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Overview of Construction Products and Methods in JFE Group

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Abstract:

JFE group has been developing the various products and construction methods to respond to construction market demands. Taking advantage of the excellent characteristics of steel materials, we are promoting the development and technology dissemination activities of various products and construction methods.

This paper introduces representative products and construction methods such as: earthquake resistant technology, disaster prevention technology and productivity enhancement in architecture and civil engineering fields.

1. Introduction

Japan is located in one of the world's most disaster-prone regions and has experienced frequent large-scale natural disasters up to the present day. Moreover, because great earthquakes are also expected in the future and large-scale flood damage driven by global warming is becoming more severe by the year, disaster risk on levels exceeding past assumptions for these natural disasters is a concern. Strong, resilient infrastructure facilities are also demanded in order to maintain and develop the country's economic society and ensure the safety of human life and activities. On the other hand, with the strong construction demand ahead of the 2020 Tokyo Olympic and Paralympic Games, particularly in the Tokyo Metropolitan area, the construction industry is faced with the serious problem of low birthrate and aging population, and a rapid decrease in skilled workers and the need to improve productivity have become urgent issues. This paper presents an overview of the construction products and methods developed in the civil engineering and construction fields by the JFE Group (hereinafter, JFE) to date in order to respond to these social conditions.

2. Civil Engineering Products and Construction Methods

2.1 Development of Products and Use Technologies in Civil Engineering Field

Classified by social issues, JFE construction products in the civil engineering field can be divided into three types, "Earthquake resistance/disaster prevention," "Underground" and "Labor-saving technologies." First, because "Earthquake resistance/disaster prevention" is the most important field of core technologies that protect the foundations of Japanese society, JFE is actively grappling with the development of products and construction methods that both ensure safety and security and are economical. Next, in the "Underground" field, considering restrictions on available construction land and construction periods, mainly in the redevelopment of urban areas, JFE is promoting the development and dissemination of products and construction methods that respond to the problems of limited space and adjacent construction by utilizing the strengths of steel materials. JFE is also grappling with "Labor-saving technologies," prioritizing the development of products and construction methods that respond to shortages of skilled labor such as welders and rebar construction workers. The following presents representative examples in each of these fields.

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2.2 Earthquake Resistance and Disaster Prevention Field

2.2.1 High strength steel pipe piles (TS = 570–590 N/mm^2 class)

High bearing capacity in piles has progressed in recent years from the viewpoint of economical design, and materials with higher bearing capacity than conventional piles are continuing to be demanded. In addition, due to the review of design external forces such as earthquakes and tsunamis following the 2011 off the Pacific coast of Tohoku Earthquake, cases in which designs were not materialized with steel pipe piles with the conventional plate thickness and materials have also been seen occasionally. In response to these problems, JFE developed high strength steel pipe piles with tensile strength TS = 570-590 N/mm^2 (yield strength: 440-450 N/mm^2), which is more than 40% higher than the design strength of the conventional steel pipe pile SKK490 (yield strength: 315 N/mm^2), and commercialized this product up to a heavy gauge type with a maximum plate thickness of t25 mm by the spiral manufacturing method and electric resistance welding manufacturing method, which are the main manufacturing methods for steel pipe piles. JFE has also conducted wide-ranging technology dissemination activities, centering on the port and harbor[1], mountain improvement and construction fields, by developing and proposing design and construction methods using these products.

