Sigeru; Ochi, Kenshi; Kurobane Yoshiaki. Load-carrying and deformation capacities of high-strength steel tubes: part 1, Stub-column and tensile coupon tests. Summaries of Technical Papers of Annual Meeting (AIJ). C, Japan, 1990, p. 1487–1488.
19) BCJ et al. "2008 Nenban reikanseikeikakugatakoukan sekkei-sekou manual." 2008. (Japanese)
20) AIJ. Recommendation for Limit State Design of Steel Structures. 2002, p. 121–124. (Japanese)
21) Kinoshita, Tomohiro; Murakami, Yukio; Fujisawa, Seiji; Kamura, Hisaya; Ueki, Takuya. Verification for lateral buckling performance of H-shaped beam using 550N/mm^2 strength steel. Summaries of Technical Papers of Annual Meeting (AIJ). C-1, Japan, 2010, p. 889–890.
22) Hirano, Osamu; Tomori, Koichi; Oki, Koji; Watanabe, Kazuo; Yamaguchi, Tanemi; Kawabe, Soichi; Yasufumi, Sasaki. Relationship between weld layer configuration of NBFW and its strength & toughness. Kou Kouzou Rombunshuu. Japan, 2010, vol. 17, no. 66, p. 1–10.
23) ANUHT. "Konkuri-to juuten koukan CFT zou gijutsu kijun doukaisetsu no unyou oyobi keisanrei nado." 2005. (Japanese)
24) Mori Koji; Fukumoto Noboru. U. S. -Japan Cooperative Structural Research Project on Composite and Hybrid Structures (CFT-9) Shear-Flexural Behavior of Concrete-Filled Steel Tubular Columns Part 3. Summaries of Technical Papers of Annual Meeting (AIJ). C-1, Japan, 1996, p. 1027–1032.
25) AIJ. "Guide Book for Fire-Resistive Performance of Structural Materials." 2009.