Development of New H-Section Steel Shape with Inner Rib, "J-grip H," and Its Application to Steel Concrete Composite Diaphragm Wall†

ONDA Kunihiko[*1] KOJO Rinya[*2] AOKI Hidemi[*3]

Abstract:

JFE Steel has developed new H-section steel shapes, J-grip H, which shows excellent adhesion performance with concrete materials, due to ribs formed inside flange during hot rolling and applied to the steel-concrete (SC) composition diaphragm walls as the wall body. J-grip H greatly contributes to cost reduction by thinning wall thickness of SC composition structure. This paper describes manufacturing methods, basic mechanical data of SC composition structure, such as adhesion and bending performance, and an example of actual application of J-grip H at the examination construction of the Nakanoshima new line.

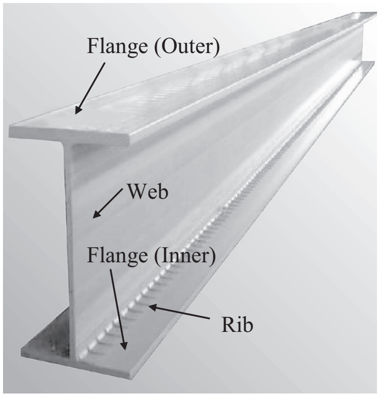

Photo 1 J-grip H

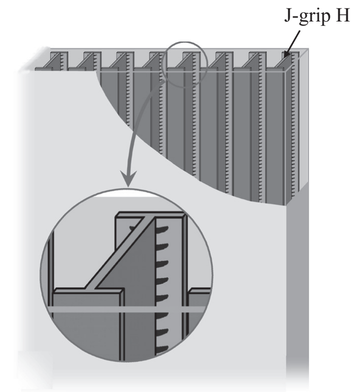

Fig. 1 Steel- concrete composition diaphragm walls

1. Introduction

Steel and concrete have a mutually complementary relationship in civil engineering and building structures, and steel-concrete composite structures generally contribute to rationalization of structures.

In recent years, the demand for rationalization of structures contributing to cost reduction has become particularly strong. To meet this need, JFE Steel developed "J-grip H" (**Photo 1**) as a specialized steel product for use in composite structures based on a unique technology, with the aims of achieving further labor-savings in construction and strengthening cost competitiveness. As a construction method for underground projects such as subways and underpasses in urban areas, which have being constructed at increas-

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*2 Senior Researcher Manager,
Rolling & Processing Res. Dept.,
Steel Res. Lab.,
JFE Steel


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


*3 Staff Manager,
Shape Sec., Products Design & Quality Control for Steel Products Dept.,
West Japan Works (Kurashiki),
JFE Steel

ingly greater depths, JFE Steel and Obayashi Corporation jointly developed a Steel-Concrete Composite Diaphragm Wall Construction Method (**Fig. 1**) using "J-grip H" as the core material.

2. Manufacturing Method and Shape of "J-grip H"

2.1 Manufacturing Method

The shape of the ribs of "J-grip H" is formed by a rolling method. As shown in **Fig. 2**, grooves are machined in the side faces of horizontal rolls from the corner part, and ribs are formed by transferring this shape to the inner surface of the flange of H-section steel shapes during finishing universal rolling. At this time, the formed ribs will not be crushed at the delivery side of the rolling mill as the groove shape is formed in a curved shape[1]. In comparison with production by conventional built-up methods by welding and similar techniques, this rolling method enables high efficiency production of H-section steel shapes with ribs on the flange inner surfaces.

2.2 Selection of Optimum Rib Shape

As ribs are formed by rolling, there are restrictions on the sizes of the ribs which can be formed (**Fig. 3**). The optimum rib pitch was studied assuming a rib height of 3 mm or less, rib length of 50 mm or less, and rib width of 12.5 mm or more.