2.2.2 Steel pipe pile construction methods

JFE has promoted the development of various pile construction methods that demonstrate the strengths of steel pipe piles to the fullest possible extent. The HYSC pile (Steel Pipe Soil Cement Pile) construction method is a composite pile method in which a ribbed steel pipe is installed in a soil cement column constructed by injecting and mixing cement milk in the soil of the original ground. Because the soil cement column can be regarded as part of the pile body, high bearing capacity and horizontal resistance can be obtained. Construction of soil cement columns with a maximum size of ϕ1 600 mm (steel pipe diameter: ϕ1 400 mm) is possible. HYSC piles have been used in more than 500 projects, primarily in roads and railways. The Tsubasa Pile™ method is a simple, economical screwed steel pipe pile construction method using a pile with a toe wing, which are formed by attaching a pair of semicircular steel plates having an outer diameter 1.5 to 3 times larger than the pile diameter. This method has the advantages that large push-in bearing force and pull-out resistance can be obtained by the toe wing, there is no soil discharge, and absolutely no cement milk is used during construction. The Tsubasa Pile method can also be applied to a wide range of pile diameters from ϕ100 to 1 600 mm, and has been used in a combined total of more than 900 projects in the civil engineering and construction fields. The Kongo Pile™ method (**Photo 1**) is a new pile construction method for building which makes it possible install piles with a maximum diameter of ϕ1 500 mm and a enlarged solidified root part diameter of ϕ3 000 mm. This design enables one-pile, one-pillar construction of large distribution warehouses and plant facilities with column loads exceeding 15 000 kN. The features of the Kongo Pile include excellent economy, which is realized by combining a steel pipe pile and precast concrete pile in the pile, and highly reliable construction management by confirming the expansion condition of the pile head in real time from ground level when installing the solidified root. The Kongo Pile method received general certification from the Center for Better Living (CBL) in March 2017[2].

Photo 1 Kongo Pile™ method

2.2.3 Earthquake resistance and disaster prevention methods for port and harbor facilities

As improvements of port and harbor facilities, Japan is now actively promoting construction of strong, resilient seawalls, embankments and other facilities and improvement of earthquake resistance in preparation for anticipated large-scale earthquakes, and renewal of existing port and harbor facilities in order to increase port capacity by increasing depth. In response to these trends, JFE has developed Hybrid Tide Embankment™ and Jacket Type Quay with Arc-Shaped Retaining Wall[3]. Hybrid Tide Embankment consists of foundation piles and precast members with a hybrid structure of steel and concrete, and not only saves space at narrow construction sites along coastal roads, but also greatly reduces construction time at the site. The Jacket Type Quay is a quay construction method in which steel sheet pile cells called arc-shaped retaining walls and a jacket-type pier are integrated.

Application to deeper water piers is also possible by using straight web sheet piles to efficiently bear earth pressure by tensile force in the in-plane circumferential direction of the sheet piles, combined with support by the jacket structure on the front side.

2.2.4 Metal Road™ method

Metal Road™ method[4] is a 3-dimensional rigid-frame prefabricated pier-type road bridge, in which the floor slab is laid on a structure integrated by rigidly connecting a superstructure consisting of rolled H-shapes and a steel pipe pile foundation. Driving steel pipe piles by the launching method makes it possible to complete construction in a short period while continuing to use the existing road, even in confined areas. To date, Metal Road method has a record of use in more than 500 projects, centering on construction to expand the width of main roads located on steep slopes in mountainous areas. In recent years, JFE has carried out research on evaluation of the earthquake-resistant performance of the distinctive structural system of the Metal Road method in order to expand application to arterial roads.

2.2.5 J-type steel slit dam and JD Fence™

The J-type steel slit dam belongs to the class of permeable sabo structures (check dams). It is installed in mountain streams, as its open structure minimizes dammed backwater during floods and enable sure capture of the leading edge of debris flows. On the other hand, countermeasures are now demanded in areas called "zero-order streams," where running water does not normally exist, like the area in Hiroshima City that suffered catastrophic damage as a result of debris flows in 2014. To meet this need, JFE is actively developing products that contribute to prevention of new forms of sediment disasters, for example, by developing the compact disaster prevention facility "JD Fence™," which can be applied in areas where it is difficult to install conventional sabo dams.

2.3 Underground Field

2.3.1 Technologies for use of underground construction products in main structures

With active redevelopment of urban areas in recent years, construction of underground walls in the limited space of constricted construction sites has been demanded in an increasing number of cases involving the construction of underground passages and underground external walls of existing buildings, represented by seismic isolation retrofit. Based on these needs, JFE has conducted research and development on the use of sheet piles in permanent main structures (J-Wall™) and thinner walls of steel sheet piles (J-Wall II). The J-Wall method[5] is a construction method in which a permanent composite underground wall is constructed by welding studs with heads to the hat shape steel sheet piles used in the temporary earth retaining wall after ground excavation, in order to integrate the piles with post-cast reinforced concrete. On the other hand, the J-Wall II method (**Fig. 1**)[6] uses a composite structure steel sheet pile (Beetle Pile) that CT shape steel and fixing reinforcing bar are attached to the hat shape steel sheet piles in advance in the shop instead of welding studs with heads. This method enable to shorten the process after excavation and can also realize an even thinner wall by increasing the joint strength between the steel sheet piles and reinforced concrete.

