Development of High Performance Composite Wall "J-WALL II"

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ABSTRACT

J-WALL II is a construction method that uses steel sheet piles (product name: Beetle pile) as a temporary retaining wall, then integrates them with the reinforced concrete part after ground excavation to construct a composite underground wall. Here, "Beetle pile" is a new steel sheet pile formed by joining T-shaped steel and fixing a reinforcing bar to a hat-type steel sheet pile. A T-shaped steel and a fixing reinforcing bar function as a shear connector when joining the temporary retaining wall and the reinforced concrete part. Main features of J-WALL II are as follows. 1) Saving construction space and shortening construction period. 2) Favorable for construction in a narrow space. 3) Composite wall having excellent structural performance. In order to confirm the performance of the J-WALL II construction method, we conducted following investigations. (1) It was confirmed that there was no difference in press-in resistance and construction speed compared with the conventional hat-type steel sheet piles by the installation test of new steel sheet piles for a composite wall "Beetle pile" by the Silent Pillar (Press-in Method). (2) Strength of the shear connector part of J-WALL II was confirmed by a punching shear test between the "Beetle pile" and the reinforced concrete part. And we built the design method of the shear connector part. (3) By a bending test of the actual J-WALL II structural member, we confirmed that the wall body can be designed as an integral wall structure (complete composite wall) up to the ultimate limit state.

Key words: *Composite wall, steel sheet pile (H-type), Silent Pillar (Press-in Method), Shear strength*

1. Introduction

Construction of an outer wall of an underground road approach such as a three-dimensional intersection is often carried out under difficult construction conditions (eg. narrow space, upper obstacles etc.). Normally, after constructing a temporary soil fastening wall, a method of constructing another main wall (mainly an RC structure) has been adopted, but shortening of the construction period and cost reduction are desired. The J-WALL II construction method uses a steel sheet pile for synthetic structure (product name: Beetle Pile) as a temporary soil retaining wall and integrates it with a reinforced concrete wall after excavating the ground, so that it has a thin wall thickness, high rigidity and high strength. It is a technology to realize an underground wall. Furthermore, it is possible to shorten the construction period and a construction in a narrow space than the existing construction method. In this paper, we first describe the technical outline and features of the J-WALL II construction method. In addition, we report construction experiments and structural experiments conducted to confirm the performance of the J-WALL II construction method.

2. J-WALL II construction method

2.1. Outline of J-WALL II construction method

The J-WALL II construction method uses a steel sheet pile for a composite structure (product name: Beetle Pile) as a temporary soil retaining wall and integrates it with a reinforced concrete wall after excavating the ground (=post constructed RC wall), so that it has a thin wall thickness, high rigidity and high strength. It is a technology to realize an underground wall (**Fig. 1**).

"Beetle pile" is a new steel sheet pile in which a T-shaped steel and a fixing reinforcing bar are welded to a hat-shaped steel sheet pile (**Fig. 2**). A T-shaped steel, a fixing reinforcing bar, and a shear reinforcing bar (penetrating the web of T-shaped steel) are used as a shear connector with a post constructed RC wall (**Fig. 3**). With the above function, J-WALL II can demonstrate its performance as a strong composite structure up to the ultimate limit state. **Table 1** shows cross-sectional performance of the Beetle Pile. Hat-type steel sheet piles JFESP-25H and JFESP-10H are applied to the steel sheet piles constituting the Beetle pile. The size of the T-shaped steel is based on a flange width of 204 mm and a web height of 106 mm so as to be compatible with the gripping structure (chuck) of an existing low vibration / low noise type hydraulic press-fitting machine. **Fig. 4** shows the sectional shape of the Beetle Pile.

2.2. Feature of J-WALL II construction method

Main features of The J-WALL II construction method are as follows.