Here, it is assumed that the area of bearing pressure increases as the height and length of the ribs become larger, resulting in an increased adhesive capacity. Accordingly, the maximum dimensions of 3 mm and 50 mm, respectively, were set as the optimum target shape. As the rib width, because the area that contributes to shear strength of the concrete decreases as the rib width increases, and shear failure of steel is difficult to imagine with a rib width of 12.5 mm, the minimum value of 12.5 mm was selected as the optimum target shape.

To determine the rib pitch, an adhesion experiment were carried out with rib pitches of 50, 100, and 150 mm.[2] It was found that the maximum adhesive force increases as the rib pitch becomes larger, and adhesive rigidity increases as the rib pitch becomes smaller. On the other hand, for composite structure materials, the optimum adhesive properties were studied by nonlinear 2-dimensional finite element method (FEM) analysis[3]. As a result, a rib pitch of 50 mm was selected as the optimum target shape because the case of large adhesive rigidity most nearly approximated perfect adhesion.

2.3 Size Repertory

The size repertory of "J-grip H" is shown in **Table 1**.

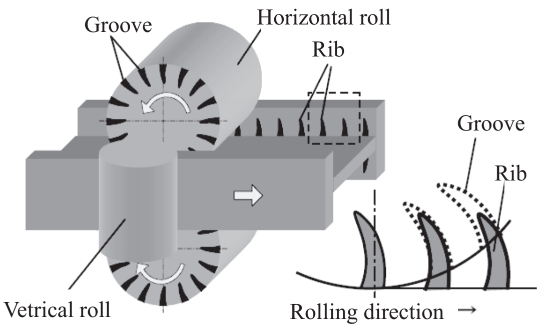


Fig. 2 Formation method of ribs on H-section steel shape by universal finishing mill

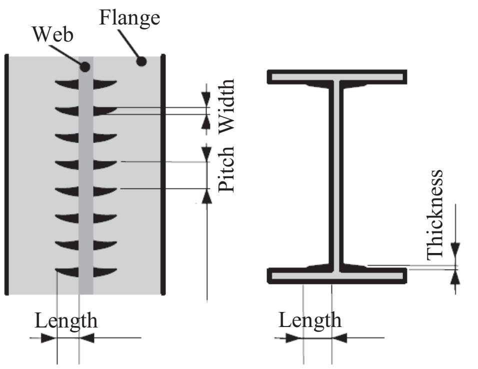
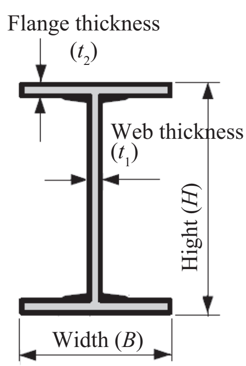


Fig. 3 Definition of the rib specifications

Table 1 Size repertory of J-grip H

Height (H)	Width (B)	Web thickness (t_1)	Flange thickness(t_2)
610	300	12	25
616	302	14	28
624	304	16	32
632	307	19	36
640	307	19	40
690	300	13	25
696	301	14	28
704	303	16	32
712	306	19	36
720	306	19	40



3. Application to Steel-Concrete Composite Diaphragm Wall

3.1 Current Status of Diaphragm Wall Construction Methods and Related Issues

In recent years, there has been a tendency to construct underground structures such as subways and underpasses at increasingly great depths in urban areas, heightening the necessity of underground walls with a combination of high bearing capacity/high rigidity and economy. Furthermore, since it is becoming more difficult to secure surface land, construction technologies for underground space which are economical and enable space-saving are also demanded.

The diaphragm wall construction method enables highly precise excavation even at great depths, and has an extensive record of use as a high reliability underground wall construction method with excellent structural performance. However, with the conventional reinforced concrete (RC) diaphragm walls, there is a tendency toward thick walls and overcrowded arrangement of reinforcements as underground structures become larger and are constructed at greater depths. This results in problems in securing land for construction and problems of executability. In many cases it is also difficult to secure the work yards necessary for fabrication of cages and other work in urban areas.