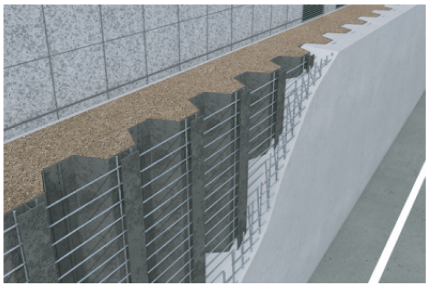

Fig. 1 J-Wall™ II method

J-domer™ is a high sectional rigidity earth retaining wall that combines straight web sheet piles and H-shape steel and can reduce wall thickness by approximately 300 to 500 mm in comparison with steel pipe sheet piles having the same rigidity. Until now, J-Domer has been adopted as a permanent wall in road retaining walls, river revetments, side walls of underground rivers and similar applications. However, application to underground redevelopment projects at narrow sites in urban areas is also expected in the future.

2.3.2 Underground tunnel and vertical shaft construction technologies

Since the "Law on Special Measures for Public Use of Deep Underground" was enacted in 2000, projects for construction of large-scale roads, railroads, waterworks and sewerage and rivers underground have been promoted. To meet these needs, JFE has developed and produces various types of segments for shield tunnels, including steel, concrete and steel-concrete composites. JFE also commercialized the "Urban Ring Method™" as an urban-type press-in caisson using steel or concrete segments[7]. Since the Urban Ring method greatly reduces the construction period while making it possible to carry out construction at narrow sites, sites with other adjoining construction and construction under height restrictions in comparison with RC caissons and other conventional construction methods, it has been

Photo 2　Urban Wall™ method

Fig. 2　High Mecha neji™

adopted in a cumulative total of more than 350 projects, mainly in underground bicycle parking, bridge pier substructures, vertical shafts, etc. with an outer diameter of 3 to 15 m and a maximum depth of approximately 70 m. JFE is also working on development of the Urban Wall™ method (**Photo 2**) using steel-concrete composite segments in response to the need for vertical shafts with larger diameters and depth than the Urban Ring method.

2.4 Labor-Saving Technologies

Based on strong promotion of workstyle reform at construction sites by Japan's Ministry of Land, Infrastructure, Transport and Tourism (MLIT) since 2016, further increases in demand for labor-saving technologies are foreseen in the future. This section introduces representative labor-saving technologies of JFE in the civil engineering field.

2.4.1 Mechanical joints for steel pipe piles

Based on recent demand for shortening of construction period and labor-saving construction methods, JFE has developed various types of mechanical joints corresponding to the use conditions of steel pipe piles. The threaded joint "JFE Nejiru," which was developed for use with landslide prevention piles has been commercialized for heavy gauge steel pipe piles, which demonstrate excellent economy in restricted construction environments in mountainous regions. In this product, a multi-thread taper screw was adopted as a design innovation for obtaining high bending strength and enabling joining of threaded joints with approximately 1 turn. "High-Mecha-Neji™" (**Fig. 2**) was developed as a joint for general piles. This joint has a parallel thread that allows easy positioning of the thread during joining, even under environments with height restrictions where a crane or other equipment cannot be used, and is also resistant to galling. The joint specification includes a separation prevention mechanism for counter-rotation work during pile driving of rotary piles, etc. The maximum diameter of High-Mecha-Neji is ϕ2 000 mm. Applicability to steel pipe sheet piles and pile installation by the hammer pile method has been confirmed, and Construction Technology Review and Certification by the Public Works Research Center was renewed (change of content) in 2018[8]. As another mechanical joint for general piles, the insertion-type mechanical joint "KASHEEN™" was developed targeting application to large diameter piles, and has been applied in sizes up to a maximum of ϕ1 700 mm. To date, the KASHEEN joint has been used in driven piles and bored piles in the port and harbor and road fields.

