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# Application Expansion to Land Area of "J-Pocket Pile™," Leak-Proof Cut-Off Steel Sheet Pile with Sealed Joints†

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***Abstract:***

*"J-Pocket Pile™," which was developed especially for cut-off walls at sea area waste disposal sites, has been improved in order to expand its applicability at land area. As a result, weight reduction was obtained by combining with the wide-width steel sheet pile, and a new type sealing material was additionally applied. By applying improved shapes of the joint portion, and by conducting an on-site installation test and a water shielding performance test, it was confirmed that it ensures the performance nearly equivalent level to the conventional type.*

## 1. Introduction

"J-Pocket Pile™" is an "Only One" water-shielding steel sheet pile of JFE Steel in which a hollow part (hereinafter, "pocket") having a size of approximately *Φ*10 mm is formed in bottom of the claw part of the joint during hot rolling. A general view and a detail of the pocket are shown in **Photo 1**. The fact that it is possible to avoid damage during pile driving and construct high-reliability cut-off works by installing a sealing material in the pocket is an important feature of "J-Pocket Pile™"[1].

"J-Pocket Pile™" was developed mainly as a vertical cut-off wall for sea waste disposal sites[2], and was commercialized in 2 types, 4WS and 5WS. As a result of the revision of the Soil Contamination Countermeasures Act in 2010 and the Great East Japan Earthquake of 2011, there is now a heightened need for this type of product in land areas, namely, for containment works and cut-off works. However, because "J-Pocket Pile™" was developed for sea waste disposal sites, the section performance of these pile is frequently over-specification when applied to containment works, cut-off works, etc. on land, where large earth pressure does not act on the piles.

Therefore, with the aim of expanding application to land locations, a new type of "J-Pocket Pile™" for land

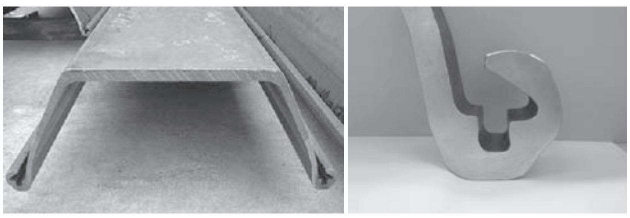

Photo 1 "J-Pocket Pile™"

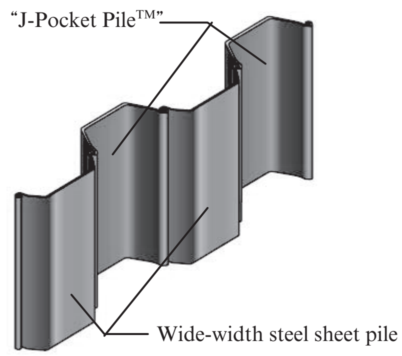


Fig. 1 Schematic figure of "J-Pocket Pile™" for land area

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areas was studied using an alternating arrangement of "J-Pocket Pile™" and conventional wide steel sheet piles, as illustrated in **Fig. 1**. As part of this study, section performance was optimized, and application of bentonite as the sealing material in place of the conventional silicone resin was examined[3)].

This paper presents an outline of "J-Pocket Pile™" for land areas, and describes improvement of the joint shape, which was carried out for use in combination with wide steel sheet piles, an on-site pile-driving performance test, which was performed in application of the new pile to a land area, and an outline of a water-shielding performance test and its results.

## 2. Outline of "J-Pocket Pile™" for Land Areas

### 2.1 Background and Purpose of Study

Until now, the standard practice for water sealing in cut-off works using steel sheet piles was to coat the pile joints with a sealing material. However, the possibility of partial peeling of the sealing material due to friction with the ground and the joint being fitted, and a resulting reduction of the water-shielding property, had been suggested[4)]. Water-shielding performance problems caused by uneven coating of the sealing resin and similar factors were also a concern. Therefore, "J-Pocket Pile™" was developed as a product with dramatically improved reliability in water-shielding performance by forming pockets with a size of approximately $\Phi$10 mm in the joint part during hot rolling, and installing a sealing material inside this pocket.

Because "J-Pocket Pile™" was developed mainly targeting sea waste disposal sites, where demand was foreseen at the time, its cross-sectional profile was decided considering wave pressure during construction and earth pressure during its service life, under the condition of a comparatively long steel sheet pile length.

