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Abstract:

Steel products play an important role as construction materials by taking advantage of a number of outstanding features, which include easy formability, high strength combined with high earthquake resistance based on excellent plastic deformation performance, recyclability and so forth. This paper describes an outline of representative new construction products and JFE Steel's approach to product development based on trends and needs in the social environment.

1. Introduction

Construction materials are an enormous market in Japan, accounting for half of total steel demand, and therefore are an extremely important f eld for steel makers in deciding business strategy. JFE Steel's involvement in the construction materials business dates from the 1950s, when the company began building coastal steel works and peripheral facilities such as dormitories, employee housing, hospitals, and gymnasiums. The prototypes of today's key products such as steel pipe piles, steel sheet piles (especially for steel pipe sheet pile foundations), and H-shapes were all born during this period. At the same time, the company also developed a wide range of use technologies for construction materials, including construction technologies for heavy structures such as blast furnace foundations, port and harbor construction technologies, technologies for improving soft stratum, and construction technologies for steel structures and buildings.

Since that period, JFE Steel and its group companies have developed construction materials which respond to diverse social needs, including changes in the construction environment (low noise, low vibration), advanced earthquake resistance requirements occasioned by the 1995 Kobe Earthquake, reduced construction costs, and environment-friendliness, and have commercialized a large number of products.

This paper describes the development of construction materials made by JFE Steel in the respective f elds of civil engineering and construction, focusing on Only 1 and No.1 products.

2. Construction Materials for Civil Engineering

2.1 Highways and Railways

In the highway/railway f eld, JFE Steel has developed and popularized construction material use technologies centering on steel pipe piles for bridge foundations and steel pipe sheet pile foundations. Although conventional pile driving was originally the primary method of executing pipe pile works, JFE Steel developed various new methods in response to noise and vibration regulations, including the inner excavation en

Steel has given a renewed attention to the use of underground space. Methods of utilizing underground space include the open excavation method using sheet piles

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general rectangular shape (**Photo 3**).

2.2 Ports and Harbors

Ports and harbors in Japan are frequently constructed in areas with weak alluvial ground, where steel easily demonstrates its numerous advantages, including high performance in anchoring in deep bearing strata and high bending/shear properties, which are necessary to resist horizontal external forces such as earthquakes and waves. As examples, the cantilelver type, equipped with anchorage type, and equipped with coupled-pile anchorage type seawall are widely recognized as general revetment and pier structures for weak ground. Increasingly important JFE Steel's products include double-walled steel (pipe) pile structures and steel sheet pile cellular-bulkhead structures as structural types which utilize the shearing resistance of the ground, and more recently, the strutted frame method, which is a rational structural method for deep water and resistance to large horizontal external forces such as high waves.[9]

Among new f elds, there is now an active trend toward construction of marine-area waste land f lls due to the recent shortage of conventional land f ll sites. Here, JFE Steel has a growing supply record in water barrier wall construction using steel (pipe) sheet piles.[10]

(1) Strutted Frame Method

The strutted frame (panel point strut) method (**Photo 4**) is a construction method in which the rigidity of a rigid frame of steel pipe piles and steel pipe sheet piles is reinforced with struts. This method effectively utilizes the vertical and horizontal supporting capacity of the ground by distributing external forces acting on the structure in the vertical and horizontal directions, making it possible to realize high horizontal rigidity. In recent years, upkeep and repair of existing facilities have become key words, and there has been an increasing tendency to improve existing quay walls where construction land is limited. By combining various components such as piles and struts, this method makes it possible to select the structural form best suited to site conditions and minimize the occupied width in comparison with conventional methods, thus demonstrating true value under restrictive conditions.

(2) Steel Water Barrier Wall Using Steel (Pipe) Sheet Pile

Because steel itself is imper i v h

responds to recent environmental problems, in that the pile penetrates the ground by rotation using the toe wing, generating no waste soil.

The Tsubasa Pile was approved by Japan's Minister of Construction in 2002 and received construction technology certification from Public Works Research Center in 2003, and thus can be used in foundations for civil works, mainly in building foundations. Through fiscal year 2002, JFE Steel had supplied a total weight of 31 000 t.

(2) Inner Pile Excavation Method Using Steel Pipe Pile (KING Method)

To expand the use of steel pipe piles in building foundations, JFE Steel undertook the development of an inner excavation/foot guard method for steel pipe piles as a method which is suitable for large diameter and long piles and can be applied with a wide range of ground types. Commercial use of this technology as the KING method began in 1998 (**Photo 8**).