① Saving construction space and shortening construction period

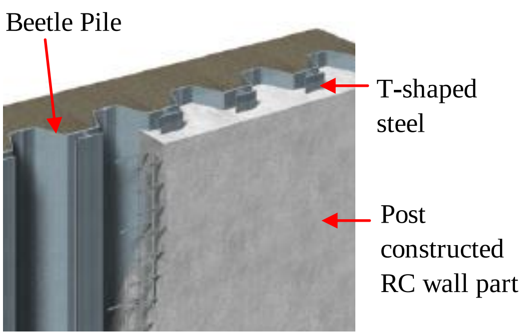


Fig. 1 J-WALL II construction method

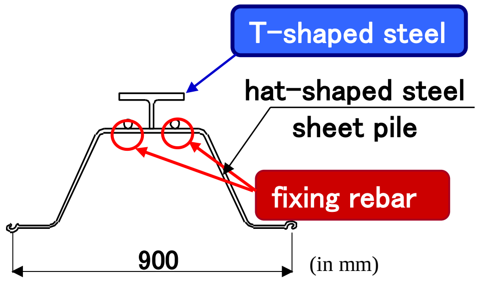


Fig. 2 Outline of Beetle pile

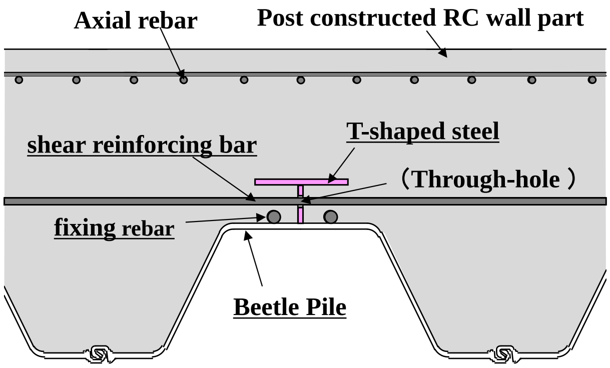


Fig. 3 Section of J-WALL II

Table 1. Cross - sectional performance of the Beetle Pile

Type	Sectional area	Moment of inertia	Section modulus
	cm²	cm⁴	cm³
"B-25H" 【T-shaped】 +【JFESP-25H】	192.32	41,836	2,123
"B-10H" 【T-shaped】 +【JFESP-10H】	158.31	23,158	1,438

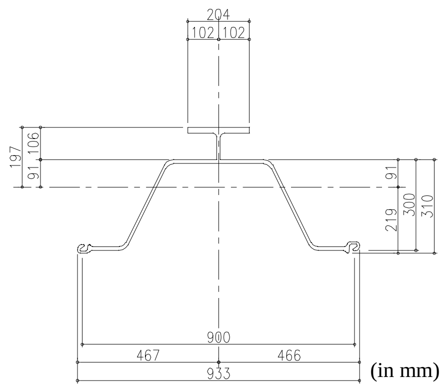


Fig. 4 Sectional shape of the Beetle Pile (B-25H)

By using the steel sheet pile as both a permanent structure and a temporary structure, it is possible to reduce the required width of the work and the thickness of the underground wall compared with the existing construction method. Therefore, it is possible to effectively utilize the site. And The construction quantity of the underground wall construction and the process can be reduced.

②Construction in a narrow spot

It can be constructed by the Silent Pillar (Press-in Method) as the ordinary steel sheet pile, and it is possible to construct at a narrow place.

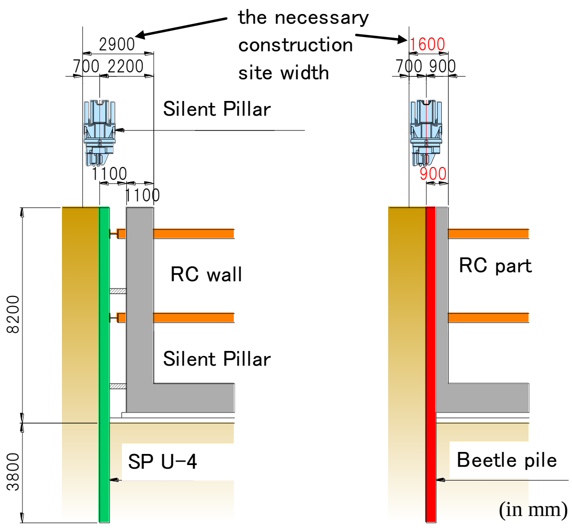
③Composite wall

It is an underground wall integrating "Beetle pile" and the reinforced concrete part constructed after excavating the ground, to realize high rigidity and high proof strength as a complete composite structure, realizing a thin wall.