Moreover, two types of sealing materials were prepared, these being a water-swelling rubber sealing material and a silicone resin sealing material. The water-swelling rubber material was adopted because it had an extensive record of use as a joint filler for segment seals, and displays excellent durability, is inexpensive, etc. Silicone resin is used as the sealing material in the part exposed to air, where the swelling reaction cannot be expected. However, since the material was selected not assuming use simply in an air environment, but rather, use in sea water, the material which is actually used is a comparatively expensive dedicated silicone sealant, which is given a thixotropic property so that it will not flow out of the joint during filling.

Thus, "J-Pocket Pile™" has high applicability as a cut-off wall for sea areas, and its usefulness has been recognized based on its extremely high performance. This product has compiled an lengthy record of actual use at sea waste disposal sites in Sangawa (Ehime Pref.), Mizushima (Okayama Pref.), and Hibikinada (Fukuoka Pref.). However, if "J-Pocket Pile™" is applied as-is to land areas, where the piles are not subject to large earth pressure, its cost competitiveness is low compared to that of other construction methods, as can be understood from the history of development outlined above. Therefore, in order to encourage wide use of the outstanding technologies possessed by "J-Pocket Pile™" in land areas as well as sea areas, the following two improvements were carried out for land use.

(1) Alternating combination with wide steel sheet piles
(2) Addition of low-cost bentonite to options as a sealing material for use in the part exposed to air

### 2.2 Effect of Combination Design in Reducing Weight of Steel Materials

The section performance of "J-Pocket Pile™" 4WS is on the same order as that of wide steel sheet piles. However, in applications in land areas, a function as an earth-retaining structure is frequently unnecessary; the requirement for cross-sectional rigidity is determined by the pile-driving property during installation, and in many cases, 2W or 3W section performance is sufficient. Therefore, the weight of steel materials was reduced by using an alternating combination of 4WS "J-Pocket Pile™" and 3W or 2W. **Table 1** shows the section performance per meter of wall, under the condition that

Table 1 Comparison of section performance

| Case | Per meter of wall width | | | |
|---|---|---|---|---|
| | Sectional area ($\times10^{-4}$ m$^2$/m) | Geometrical moment of inertia ($\times10^{-8}$ m$^4$/m) | Section modulus ($\times10^{-6}$ m$^3$/m) | Unit mass (kg/m$^2$) |
| 4WS+4WS | 234.8 | 57 000 | 2 720 | 184 |
| 2W | 131.2 | 13 000 | 1 000 | 103 |
| 3W | 173.2 | 32 400 | 1 800 | 136 |
| 4W | 225.5 | 56 700 | 2 700 | 177 |
| 4WS+2W | 183.0 | 29 900 | 1 630 | 144 |
| 4WS+3W | 204.0 | 43 400 | 2 120 | 160 |

reduction by joint efficiency is not considered. Section performance close to that of 3W can be obtained by using a combination of 4WS and 2W, and in this case, the unit mass is reduced by 22% in comparison with using pairs of 4WS piles. Since the cost of steel materials accounts for a large part of the total cost in vertical cut-off works using steel sheet piles, adoption of this method has a large effect in reducing the total construction cost.

### 2.3 Features of "J-Pocket Pile$^{TM}$" for Land Areas

"J-Pocket Pile$^{TM}$" for land areas retains the strong points of the original "J-Pocket Pile$^{TM}$" for sea areas, but also offers the following advantages in comparison with other construction methods when used in land areas.

(1) Cut-off wall construction method which does not generate surplus soil from construction.
(2) Can be applied to groundwater having diverse conditions.
(3) Construction is possible at sites in confined areas.
(4) Possible to shorten the construction period.
(5) High reliability cut-off wall construction method.

One vertical cut-off barrier construction method which is used in land areas is the soil-cement cut-off wall method, in which soil from the site and cement milk are stirred and mixed, and are then solidified so as to construct a soil-cement cut-off wall. In general, this method generates excess sludge, which contains cement and other materials, and in cases where the soil does not meet environmental standards, this excess sludge (waste sludge) may also contain hazardous substances. In contrast, because the cut-off wall construction method using steel sheet piles does not generate excess sludge, there are no surplus soil treatment costs. The steel sheet pile method is also a construction method which is not affected by groundwater conditions such as infiltrated water or artesian water or by soil properties. Construction is possible in confined areas by using a silent piler, and the steel sheet pile method is also applicable to urban areas, where low vibration and low noise are required.