In the KING method, an auger is inserted inside a steel pipe pile, and the pile is sunk to the bearing stratum while excavating earth and sand from the leading end, using the pile as a casing. On reaching the bearing stratum, cement-milk is injected into the leading end of the pile to construct an expanded foot guard section, and bearing force is secured when the foot guard hardens.

The KING method has been approved by the Minister of Construction based on the former Building Standards Act, No. 38 for pile diameters up to ø1 000 mm. From 2001 through 2002, loading tests were carrie !

heating work can be omitted.

(2) The weld bead length in assembly welding (tack welding) can be shortened.

(3) Deterioration in mechanical properties due to local heating is minimum.

(4) Deterioration in mechanical properties due at butt welds and f tting welds is minimum.

Beginning immediately after the development, various advantages of developed steel were highly recognized by both steel frame manufacturers and designers, and HBL385 has already been adopted in a large number of projects. Orders received and manufactured have now reached more than 4 000 t.

In order to meet more recent requirements of high HAZ toughness in welds, JFE Steel also developed a 590 N/mm^2 class steel which has excellent toughness not only in beam-end welds, but also in members welded by high-ef f ciency ultra-high heat input methods, including corner welds in box columns (submerged arc welding) and diaphragm welds (electro slag welding), meeting toughness requirements of 70 J or higher at 0°C in steels from the 490 N/mm^2 class to 590 N/mm^2 class. These materials are produced using the JFE Steel's high HAZ toughness technology (JFE EWEL) which is being employed for ultra-high heat input welding of shipbuilding materials. JFE EWEL was realized through a fusion of JFE Steel's echnologies. Speci f cally, JFE EWEL utilizes TMCP technology, which is one of JFE Steel's advantages, and a reduced C_{eq} secured by TMCP,[14] in combination with JFE Steel's high toughness technology for the HAZ,[15] which consists of the re f nement of prior γ grain size and promotion of ferrite nucleation through controlling of f ne nitride, oxide, and sulf de particles, as well as suppression of brittle phases such as upper bainite microstructure (**Fig. 10**). JFE Steel has also developed welding consumables which satisfy high weld metal toughness requirements for use in submerged arc welding of corner welds and electro slag welding. And also JFE Steel can propose the optimum combination of steel materials, welding consumables,

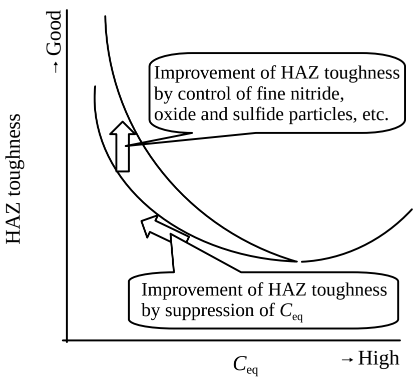


Fig. 10 Concept of improvement technology in HAZ toughness for high heat input welding

and welding techniques. HBL325 (490 N/mm^2 class) and HBL355 (520 N/mm^2 class) steels already have records of use in designated columns where high toughness in HAZ is required. In the future, JFE Stee will also encourage applications of HBL385 and SA440 to designated columns in high-rise buildings. It is believed that this can contribute to enhanced safety and reliability in these structures.

3.1.3 High durability Cr-added steel for building structural use "JFE410DH"

As one measure against global environmental problems, the Japanese government is now creating a legal system for a recycling-based society. The Green Procurement Law for government agencies has been enacted, and the Construction Recycling Law has taken effect in construction-related f elds. Because there is an established recycling system for steels and corrosion resistance of steels can be secured by taking appropriate rust-prevention measures, steel products is one of the construction materials with low environmental-load. "Sustainable architecture" such as column and beam reuse methods for heavy steel frame members, long-life 3-generation housing, and recycling of steel from used housing has begun to expand to residential and other construction. However, steel products are typically rust-proofed by general painting or galvanizing, and therefore require touch-up painting at the constructing site and supplementary work such as curing at high-tensile bolt connections in some cases. Stainless steels such as Type 304A can now be used following the revision of the Building Standards Act and offers extremely high corrosion resistance without rust-proo f ng, but stainless steel products are expensive and design methods differ from those used with general carbon steel. As a result, stainless steel is still rarely used except in parts where appearance is a priority, such as entrance foyers.