The "Steel-Concrete Composite Diaphragm Wall Construction Method" was developed in order to solve these problems, and makes it possible to achieve high bearing capacity and high rigidity with a thin wall thickness. The wall of the steel-concrete composite structure, which is integrated with the concrete using "J-grip H" for composite structures, is suitable for large-scale excavation under difficult land conditions in urban areas.

3.2 Features of Construction Method

(1) Realization of Cost Reduction by Reducing Wall Thickness

As shown in **Fig. 4**, a Steel-Concrete Composite Diaphragm Wall with a wall thickness of 900 mm is capable of demonstrating the same moment of resistance (bending moment) as an RC diaphragm wall with a thickness of 1 400–1 500 mm, and rigidity comparable to that of a 1 100 mm RC diaphragm wall is also possible. As a steel-concrete composite structure, this wall also has high toughness and can be applied to structures which require earthquake resisting.

In cases where the specifications of an underground wall are decided by bearing capacity, a large reduction in wall thickness is possible, and the construction costs of the underground wall can be reduced by 20–30%. When the specifications of an underground wall are determined by rigidity due to strict limitations on the displacement of the temporary sheathing, for example, in construction near neighboring structures, the wall thickness reduction is on the order of 20 cm, and the cost is substantially the same. However, additionally, this method has large merits, particularly in the construction of underground space in urban areas, such as reduction of land costs by reducing the wall thickness of structures. In impervious walls, in cases where the toe of the diaphragm wall becomes long, and there are many sections that do not require a thick wall for stress-related reasons, this method has a large wall thickness reduction effect.

(2) Integration with Concrete by Inner Ribs

A confining effect of the two opposing flanges is

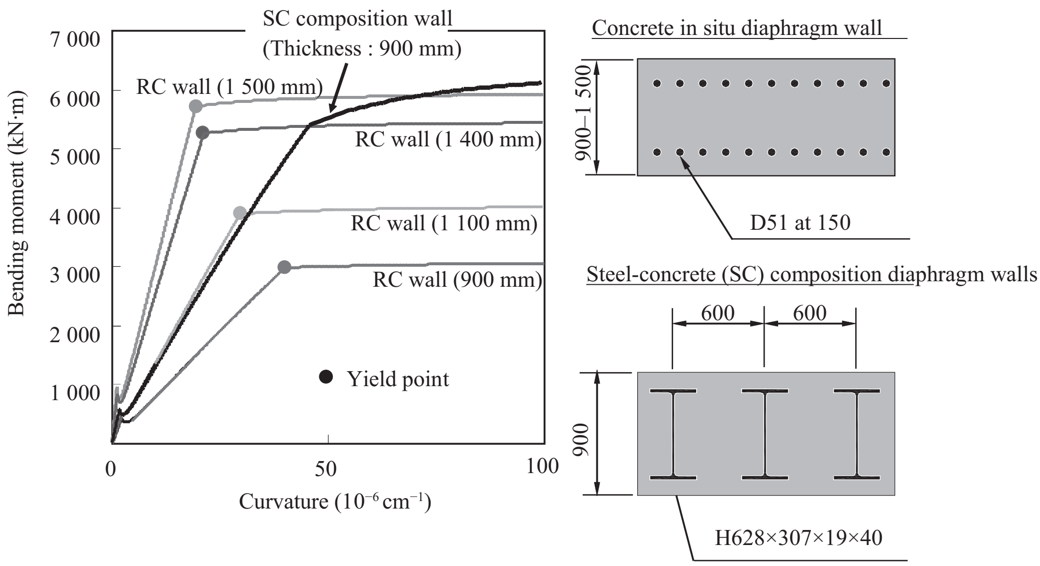


Fig. 4 Effect of wall-thickness reduction

demonstrated as a result of the web reaction force when ribs are provided on the flange inner faces, and the structure displays a tenacious adhesive property even at after reaching maximum strength. Regarding adhesive capacity, because this is a bearing pressure-type wall in which the ribs catch the concrete, sufficient bearing capacity can be obtained even in concrete pouring in a mud flow. In addition to the fact that reinforcements are not necessary for integration, placement of the H-section steel shapes in one piece units is also possible, solving the problem of yard space necessary for cage fabrication.