Although the method of coating the joints between piles with a sealing resin is generally used as a construction method for vertical cut-off works using steel sheet piles, various issues exist from the viewpoint of water-shielding performance, as mentioned in Section 2.1. In contrast, high-reliability water-shielding performance can be obtained in cut-off walls using "J-Pocket Pile$^{TM}$" because the enclosed pocket structure is used when installing the sealing material.

Thus, like the original "J-Pocket Pile$^{TM}$," "J-Pocket Pile$^{TM}$" for land areas continues to provide the advantages of steel sheet piles, while also improving joint water-shielding performance and reliability, and has the distinctive feature of being a safe and secure cut-off wall construction method.

### 2.4 Examples of Application of "J-Pocket Pile$^{TM}$" for Land Areas

The main applications which are assumed for "J-Pocket Pile$^{TM}$" for land areas are as follows.

#### 2.4.1 Example of containment work

Containment work, as illustrated in **Fig. 2**, is a construction method which prevents the spread of hazardous substances via water by enclosing the sides of an area where contaminated soil exists with a vertical cut-off wall. Under the Soil Contamination Countermeasures Act, which was revised in 2010, the condition of contamination by designated hazardous substances is investigated on certain occasions, and when an area requiring action is designated, "*in situ* containment" is the standard measure. "J-Pocket Pile$^{TM}$" for land areas is the optimum pile for vertical cut-off works in which high reliability is required in water-shielding performance of this type. In cases where "*in situ* containment" is adopted as an action based on the Soil Contamination Countermeasures Act, it is necessary to drive piles to the impermeable layer underlying the soil that does not conform to environmental standards. ("Impermeable layer" is defined as a layer which is at least 5 m in thickness, and which has a coefficient of permeability of no more than 100 nm/second ((Lugeon unit in bedrock) = 1) or a water cut-off effect equal or higher than this.) Accordingly, it is necessary to confirm that an impermeable layer exists at a shallower depth than the limit depth for driving steel sheet piles. In addition, a supplementary