2.4.2 Rapid construction technologies for bridge piers and girders using deformed flange H-shapes

JFE is working to develop and disseminate labor-saving methods for reinforcing bar work in bridge pier and bridge girder construction by using a deformed flange H-shape steel product called "Stripe-H," which makes it possible to obtain high bonding performance with concrete. The REED construction method, which was developed for bridge pier applications, is a bridge pier construction method that combines the high durability embedded formwork "SEED form" that can be used as part of the permanent structure, and Stripe-H in place of rebars. The REED construction method is steadily accumulated a track record as a technology that can substantially shorten the construction period in comparison with the conventional cast-in-place concrete construction method. River Bridge (KCSB) and River Deck (KCSD) have also been commercialized as a steel-concrete composite slab bridge using deformed flange T-shape steel, which is produced by cutting deformed flange H-shapes in half. Installation of stud shear connectors is not necessary in this composite deck slab system, as the deformed flange T-shape steel is used as a shear connector to prevent slipping with the concrete. Temporary construction works can be reduced because the erection weight of steel panels is less than that of concrete decks, and the bottom steel plates are also used as the formwork for casting the slab. Considering these advantages, this method has gained wide acceptance as a method that realizes a

Fig. 3 Square steel pipe structs method

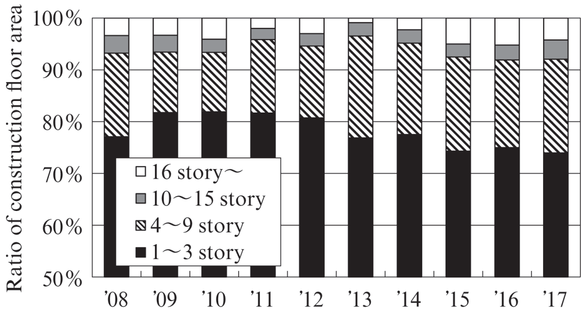

Fig. 4 New construction floor area by number of story of steel structure[10)]

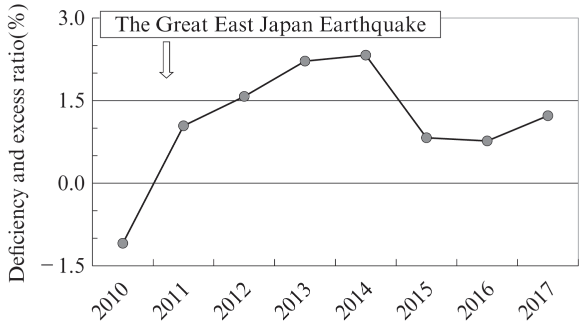

Fig. 5 Deficiency and excess ratio of construction skilled workers[11)]

short work period in site construction.

2.4.3 Square steel pipe structs method

Study of labor-saving and rationalization is also progressing in the field of heavy temporary construction, including earth retaining walls (landslide prevention walls) and covering work. As part of this, the "square steel pipe structs method" (**Fig. 3**) use of column struts (square steel pipes □350 to 400 mm) with high buckling resistance makes it possible to reduce the number of intermediate piles by realizing a large span in comparison with conventional construction methods using H-shape struts. This also improves efficiency in excavation and main frame construction work, as a wide working area can be secured, and as a result, this method greatly improves productivity at the construction site. The square steel pipe structs method has already been used in more than 170 projects, and further dissemination is expected in the future.

3. Construction Products and Methods for Building Construction

3.1 Development of Products and Application Technologies in Building Construction Field

In the runup to the 2020 Tokyo Olympic and Paralympic Games, the building construction field has enjoyed a robust demand environment in Japan in recent years. JFE has developed and commercialized a diverse range of steel material products and application technologies in response to this demand environment, mainly on steel plates, H-shapes and steel pipes.