The comparison between the existing construction method in which the temporary soil fixing wall and the main site bottom wall are constructed with different structures and the J - WALL II construction method are shown in **Table 2** and **Fig. 5**. In the existing construction method, after using the U-shaped steel sheet pile IV as a temporary soil closure, a cast-in-place reinforced concrete wall (t = 1100 mm) is constructed as the main wall, and finally the necessary construction site width becomes B = 2900 mm .On the other hand, in the J-WALL II construction method, the construction width is B = 1600 mm because it is constructed with an integral wall structure of Beetle Pile and Reinforced Concrete Wall (t = 900 mm). Therefore, it can be reduced by 55% compared with the existing construction method.

Table 2. Comparison with the existing construction method

	(a) Existing method	(b) J - WALL II
Temporary soil retaining wall	Steel sheet pile U shaped-4	Beetle Pile B-25H
Permanent Wall	cast-in-place reinforced concrete wall (t=1100mm)	Integral wall of Beetle Pile and RC Wall (t=900mm)
Construction period		The following steps can be omitted. ・Assembly and dismantling of outer scaffold and formwork ・Backfill process



(a) Existing method (b) J - WALL II

Fig. 5 Comparison with the existing construction method

3. Installation test of Beetle Pile

3.1. Outline of Installation test

In order to confirm the workability of the Beetle Pile, we conducted an installation test and compared it with a conventional hat-shaped steel sheet pile. The Beetle pile used for the test consists of a hat-shaped steel sheet pile (25 H) and a T-shaped steel (106 × 204 × 12 × 18), and its length is L = 15 m. For further comparison, a hat-shaped steel sheet pile (25 H) L = 15 m was also prepared. The test number and test conditions are shown in **Table 3**. The appearance of the Beetle pile is shown in **Photo 1**. The installation test was carried out by Press-in Method（Silent Pillar ECO900 / Power unit EU 300）. SP No. ① and ② (Joint Fitting: ×) were installed as single pile. Other SP No. (Joint Fitting: ○) were installed while fitting joint of next sheet pile installed previously. In the installation test, the Press-in force, installation time and available length were measured. The situation of the press-in installation test is shown in **Photo 2**. **Fig. 6** shows the Boring log of the installation test site (the groundwater level is deeper than GL - 25 m). The ground composition of the press-in installation test site is a soft loam / clay layer from the surface layer to the depth of about 10 m. However, at depths of more than 10 m, it becomes a tight fine sand layer, and the press-in resistance increases. And it was expected that installation will be difficult.

3.2. Result of Installation test

The results of press-in installation test on Beetle Piles and hat-shaped steel sheet piles are shown in **Table 4**. The length that could be finally cast by the press-in machine was about 12 m for both the Beetle piles and the hat steel sheet piles. Furthermore, the arrival time to the depth of 10 m (loam / clay layer) (casting time) was 300 sec - 400 sec. From these facts, it was found that the workability of the Beetle piles is the same level as the workability of the hat -shaped steel sheet piles. **Fig. 7** shows comparative examples of press-in resistance (press-in force) of Beetle Piles and hat-shaped steel sheet piles. It can be seen that in each case with or without joint fitting, the press-in resistance of Beetle Piles and hat-shaped steel sheet piles at each casting depth were about the same.

