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

Table 1 Chemical compositions of HBL™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*

shown in Table 1 and Table 2, respectively.

As mentioned above, while the products in the HBL™385 Series are high-strength steels with tensile strength of 550 N/mm² 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/mm² 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™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™385 Series products also possess mechanical properties conforming to those of plates.

HBL™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™385 plates, HBL™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/mm² class cold-press-formed square steel tube G385 and the 550 N/mm² 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

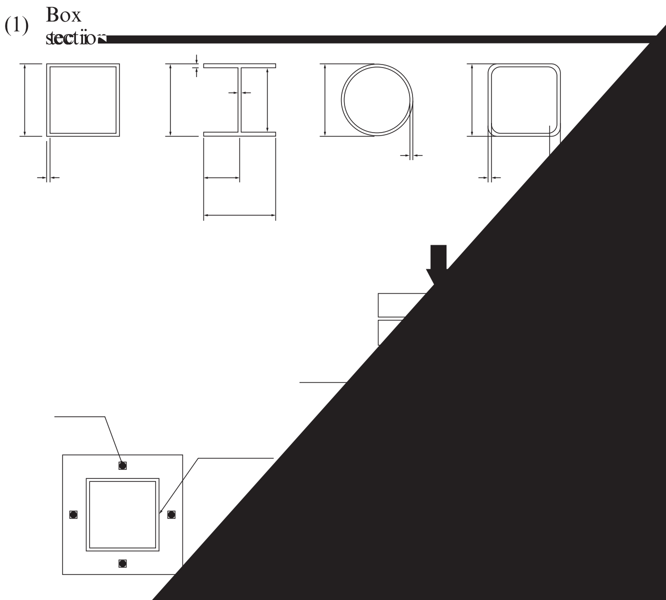
The 1980 notification of the Ministry of Construction No. 1791, Article 2 and notification No. 1792, Articles 1 and 3, as revised in 2007, provided width-thickness ratios for carbon steel with specified design strength 205–375 N/mm².[2,12)] However, the treatment of the HBL™385 Series was not clarified since its specified design strength is 385 N/mm². 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 [illegible] performing a stub column compression test usin[illegible] width-thickness ratio as a parameter.

Figure 1 shows an outline of the test. In ac[illegible] with the literature[13)], monotonous loading in [illegible] direction was performed so as to appl[illegible] formly to the cross section.

Table 3 (a)–(d) show the section [illegible] men and the calculated yield loa[illegible] and (4), the height h of the spe[illegible] times the diameter D, and w[illegible] times the width B.

The calculated yie[illegible] obtained by multipl[illegible] culated from the [illegible] strength σ_y in a[illegible] men.

Figure[illegible] nification[illegible] for [illegible] c[illegible]



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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 ($_{SD}$) 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.

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 ($_{anl}M_u$) 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[8–24] 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)	$_SYR$ (%)	$_C\sigma_B$ (N/mm^2)	n (=N/N$_0$)
G1	350	12	29.2				63.8	0.4
G2	350	12	29.2	395	542	73	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
$_SYR$: 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

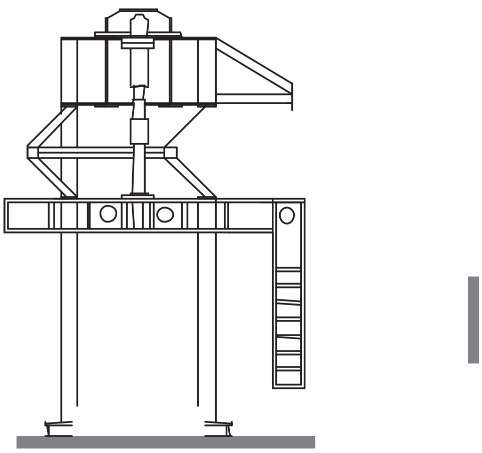

Fig. 5 Overview of shear bending test under constant axial force

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.

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