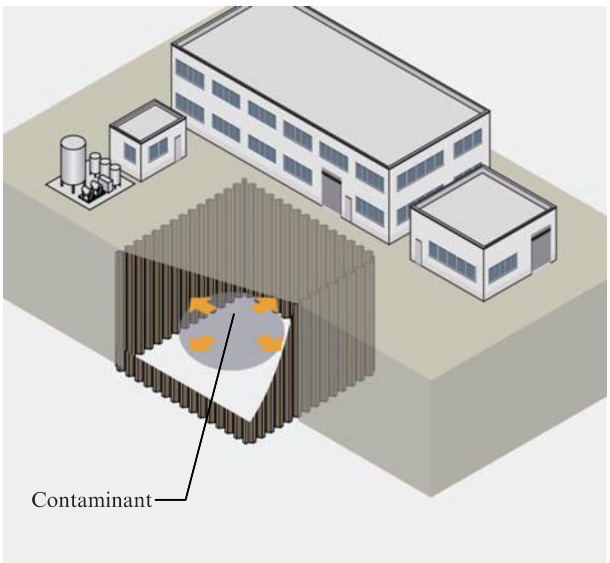


Fig. 2 Application example of containment work

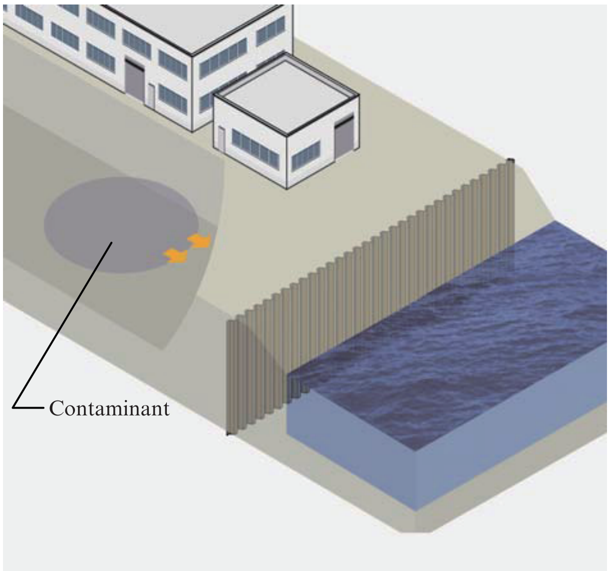


Fig. 3 Application example of cut-off sealing work

construction method is required in cases where the cut-off wall penetrates bedrock.

#### 2.4.2 Example of application as cut-off sealing work

In cut-off sealing work, as illustrated in **Fig. 3**, a vertical cut-off wall is installed on the site boundary line, for example, in cases contaminated groundwater has a hydraulic gradient, etc. In particular, dispersion of hazardous substances into rivers and sea areas by way of groundwater is assumed at riverbanks and at coastlines which are affected by the ebb and flow of tides, as water differential head occurs easily under these conditions. In such cases, application of "J-Pocket Pile™" for land areas is conceivable, based on the required cut-off performance. However, adequate study of the installation length for the contaminated area is necessary.

## 3. Improvement of Joint Shape

The combination of "J-Pocket Pile™" and wide steel sheet piles is not realized in a simple manner, but requires sufficient study preconditioned on the mutual fittability of the two types of piles. This chapter presents an outline of improvement of the joint shape of "J-Pocket Pile™" 4WS.

### 3.1 Issues Related to Fitting with Wide Steel Sheet Piles

A study of the fittability of "J-Pocket Pile™" 4WS and wide steel sheet piles was carried out using actual products. The items measured in this study were the opening width and rotation angle, which affect the pile-driving property, and the compression fitting clearance, which affects the water-shielding property. Based on past knowledge[5], the resulting value of the compression fitting clearance between 4WS and 3W was judged to be large. Therefore, fittability was improved by improving the shape of the joint.

### 3.2 Improvement of Joint Shape and Results

Because wide steel sheet piles are widely used, not only in vertical cut-off works, but also as a general earth-retaining construction method, improvement of the shape of these piles was not considered. Therefore, only the shape of the joint of 4WS was modified in order to improve the water-shielding property. So as not to reduce the existing fittability between pairs of 4WS piles, the excess space in the joint was not simply narrowed. Rather, in this improvement, the height and angle of the claw part and the angle of the flange part were modified from the viewpoints of the method of connecting pairs of claws and preventing pullout of the claw part in the direction of compression.

As a result, it was possible to secure a compression fitting clearance which satisfies fittability with wide steel sheet piles. The angle of rotation is important from the viewpoint of workability. Although this angle decreased somewhat, it did not become so small as to impair workability with 2W, 3W, or 4W. Thus, satisfactory results were obtained in terms of both the water-shielding property and workability.

## 4. Installation Test

The improvement of the joint shape of "J-Pocket Pile™" 4WS affects (1) the pile-driving property of the steel sheet pile, (2) workability in joint sealing treatment, and (3) sealing performance between pairs of joints. In combination with the improvement of the joint shape, bentonite was investigated as a sealing material for use in place of the conventional silicone resin in cases where steel sheet piles are placed in the ground, for example, in containment of contaminated soil, etc. In order to clarify the effects of these changes, actual installation was carried out using 4WS with the improved joint shape, and water-shielding performance was verified by performing sealing treatment between joints with bentonite.

### 4.1 Outline of Test

Steel sheet pile specimens with a length of 12.5 m were driven in a straight line using a hydraulic press-in type machine (silent piler) for use with wide steel sheet piles. Three types of steel sheet pile specimens were used, these being "J-Pocket Pile™" 4WS and wide steel sheet piles 3W and 2W. Three joint combinations (4WS-4WS, 4WS-3W, and 4WS-2W) were studied. **Figure 4** shows a plan view of the arrangement. The ground con-