Table 3. Condition of Installation test

	SP No.	Length of SP	joint fitting
Hat shaped-25H	①	15.0m	×
	②	15.0m	○
	③	15.0m	○
Beetle Pile B-25H	④	15.0m	○
	⑤	15.0m	○
	⑥	15.0m	○
	⑦	15.0m	○
	⑧	15.0m	×
	⑨	15.0m	○

Photo 1. Beetle pile

Photo 2. Situation of installation

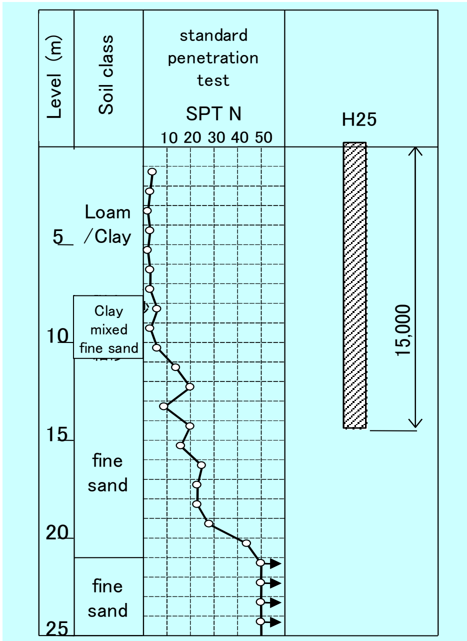
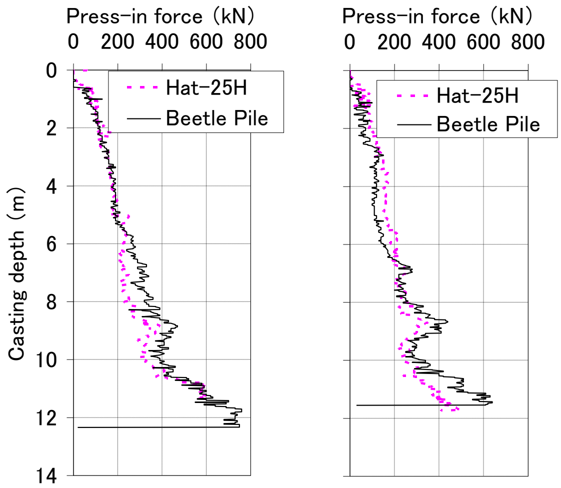


Fig. 6 Boring log of the installation test site

Table 4. Result of Installation test

	SP No.	joint fitting	length could be finally cast	arrival time to the depth of 10 m
Hat shaped-25H	①	×	12.5m	380sec
	②	○	12.1m	280sec
	③	○	11.4m	434sec
Beetle Pile B-25H	④	○	12.4m	329sec
	⑤	○	11.6m	413sec
	⑥	○	11.1m	418sec
	⑦	○	11.1m	276sec
	⑧	×	11.8m	321sec
	⑨	○	13.0m	324sec



(a) joint fitting (b) without joint fitting

Fig. 7 Press-in force of Beetle Pile and hat-25H

4. Shear strength of the shear connector part of J-WALL II

4.1. Outline of punching shear test

A punching test was conducted to evaluate the integrity of the steel sheet piles and the post constructed RC wall (**Photo 3**). The specimen had a symmetrical shape with two steel sheet piles facing each other so that it could push evenly. The bottom end of the steel sheet pile and T shape steel was preliminarily box-pulled out, only the concrete was grounded, and at the upper end only 150 mm of the steel sheet pile protruded, and we applied it here (**Fig. 8**). **Table 5** shows test specimen conditions and experimental results (shear strength). In this experiment, we mainly checked the influence of shear reinforcing bar (penetrating the web of T-shaped steel) sizes and the concrete strength. In each of the cases, two fixing bars were installed in the web of the steel sheet piles (single-sided flare welding).

4.2. Result of punching shear test

The test results are shown below.