4. Adhesive Capacity

In composite structure walls like those with this construction method, the largest problem is integration of the concrete and steel. Therefore, a push out test[4] was performed in order to evaluate the adhesive capacity with concrete.

4.1 Experimental Method

The loading method was monotonous push-out loading by displacement control. An outline of the loading method is shown in **Fig. 5**. Specimens were prepared by using the "J-grip H" flange and bottom 50 mm of the web as a block-out box so that the concrete would be in contact with only the inner face of the "J-grip H." Using these specimens, adhesive capacity was evaluated by measuring the relative displacement between the steel and the concrete when loading was applied to the top edge of the H-shape. With this construction method, the adhesive property becomes a problem when there is a confining effect between the two opposing flanges. Therefore, a cross section of an H-shape was used as the test specimen. Since the concrete strain in the minor axis direction (wall longitudinal direction) of the H-shape becomes very small in diaphragm wall members, displacement in the said direction was confined with a confining device (restriction boards), and the boundary condition is considered to be equivalent to the diaphragm wall member. Because this confining device confines the deformation generated by adhesive force, initial tension is not given.

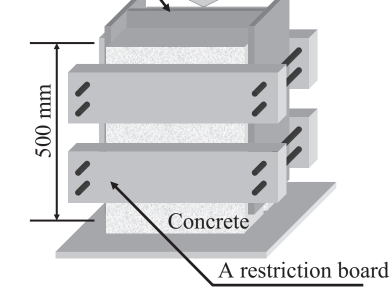


Fig. 5 Push out test

Table 2 Test condition and result

Case	Test condition		Test result			
	Rib shape	Concrete strength (N/mm²)	Load at the maximum, P_{max} (kN)	Quantity of gap (at P_{max}) (mm)	Shear strength (N/mm²)
1	Inner rib order direction	35.6	1 301	5.5	4.53
2		35.6	1 282	5.2	4.45
3		25.2	1 074	6.3	3.73
4		50.2	1 673	7.1	5.81
5	Inner rib opposite direction	36.2	1 377	5.4	4.78
6	No rib	29.0	54	1.4	0.19

In actual underground wall structures, concrete is poured in a mud flow. Therefore, a form release agent was coated on the surface of the steel in advance, considering the possibility that adhesion between the steel surface and concrete might be reduced. An outline of the test conditions and test results is shown in **Table 2**.

4.2 Experimental Results

(1) Adhesive Properties of "J-grip H"

As shown in **Fig. 6**, the maximum shear strength (shear stress) of "J-grip H" was 4.4–4.8 N/mm², which was more than 20 times higher than with the specimen without ribs. Due to the confining effect of web reaction force, there was no brittle decrease in adhesive force even after the maximum value. Good agreement was obtained in the adhesive properties in Case-1 and Case-2, in which tests were performed under similar experimental conditions, thereby confirming the reproducibility of these results. When the condition of the fracture surface was observed after completion of loading, there were no traces showing upward sliding of the ribs on the concrete surface, and for the most part, shear failure had occurred (par-

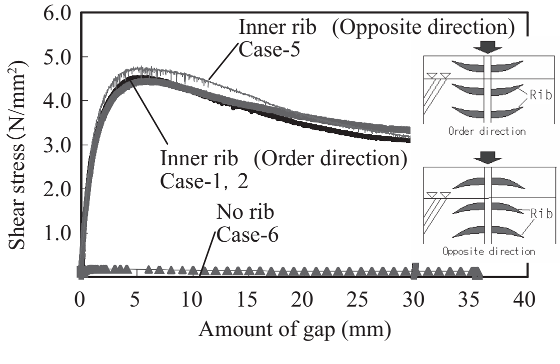


Fig. 6 Relation of shear stress and gap (Rib shape and direction)