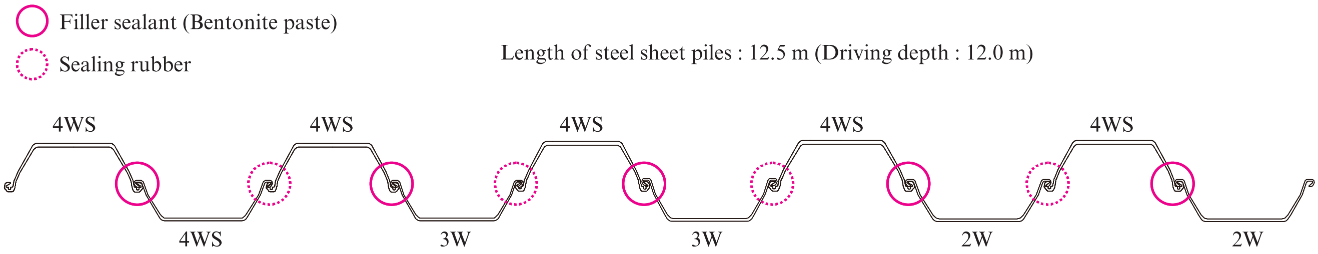


Fig. 4 Arrangement of test specimen and sealing method

ditions were a silt layer with an *N* value of approximately 5, which contained an intermediate sand layer with a maximum *N* value of 15. The water table was at a depth of 5.4 m below the ground surface. Two types of sealing methods were used. In one type, a water-swelling rubber sealing material was placed inside the joint in advance, and in the other, the joint was filled with bentonite paste after pile driving. Also assuming cases in which steel sheet piles are used in sea water at sea waste disposal sites, another method was used, in which the joints were filled with a dedicated silicone sealant with a thixotropic property so that the sealing material will not flow out of the joint. On the other hand, because soil and sand exist around steel sheet piles which are installed in land areas, application of bentonite, which has a record of actual use in cut-off works at landfill sites, etc. was also studied. Like silicone rubber, bentonite is filled in the joints by pumping the material, in paste form, with a high pressure pump. After driving the steel sheet piles and filling the sealing material were completed, a trench was excavated near the steel sheet pile wall, and the joint part was cut out from the ground surface to a depth of 1 m. The sampled specimen and the adjoining steel sheet pile were fixed so that the joint would not slip, and the two piles were then extracted as a pair by using a vibro-hammer. Next, the part positioned at a depth of 10 m below the surface was cut out. Using this part as specimen, a leakage measurement test was performed, and the converted permeability coefficient was obtained.

### 4.2 Pile-Driving Performance Test

**Photo 2** shows the condition of piling of the steel sheet piles. The time required for pile driving was 9 min per pile, and the cycle time was 12–15 min, including time for movement of the piler. No differences due to the type of pile were seen. The difference in press-in force due to the type of pile was also small and was roughly proportional to the cross-sectional of the steel sheet piles. Joint resistance did not become a problem. **Figure 5** shows a boring log and the press-in force for the cases of a single 4WS pile, a combination of two 4WS piles, fitting of 4WS to a 3W pile, and fitting of 4WS to a 2W pile. **Photo 3** shows the fitting condition between a 4WS pile and a 2W wide steel sheet pile. No differences due to the combination of joints occurred in the bentonite paste filling work. When the trench was excavated near the ground surface after filling, bentonite paste was observed protruding continuously from the joint gap, confirming that filling was achieved as sup-


Photo 2 Piling by silent piler

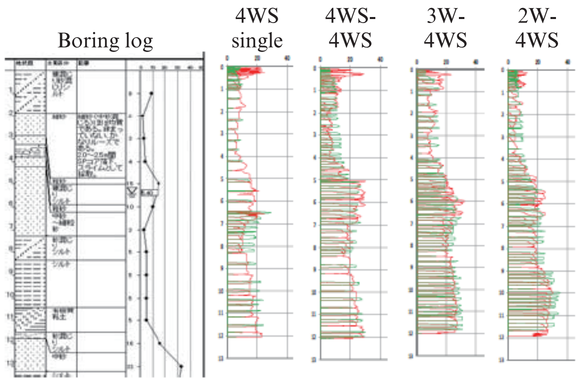


Fig. 5 Boring log and press-in force of silent piler


Photo 3 Fitting condition between 4WS and 2W

posed.