(1) Failure mode

In either case, the shear strength decreased after shear failure of one side of the concrete from the tip of the T-shaped steel flange to the end of the steel sheet pile web. On the other hand, adhesion performance around the fixing rebars was maintained, and removal of the reinforcing bars was not observed (**Photo 4**).

(2) Influence of shear reinforcing bar size

According to **Fig. 9**, except for the case where the shear reinforcing bar is D25, the tensile yield load of the shear reinforcing bar (sum of four bars) and the experimental shear strength increment (Case D0-F30 shear strength subtracted) correspond to 1: 1. In the case of D25, one-sided shear failure of the concrete eventually occurred along the position of the reinforcement (**Photo 5**). It seems that destruction progressed in the following process, and the Shear strength increment became small. ① occurrence of split crack → ② reduction of adhesion and binding force of reinforcing bars → ③ occurrence of one-sided shear failure. It means that bonding between shear reinforcing bar and concrete reached limit before shear reinforcing bar got yield in the case of D25.

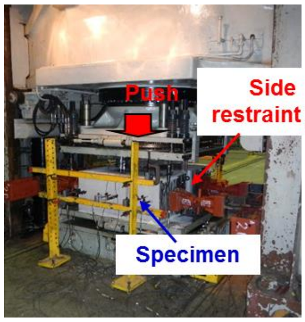


Photo 3. Punching shear test

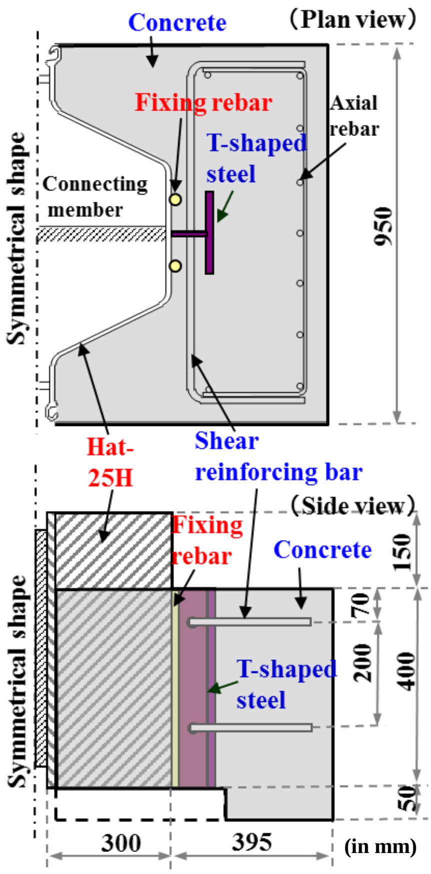


Fig. 8 Specimen of punching shear test

Table 5. Case of I punching shear test

Case	Shear reinforcing bar	Concrete compressive strength (MPa)	Shear strength (kN/m)
D13-F30	D13	29.3	1260
D16-F30	D16		1412
D19-F30	D19		1521
D25-F30	D25		1670
D16-F40	D16	38.2	1721
D16-F48	D16	47.8	1767
D0-F30	No reinforcement	29.0	1009