In the super-high-rise building field, countermeasures against earthquakes have been studied[e.g. 9)], as an increasing trend in the scale of earthquakes can be seen, for example, in the 2011 off the Pacific coast of Tohoku Earthquake and 2016 Kumamoto Earthquakes, and massive damage is also forecast in case of long-period ground motion due to a Nankai Trough Earthquake or Sagami Trough Earthquake. Strengthening of column and beam members, use of vibration control dampers and other earthquake-resistant measures have also been incorporated in practical design work for steel frame structures.

Use of steel structures is strongly associated with high-rise and super-high rise buildings, large-span buildings and other large structures. However, in actuality, many steel structure buildings are medium- and low-rise buildings, as shown in **Fig. 4**[10)]. JFE has developed and commercialized a variety of products that contribute to improved earthquake resistance and rationalization of design and construction in the medium- and low-rise building field, which comprises this volume zone.

On the other hand, shortages of skilled labor have been an ongoing trend in the construction industry in recent years due to Japan's low birthrate and aging population, as shown in **Fig. 5** (labor supply-and-demand condition; + indicates labor shortage)[11)], and as a result, labor-saving at construction sites has become an urgent issue. JFE has carried out diverse product development and construction method development to contribute to solving this problem.

This chapter introduces representative examples of products and technologies developed to date.

3.2 Super-High-Rise Building Field

3.2.1 High strength steels for building structures

Using the world's most advanced TMCP (thermos

Table 1 List of HBL™ series

	Specification	YS (N/mm^2)	TS (N/mm^2)	YR (%)
Plate	HBL325	325	490	80
	HBL355	355	520	80
	HBL385	385	550	80
	HBL440	440	590	80
	HBL630	630	780	85
H-shape	HBL-H355	355	520	80

mechanical control process), JFE developed the "HBL™ Series" as a flagship product in the field of high strength steels for building structural use with excellent earthquake resistance and weldability. **Table 1** shows a list of the products in the HBL Series. Steel plate products in the HBL Series are frequently used as skin plates for welded box-section columns, which are mainly used as columns in super-high rise-buildings. However, in recent years, HBL Series products have been increasingly used as skin plates for built-up (welded) H-shapes used in large section beams, diaphragm materials for cold-formed square steel pipe columns and base plates for exposed column bases. As other application technologies, JFE also developed and commercialized a high strength shear wall, as shown in **Fig. 6**, which is used mainly in super-high-rise buildings.

In addition to the HBL Series, JFE also offers a lineup of SA440 as 590 N/mm^2 steel (plate) and H-SA700 and HITEN780T as 780 N/mm^2 steel (plate) as high strength steels for building structures.

When welding 780 N/mm^2 steel, a high level of technology and control is necessary under the present conditions. Therefore, JFE developed and commercialized an exterior diaphragm joint (beam-to-column connection) which does not require large heat input welding, as illustrated in **Fig. 7**(b). This diaphragm connection has already been adopted in large-scale projects.

3.2.2 Vibration control dampers

Vibration control dampers are now installed in many super-high-rise buildings to absorb earthquake energy, further in response to predictions of long period and great earthquakes, as mentioned above, use is also expanding to high-rise and medium-rise buildings. Although vibration control dampers can be broadly classified as the hysteresis type, friction type, viscous type and viscoelastic type, JFE has developed and commercialized three types of hysteresis vibration control dampers using low yield point steel. As shown in **Fig. 8**, these are the brace type, stud type and wall type. These products have already been developed and applied in many vibration control structures and seismic retrofits.

In addition to the above types of dampers, JFE developed a stud-type viscoelastic damper using a new high damping rubber and is supplying this product to the market. Because this viscoelastic damper demonstrates a vibration control effect from a comparatively small amplitude region, for example, under wind loading, rational vibration control can be expected by using this device in combination with the above-mentioned hysteresis type vibration control dampers.

As a result of enforcement of MLIT Notification No. 631, "Seismic structure design based on the balance of energy," design of vibration control dampers has become easier than in the past, and in the future, expanded application of vibration control dampers, not only to high-rise buildings, but also to low-rise general buildings and reinforced concrete (RC) buildings is expected.