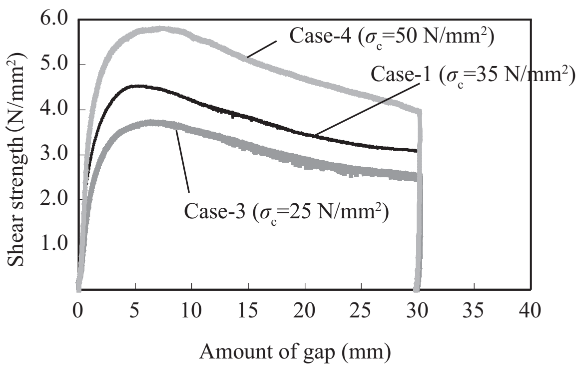


Fig. 7 Relation of shear stress and gap (Concrete strength)

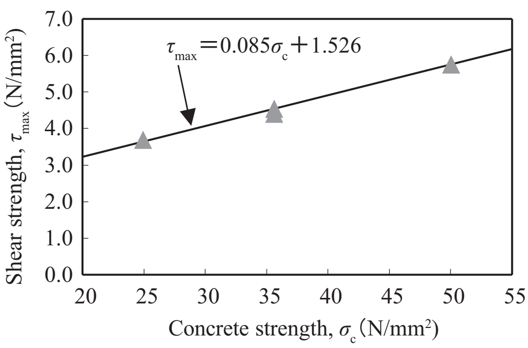


Fig. 8 Relation of shear strength and concrete strength

tial local crushing in the vicinity of the rib tip). This indicated that good interlocking and integration of the ribs and concrete had been achieved.

(2) Effect of Direction of Force Applied to Ribs

No significant differences were found in a comparison of Case-2 and Case-3, in which the direction of the loading applied to the crescent-shaped ribs was changed. From this, it can be said that there are no differences in the adhesive properties of the ribs depending on the rib direction.

(3) Effect of Concrete Strength

From **Fig. 7**, it can be understood that shape of the shear strength-sliding displacement (gap) curve is the same, independent of the compressive strength of the concrete, and there are no large differences in adhesive properties related to concrete strength. It was shown that adhesive strength increases with the increase in the compressive strength of the concrete σ_c, and as shown in **Fig. 8**, the relationship between σ_c and the maximum shear strength τ_{max} can be approximated with good accuracy by a first-order equation ($\tau_{max} = 0.085\sigma_c + 1.526$).

5. Bending Performance of Steel-Concrete Composite Diaphragm Wall

A bending test[5)] was performed with actual size specimens, and performance as steel-concrete composition members was evaluated.

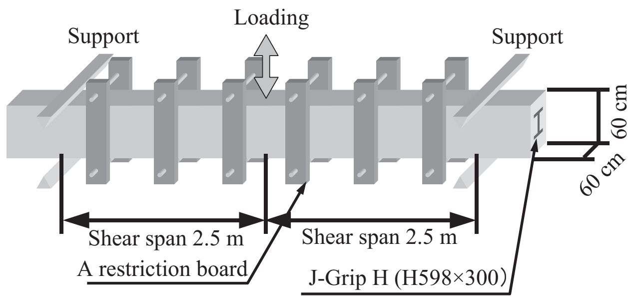


Fig. 9 Bending test (Steel-concrete composition beam)

5.1 Experimental Method

Figure 9 shows an outline of the loading method. Repeated alternate positive-negative bending by 1-point loading was applied. The test specimens were 80 cm in height, and a width of 60 cm was used, as this is the standard pitch of H-shapes in the diaphragm wall method. The distance from the support point to the loading point (shear span) was 2.5 m. In actual diaphragm walls, H-shapes are arranged continuously in the horizontal direction, and the horizontal strain of the concrete is confined. Therefore, the lateral deflection of the specimens was restrained as much as possible by confining the specimens between restriction boards using square steel pipes. For control of loading, the yield deflection δ_y was used as a standard, and deflection was increased in steps of $1\delta_y$ ($1\delta_y$, $2\delta_y$, $3\delta_y$, $4\delta_y$, . . .) until $10\delta_y$ was reached. The number of repetitions was 3 cycles/step up to $4\delta_y$, and 1 cycle/step thereafter. After $10\delta_y$, the deflection was increased at a pitch of $3\delta_y$, and this was continued as far as possible within the limits of the test machine. The yield deflection δ_y (=11 mm) was the loading point deflection when the flange of the H-shape (tension side of load point) reached yield stress (test value of material strength).