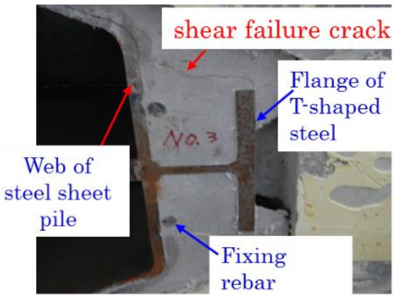


Photo 4. Failure mode

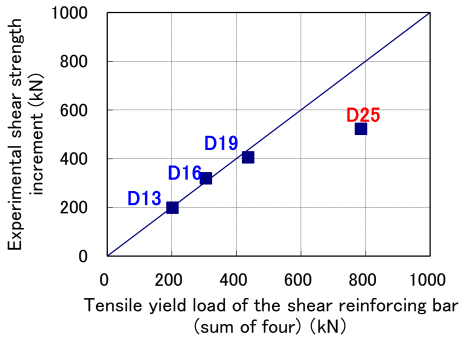


Fig. 9 Strength increment by shear reinforcing bar

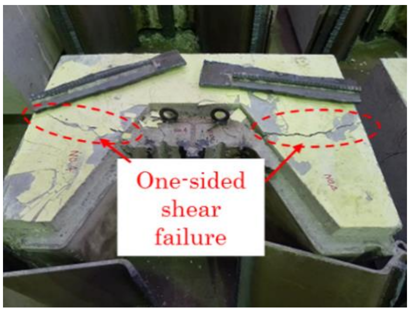


Photo 5. Failure mode (case of D25-F30)

(3) Influence of Concrete Strength

Fig. 10 shows the relationship between concrete compressive strength and shear strength. When the concrete compressive strength increased from 29.3 (D19-F30) to 38.2 N / mm 2 (D16-F40), an increase in shear strength could be confirmed but the strength ceased at 47.8 N / mm 2 (D16-F48).

4.3. Evaluation method of 4. Shear strength of the shear connector part

We evaluated the shear strength of the shear connector part of J-WALL II (converted to per meter length of beetle pile) by applying the concrete joint strength type equation (case of integral casting) derived from Okada's research1). **Fig. 11** shows the comparison of the concrete joint strength formula (in the case of integral casting) presented in **Eq. (1)** in Okada's research [1] with this experimental result. Except for the case of the shear reinforcing bar D25, it was confirmed that the experimental result exceeds the strength formula value.

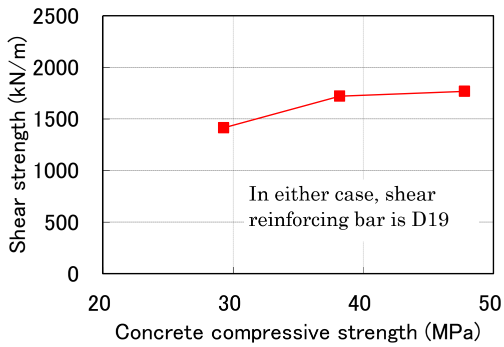


Fig. 10 Relationship between concrete compressive strength and shear strength

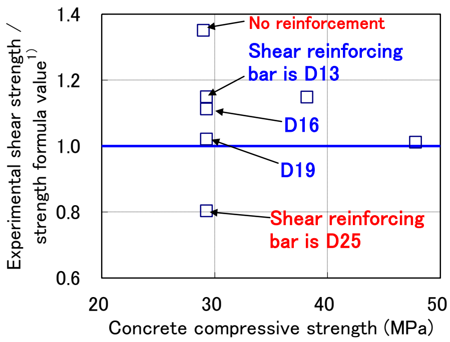


Fig. 11 Comparison of Experimental shear strength and strength formula value

$$Q_s = 0.18 \times L_T \times L_H \times f'_{ck} + 1.33 \times n_{sc} \times A_{sc} \times f_{spyk} \qquad (1)$$

L_H : Shear section length (adhesion length) (mm)

L_T : Shear fracture surface length of concrete, The web height of the T-shaped steel × √ 2 may be used (mm)

f'_c: Concrete design standard strength (MPa)

However, ≤ 45 MPa

A_{sc} : Cross sectional area of shear reinforcing bars (per one) (mm^2) However, ≤ 286.5 mm^2

n_{sc} : Number of shear reinforcing bars in the shear section

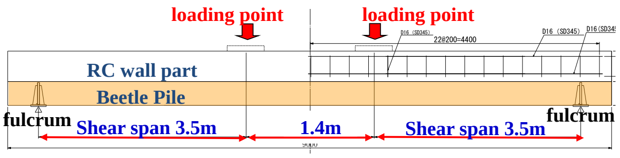
f_{spy}: Characteristic value of tensile yield strength of shear reinforcing bars (MPa)