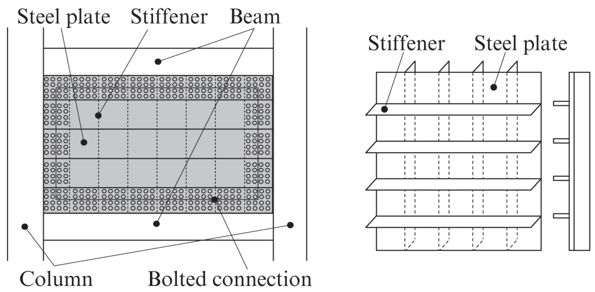

Fig. 6 Steel plate shear wall

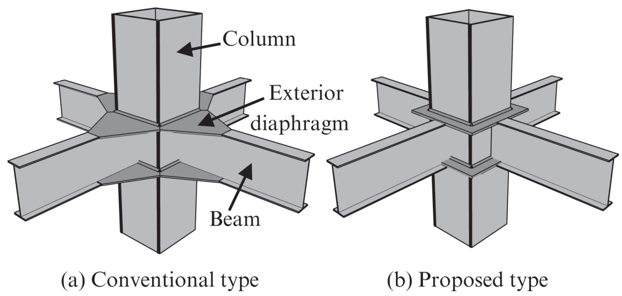

Fig. 7 Types of exterior diaphragm

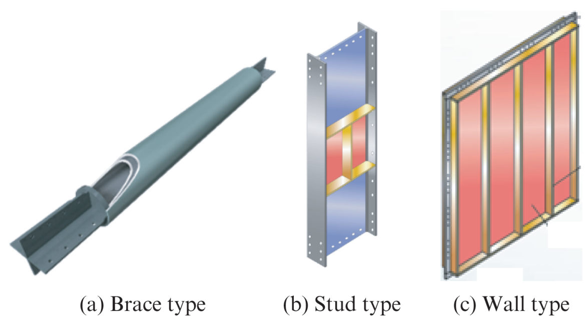

Fig. 8 Hysteretic damper

3.3 Medium- and Low-Rise Building Field

3.3.1 Cold-formed square steel pipes for building structures

Columns for medium- and low-rise buildings account for the majority of use of cold-formed square steel pipes for building structures. Placing priority on securing the weldability and seismic performance required in column materials, JFE has developed products which particularly consider the effect of the cold-forming processing and verified the performance of members, and has also played a central role in proposal and improvement of design methods. Cold-formed square steel pipes consist of two types, depending on the production method; these are cold roll-formed square steel pipes and cold press-formed square steel pipes. **Table 2** shows a list of these respective products. (In the table, BCR and BCP are trademarks of the Japan Iron and Steel Federation.)

Cold roll-formed steel pipes are widely used in low-rise buildings. JFE expanded the domestic maximum available range up to a sheet thickness of 28 mm in advance of other companies, and commercialized that product as JBCR™295, which has already been used in many buildings. JFE has also expanded the product lineup of cold press-formed square steel pipes, which are used in comparatively medium- to high-rise buildings, aiming at high performance and high strength, and is steadily extending record of use of those products.

3.3.2 Hot-formed square steel pipes for building structures

JFE supplies "Kakuhot™" to the market as a hot-formed square steel pipe for building structures. In the Kakuhot production process, seamless steel pipes with a circular cross section are formed to a square shape while still hot at the sizing mill, which is the final process in the production of seamless steel pipes. Because Kakuhot has a small cross section and its corner geometry is more sharp than that of cold-formed square steel pipes, it is used mainly in buildings where creativity is a priority. Furthermore, it is also applied frequently to beam-to-column joints in small-scale buildings, taking advantage of its small diameter and large wall thickness. Because the material is formed while hot, its deformation capacity is higher than that of cold-formed square steel pipes. In 2014, the available range of outer diameters was expanded from a maximum of 250 mm to 300 mm, and the scale of applicable buildings also increased. Therefore, further increases in adoption are expected in the future.