5.2 Experimental Results

Figure 10 shows the load-deflection relationship at

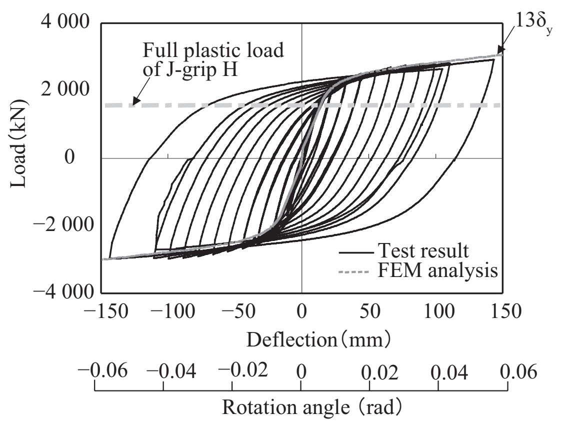


Fig. 10 Relation of load and deflection (Rotation angle)

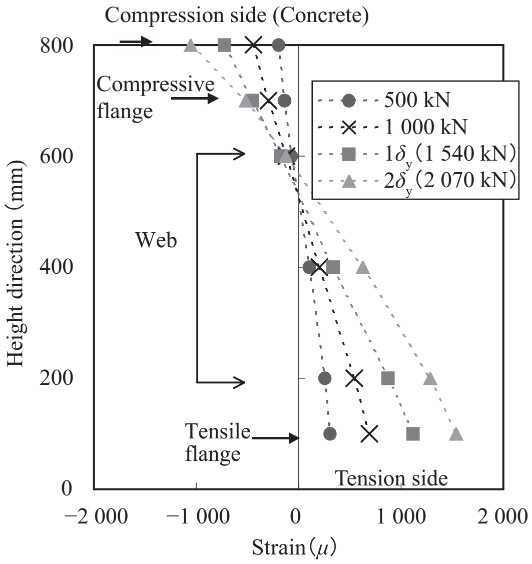


Fig. 11 Strain distribution in the section direction

the loading point position. No load reduction occurred under loading up to 13δ_y (=143 mm, rotation angle: 0.057 rad). A clear oval figured type loading loop shape was seen even after deflection had progressed, confirming that this wall has an excellent energy-absorbing capacity.

The envelope of the experimental results and the FEM analysis values using the adhesive property between the steel flange and concrete obtained in a previous adhesion experiment showed good agreement in initial flexural rigidity, flexural rigidity after yielding, and bearing capacity, and greatly exceeded the total plastic load of the H-shape itself, showing the expected behavior of a composite structure.

Figure 11 shows the strain distribution in the axis direction within the section at a position 1 000 mm from the loading point. The neutral axis is positioned on the compression side from the center of the specimen section, and shifts in the direction of the compression side as the load level increases. The composition effect can also be confirmed from this result.