5. Evaluation of structural performance of composite wall J-WALL II

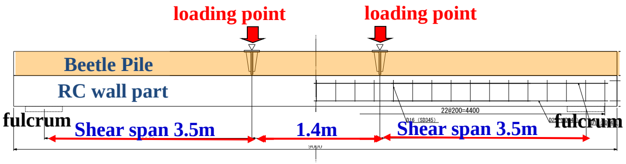
5.1. Bending test of J-WALL II structural member

In order to confirm that the wall composed by the Beetle pile and the post constructed RC wall part behave as a synthetic structure, a bending test of a real size was carried

out. In the test, a total of 2 cases were carried out: a positive bending test C1 (the steel sheet pile positioned on the tensile edge side), and a negative bending test C2 (a steel sheet pile was positioned on the compressed edge side). The outline of the specimen is shown in **Fig. 12**, and the sectional view of the specimen is shown in **Fig. 13**. The cross-sectional height of the post-constructed RC wall (height from the steel sheet pile web position) was 40 cm. The test method was a 4-point bending test, and the distance from the fulcrum to the loading point (shear span) was 3.5 m. In consideration of the restraint of concrete movement in the wall extension direction (horizontal direction) in the underground wall structure, we sandwiched the specimen using two pairs of rectangular steel tubes and constrained the lateral deformation of the specimen (**Photo 6**).



(a) positive bending test C1



(b) negative bending test C2

Fig. 12 Outline of the specimen (bending test)

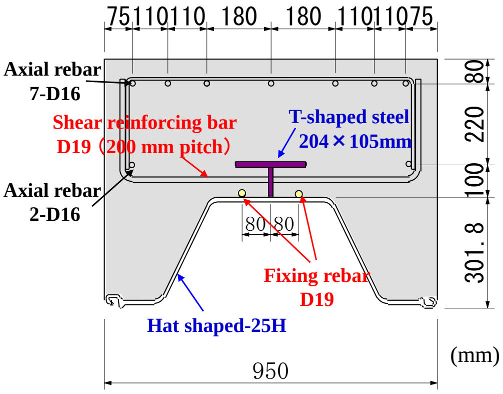


Fig. 13 Sectional view of the specimen (bending test)

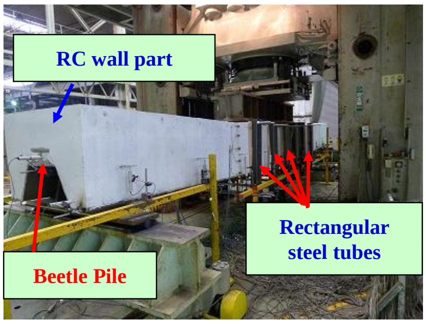


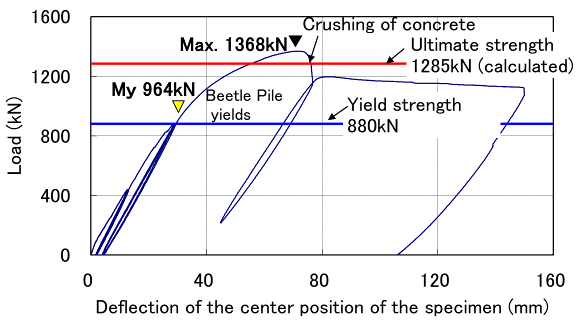
Photo 6. Bending test of J-WALL II

5.2. Result of bending test

Table 6 shows the material strength and the test result (maximum load). **Fig. 14** shows the relationship between

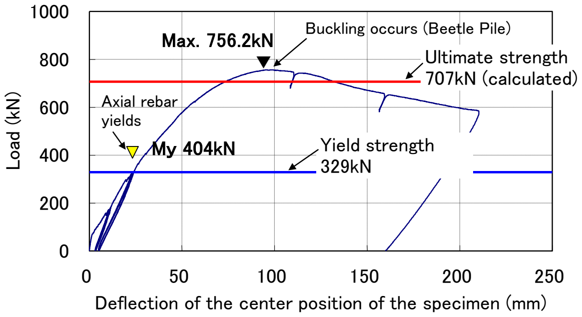
Table 6. Material strength and test result of bending test