JFE Steel therefore developed an 11% Cr steel for building structural use, JFE410DH, which has excellent corrosion resistance and uses the same design methods as general steel materials for building structural use, and has obtained material approval from the Minister of Land, Infrastructure and Transport (Jan. 28, 2002: MSTL-0071).

The mechanical properties of JFE410DH are controlled to be equivalent to those of 400 N/mm^2 class carbon steel for construction use by adopting appropriate techniques in the manufacturing process. In comparison with Type 304 stainless steel, which has an austenite structure, JFE410DH has a ferrite structure, giving it elasticity/rigidity, yield ratio, elongation, and other properties similar to those of 400 N/mm^2 class carbon steel. Furthermore, because its composition is designed to promote adequate formation of a f ne martensite structure, which has high toughness in welds, weld toughness is equal or superior to that of general steel materials for building structural use.

Due to its 11% Cr content, JFE410DH displays extremely high durability in atmospheric environments. **Figure 11** shows the results of a field exposure test. Corrosion loss with JFE410DH was 1/76 that of 400 N/mm^2 class carbon steel for construction use. According to the life-prediction formula for residential structural materials proposed by the Comprehensive Technical Development Project of the former Ministry of Construction,[16)] the life of 400 N/mm^2 class carbon steel with a 4.5 mm thickness is approximately 19 years, accordingly a simple proportional calculation shows that the life of JFE410DH is approximately 1 400 years.

There is also strong interest in the durability of structures among general consumers, as seen in the legal obligation to provide a 10-year guarantee against defects in the Law for Securing Quality in Residential Housing. As a steel product based on a new concept, JFE410DH is expected to be used not only as a steel for building structural use, which is now possible, but also in a variety of other applications which take advantage of its outstanding durability.

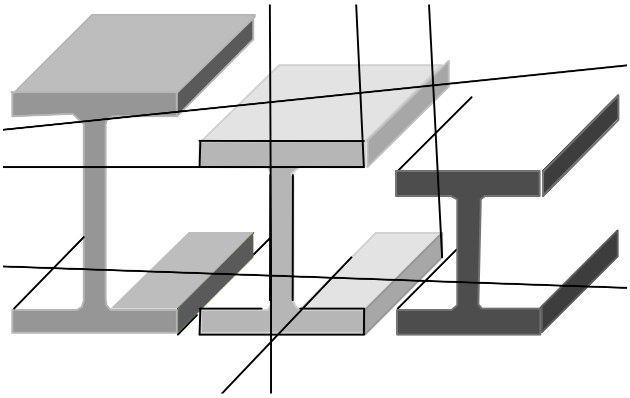
3.2 Tubular Products for Diverse Needs

3.2.1

as web heights of 1 000 mm and 950 mm in Feb. 1999,[19) was realized by expanding the capacity of the intermediate rolling mills in the modernization of the steel shape mill at Kurashiki District of West Japan Works completed in June 1996, and development of caliber rolling technology, an example of which is shown in **Fig. 17**. The relationship between the cross-sectional area and moment of inertia of each size is shown in **Fig. 18**. In SHH with web heights of 950 mm and 1 000 mm, sectional efficiency is improved by approximately 50% in comparison with SHH with web heights of 900 mm and less.

3.3.2 TMCP heavy wide flange H-shapes "HBL-JH325/355"

Application of TMCP to the manufacture of H-shapes allowed JFE Steel to develop TMCP heavy gauge H-shapes, HBL-JH325/355, with the product specifications shown in **Table 4**. Commercial production began in 1995. As with TMCP steel plates, these shape products have been approved under Article 37 of the Building Standard Law. Two design standard strength grades are available, 325 and 32 [illegible]



new product a section secondary moment 1.5 to 2 times larger than the existing series with the same sectional area.

Table 5 shows a comparison of column weight when large section H-shape column materials, which do not require a reduction in the design standard strength, and box columns (rectangular hollow sections) are applied in a structure 165 m high with 35 aboveground stories. The weight of the H-shape columns is approximately 2–3% less than that of the rectangular hollow sections. In particular, the 700 × 500 nominal size is the most efficient section shape.

3.3.3 TS 550 N/mm^2 wide flange H-shapes for building structure “HBL-H385”

In 2000, JFE Steel developed a TMCP TS 550 N/mm^2 wide flange H-shape with a design standard strength of 385 N/mm^2.[14] This product, HBL-H385, was realized by JFE Steel’s state-of-the-art TMCP device for shape steel (*Super*-OLAC S) and advanced manufacturing and quality control technologies. Available section sizes include those specified for JIS H-shapes and fixed outer dimension H-shapes.