### 4.3 Water-Shielding Performance Test

Joint parts where sealing treatment had been performed in the installation test were cut out, and a leakage measurement test was performed. In the water leakage test, a hose and acrylic pipe were connected to a pressure-resistant container in which the joint specimen had been placed, water was poured into the acrylic pipe to the specified water level, and leakage was measured from the decrease in the water level. **Figure 6** shows an overview of the leakage measuring instrument. To eliminate the effect of air temperature on changes in water level as far as possible, the pressure-resistant container was placed in a thermobath which was set to 40°C. To minimize the effect of changes in water pressure, water was added when the water level had decreased by about 10 cm so as to maintain a roughly constant water pressure, and the permeability coefficient was obtained under a constant head.

**Table 2** shows the converted permeability coefficient for a thickness of 50 cm as the steel sheet pile wall, as calculated from the cumulative amount of leakage over a 5-day period. Although measurement was not possible for Cases 3 and 4 due to trouble during the specimen processing, in all other cases leakage was $1.0\times10^{-7}$ cm/s or less, amply satisfying the performance guideline of $1.0\times10^{-6}$ cm/s.

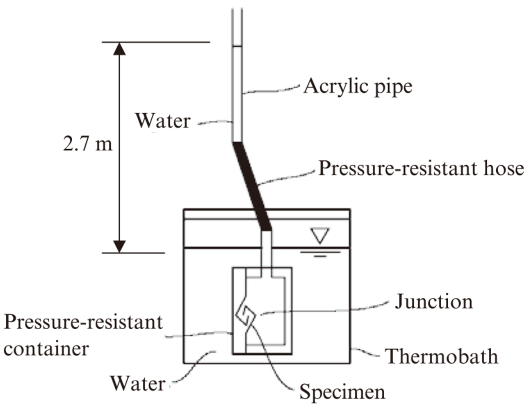


Fig. 6 Overview of leakage measuring instrument

Table 2 Converted permeability coefficient

| | Cut-off sealing material | Combination | Depth (m) | Converted permeability coefficient (cm/s) |
|---|---|---|---|---|
| Case 1 | Bentonite | 4WS-4WS | 1 | $2.64\times10^{-9}$ |
| Case 2 | Bentonite | 4WS-4WS | 8 | $7.49\times10^{-8}$ |
| Case 3 | Sealing rubber | 4WS-4WS | 1 | – |
| Case 4 | Bentonite | 4WS-3W | 1 | – |
| Case 5 | Sealing rubber | 4WS-3W | 10 | $1.12\times10^{-7}$ |
| Case 6 | Bentonite | 4WS-3W | 1 | $7.99\times10^{-9}$ |
| Case 7 | Sealing rubber | 4WS-3W | 10 | $5.89\times10^{-8}$ |
| Case 8 | Bentonite | 4WS-2W | 1 | $7.99\times10^{-9}$ |
| Case 9 | Sealing rubber | 4WS-2W | 10 | $2.64\times10^{-9}$ |
| Case 10 | Bentonite | 4WS-2W | 1 | $2.64\times10^{-9}$ |

Regarding the bentonite specimens, because this material showed water-shielding performance on the same order as that of silicone resin specimens which were tested in the past, the applicability of bentonite as a substitute for silicone resin was confirmed.

## 5. Conclusion

"J-Pocket Pile$^{TM}$" is a high-reliability vertical cut-off wall and is a product which can contribute to safe and secure community building. This paper introduced "J-Pocket Pile$^{TM}$" for land areas, which can be installed in combination with wide steel sheet piles and uses bentonite as a sealing material. This new product was developed in order to expand the range of applications of "J-Pocket Pile$^{TM}$" by providing a rational specification considering the conditions of use on land. The joint shape was improved for this application, and an on-site installation performance test and a water-shielding performance test were performed. The results confirmed that performance is on substantially the same level as that of the conventional product.

In the future, JFE Steel intend to conduct installation tests under more diverse conditions and work to further improve this technology in order to achieve wider diffusion of "J-Pocket Pile$^{TM}$" as a steel cut-off wall.

The authors wish to note that the installation tests described in this paper were carried out as joint research with Japan Foundation Engineering Co., Ltd., and express their deep appreciation to all those concerned.

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