Case	Material strength (MPa)			Test result
	Concrete compressive strength	Yield strength of steel sheet pile	Yield strength of axial rebar	Maximum load (kN)
C1	28.0	326	365	1368
C2	25.6			756



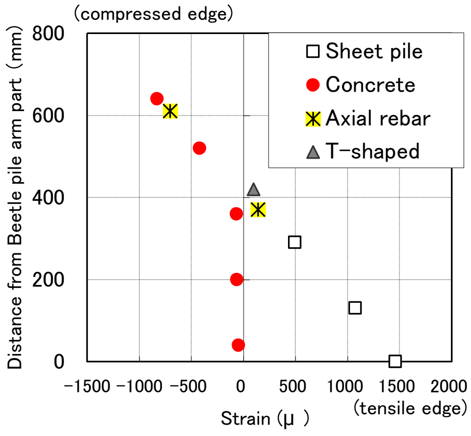
(a) positive bending test C1

Fig. 14 Relationship between the load and deflection of the center position of the specimen

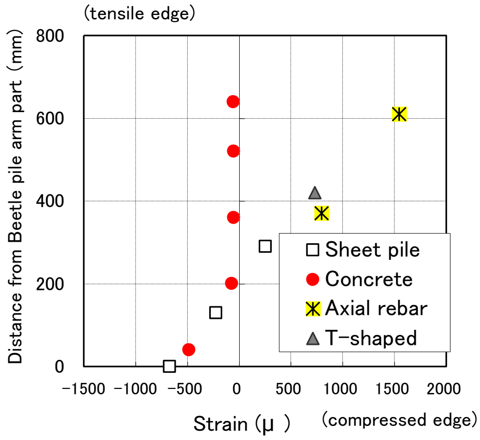


(b) negative bending test C2

Fig. 14 Relationship between the load and deflection of the center position of the specimen



(a) positive bending test C1



(b) negative bending test C2

Fig. 15 Strain distribution in the material axis direction at the yield load

the load and the deflection of the center position of the specimen. In the figure, the yield strength and ultimate strength calculated on the assumption of a perfect synthetic structure (Navier hypothesis) are shown. Steel sheet piles, concrete, axial rebar were modeled taking material nonlinearity into account.

In both cases, the experimental values exceeded the calculated values, and it was confirmed that they possess sufficient structural performance. **Fig. 15** shows the strain distribution in the material axis direction at the yield load of the positive bending test C1. Since the strain distribution shows that the condition of Navier hypothesis is established, it can be confirmed that it behaves as a perfect synthetic structure.

Regarding the fracture behavior of each test specimen, in the positive bending test C1, the load was decreased due to crushing of concrete in the central part of the specimen, but the load did not decrease sharply. In the negative bending test C2, the load gradually decreased with the progress of buckling of the steel sheet pile in the central part of the specimen.

6. Concluding remarks

In order to confirm the performance of the J-WALL II construction method, we conducted various performance confirmation experiments and obtained the following results.

(1) It was confirmed that there was no difference in the press-in resistance and the construction speed compared with the conventional hat-type steel sheet piles by the installation test of new steel sheet piles for a composite wall "Beetle pile" by the Silent Pillar (Press-in Method).

(2) Strength of the shear connector part of J-WALL II was confirmed by punching shear test between the "Beetle pile" and the reinforced concrete part. And we built a design method of the shear connector part.

(3) By the bending test of the actual J-WALL II structural member, we confirmed that the wall body can be designed as an integral wall structure (complete composite wall) up to the ultimate limit state.

References

1) Okada, T. 1994. Study on shear transfer across concrete joint interface. Journal of Japan Society of Civil Engineers, No. 502/V-25, pp. 73-82.