Photo 2 A view of construction

6. Construction Test

In 2003, a construction test of a Steel-Concrete Composite Diaphragm Wall was carried out in the "Study of Effects of Open Cut in Nakanoshima New Line Improvement Project" (**Photo 2**). Executability, including the placement of the core material ("J-grip H") and concrete pouring, and the formation of the diaphragm wall were confirmed[6,7]. As shown in **Fig. 12**, the core material ("J-grip H") was placed in 1 piece unit while fixing the positions of these members in the wall thickness direction and extension direction with spacers. Concrete was poured by inserting tremie pipes between each pair of core elements (**Photo 3**). As shown

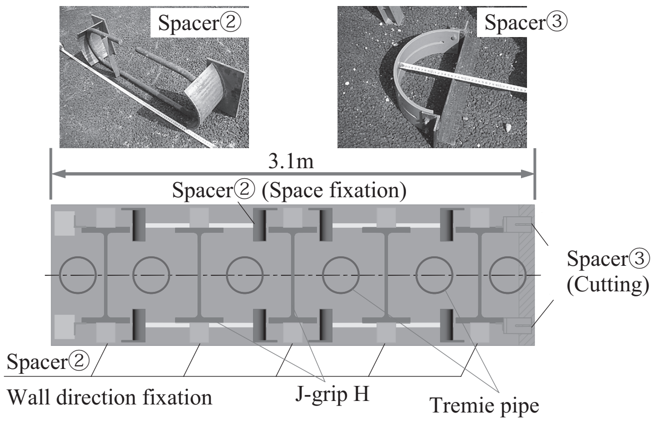


Fig. 12 The placement of J-grip H and spacer

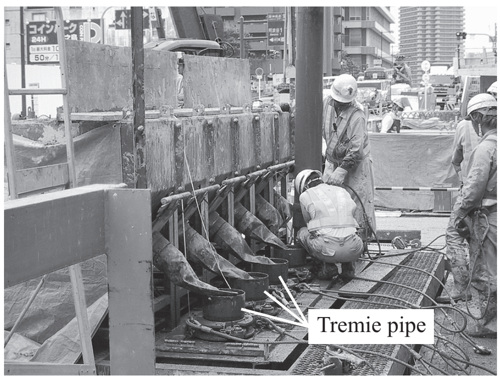


Photo 3 Concrete pouring

Photo 4 Formed surface of diaphragm walls (GL: −16.0 m)

in **Photo 4**, the formation of the diaphragm walls was extremely good, with no leakage, confirming that concrete was adequately circulated through the structure.

7. Conclusion

An experimental study was carried out, demonstrating that "J-grip H" has a tenacious adhesive property with concrete, and Steel Concrete Composite Diaphragm Walls using this H-section steel shape provide outstanding performance as a steel-concrete composite structures. An actual construction test was also conducted with satisfactory results, contributing to practical application of this construction method. In the future, the authors plan to study further improvements in this construction method, such as methods of concrete pouring, while increasing the examples of application to actual construction projects.

In closing, the authors wish to note that this development was carried out as joint research with Obayashi Corporation, and express their deep appreciation to all those concerned.

References

1) Kojo, Rinya et al. Development of H shapes with ribs on the inside of flanges. CAMP-ISIJ. 2006, vol. 19.
2) Tatsumi, Yuichi et al. Experimental study on the adhesion characteristic of concrete and H shapes with ribs on the inside of flanges. Proceedings of the 58th Annual Conference of the JSCE. 2003, vol. 58.
3) Takeda, Atsushi et al. Flexural behavior of SC-composite diaphragm wall. Proceedings of the 58th Annual Conference of the JSCE. 2003, vol. 58.
4) Onda, Kunihiko et al. Development of SC-composite diaphragm wall with the H shapes with ribs on the inside of flanges (Part 1). Proceedings of the 59th Annual Conference of the JSCE. 2004, vol. 59.
5) Yamaguchi, Akira et al. Development of SC-composite diaphragm wall with the H shapes with ribs on the inside of flanges (Part 2). Proceedings of the 59th Annual Conference of the JSCE. 2004, vol. 59.
6) Takeda, Atsushi et al. Development of SC-composite diaphragm wall with the H shapes with ribs on the inside of flanges (Part 3). Proceedings of the 59th Annual Conference of the JSCE. 2004, vol. 59.
7) Higashino, Mitsuo et al. Development of SC-composite diaphragm wall. Proceedings of the Civil Engineering Construction Technology Symposium. 2005.