Product specifications are shown in **Table 6**. In comparison with SN490, the yield strength and tensile strength are increased by 60 N/mm^2, while C_{eq} and P_{CM} are held to the same levels. Therefore, when applied in structures, a section reduction of 1–2 sizes can be achieved in comparison with TS490 N/mm^2 wide flange H-shapes, while welding costs in frame fabrication are also lower, substantially reducing construction costs. As shown in **Table 7**, adequate impact performance is secured in CO_2 gas metal arc welds, showing that performance requirements for beam-end welded joints can be fully satisfied even in a cyclic loading test of beam-to-column joints.[21]

Next, in many cases, steel reinforced concrete (SRC) structures function advantageously with high strength steel materials, for example, by providing high rigidity and buckling resistance in comparison with steel frame structures. However, because some points remain to be clarified, such as the effect of the strength difference between steel and concrete, JFE Steel’s researchers conducted cyclic bending loading tests under the axial load of the SRC structures column. An example of the test results is shown in **Fig. 20**. The strength obtained in these tests satisfied the equation for calculation of SRC structures criteria,[22] confirming that the equation for these criteria can also be applied to this steel grade.

3.4 High Earthquake Resistance Construction Methods

3.4.1 Low yield strength steel dampers

Dampers using low yield strength steel positively absorb the energy introduced into structures by earthquakes and are effective in reducing the response of the structure.

The low yield strength steel used in dampers must have a low yield proof stress in comparison with carbon steel, and deviations in yield strength must be more strictly controlled. The steel is also required to have sufficient ductility and toughness to withstand cyclical plastic deformation during earthquakes.

As shown in **Table 8**, JFE Steel's line of low yield strength steels includes a total of 5 types, with 3 grades of plate and 2 grades of seamless pipe.

Dampers are broadly classified as the shear yield type or axial yield type. JFE Steel has commercialized wall dampers, shear panel dampers, and brace dampers of these respective types.[23,24)]

Table 8 Mechanical properties of steel plates and seamless pipes with low yield strength

			TS (N/mm	YR (%)	El (%)
Plate					

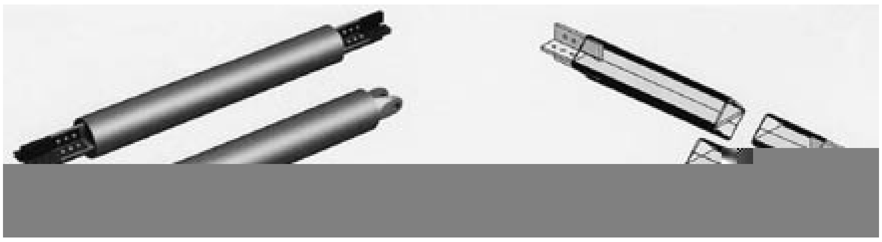
JFE Steel manufactures 2 types of brace dampers, as shown in **Fig 21**. In the double tube steel bracing in Fig. 21 (a), an outer reinforcing tube is used to restrain the buckling of the inner axial-force tube. In the flat-bar brace stiffened by square tube in Fig. 21 (2), a rectangular hollow section is used for bucking restraint of the brace axial material, which consists of flat bars.

Figure 22 shows a comparison of the hysteresis characteristics of a conventional steel tube brace and a JFE Steel's brace damper. In both rigidity and strength, the brace damper has stable historical characteristics, displaying equal compression and tension, and thus has a high plastic deformation capacity.

3.4.2 New joining method for beam-to-column joints at steel pipe column-H-shape beam connections "Earthquake Resisting Joint"

Earthquake Resisting Joint is a joining method developed exclusively by JFE Steel to prevent brittle fracture at beam ends by improving joint details and does not require complex design/welding control. The method includes two types of joints, a bolt joint type (TJB) for the bracket method and a welded joint type (TJW) for field welding.

In the TJB shown in **Fig. 23**(a), the diaphragm and bracket flange are formed by a single plate, and the width of the bracket flange is increased corresponding to the moment gradient. Because position at the first bolt hole on the beam side furthest from the column is the weakest section, energy is absorbed by the beam base material, which has high ductility, to secure a



(a) Double tube type (b) Flat-bar type

Fig. 21 Type of brace damper

technologies with strategic value.

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