Table 2 List of cold-formed square steel pipe

	Specification	YS (N/mm^2)	TS (N/mm^2)	YR (%)
Roll formed	BCR295	295	400	90
	JBCR295	295	400	90
	STKR400	235	400	–
	STKR490	325	490	–
Press formed	BCP235	235	400	80
	BCP325	325	490	80
	BCP325T	325	490	80
	G385	385	550	80
	G385T	385	550	80
	G385TF	385	550	80
	G440	440	590	80

3.4 Labor-Saving Technologies

3.4.1 Lateral buckling restrained steel beam

The lateral buckling restrained steel beam is shown in outline in **Fig. 9**. This is a method that reduces member and part fitting work at the construction site, and makes it possible to omit the small beams that had been required conventionally as stiffening members and the knee braces that were attached to the beam ends by lateral buckling restraint effects of beams by floor slabs into consideration. In particular, because fitting of knee braces is extremely complicated site work, this construction method is thought to make a large contribution to labor-saving at construction sites.

3.4.2 Reduced thickness fire-resistive covering method for steel frame columns

The shortage of skilled workers (fire-resistive covering workmen) who can perform fire-resistive covering work in steel frame construction has also become one pending issue at construction sites. To reduce the man-hours for fire-resistive covering work for steel frame columns, JFE developed a fire-resistive covering method that reduces the thickness of the fire-resistive covering, as shown in **Fig. 10**, and supplies this product to the market. This method makes it possible to reduce

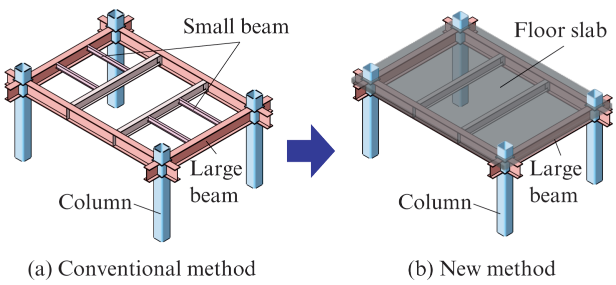

Fig. 9 Method of restrain lateral buckling of steel beam

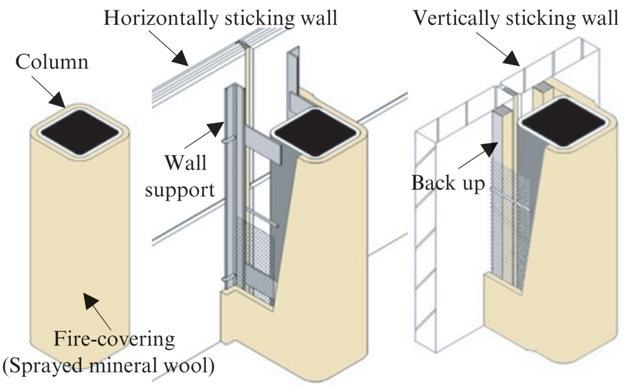

Fig. 10 Fire-resistive covering method which reduces thickness of fire-resistive covering
(The specification example of sprayed mineral wool)

the conventional thickness of the fire-resistive covering by 40% or more. Since this not only saves labor, but also has various other merits for the customer, such as reducing material and installation costs, increasing rental income by increasing the effective habitable area, and reducing environmental loads, use in an increased number of projects is expected in the future.

3.4.3 Composite slab method using deck plates

RC floor slabs and composite slabs using deck plates are mainly used in the floor slabs of steel frame buildings. On the other hand, RC floor slabs have been widely used in RC buildings, but adoption of composite slabs using deck plates has begun to increase from the viewpoint of construction site labor-saving due to the shortage of formwork workmen in recent years. For this application, JFE supplies "QL Deck," a deck plate product which is used in composite slabs and been well-liked for many years. In addition, based on the trends toward higher-rise and larger-scale buildings in recent years, JFE has obtained fire-resistance certification which expands the slab span and load-resistance performance, and supplies this product to the market.

4. Conclusion

JFE has contributed to improvement of social capital through commercialization of civil engineering and construction products based on a clear view of recent trends and customer needs in the construction market. Against the background of robust demand, products with excellent safety and economy and technical proposals based on high technical capabilities are now demanded. Moreover, improvement of social capital from the viewpoints of "Countermeasures for large-scale disasters," "Countermeasures for a low birthrate and aging population" and "Renovation of existing infrastructure" is also required. In the future, JFE will continue to make timely proposals of products and construction methods that meet these needs in the construction market while also satisfying both safety and economy.

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