# Development of "J pocket pile" Steel Sheet Pile with Grooved Joints and Application to Cut-Off Wall at Waste Disposal Sites†

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***Abstract:***

*"J pocket pile," which is the steel sheet pile with a groove in the joints, has been developed to apply to a cut-off wall at wasted disposal sites. Swelled natural rubber and silicone resin were applied as sealing materials and its impermeable performance has been confirmed through the laboratory and field tests. The installation of the sealing material has also been confirmed by various field tests. Based on these results, "J pocket pile" has been applied to cut-off walls at the coastal waste disposal sites and landfill sites.*

## 1. Introduction

With heightened environmental awareness, it has become difficult to obtain approval for construction of new final waste disposal sites in mountainous areas and other inland regions, and construction of coastal final waste disposal sites by reclamation of sea areas is increasing. When steel sheet pile walls are used in vertical cut-off walls at coastal final waste disposal sites, long piles are frequently used, placing a large load on the joints during installation. Furthermore, during the period from installation until the ground around the piles is reclaimed, the piles are subject to repeated displacement and deformation due to the action of waves and tides. As a result, there is concern that the piles may not demonstrate adequate impermeable performance with conventional waterproof methods. Therefore, JFE Steel developed an impermeable steel sheet pile, "J pocket pile" with a groove (pocket) in the joint which protects the sealing material in the joint, as shown in **Photo 1**. The effectiveness of this design was demonstrated by performing experiments to evaluate the waterproof performance and durability of the joint. Tests were also carried out to confirm the workability of the pile.

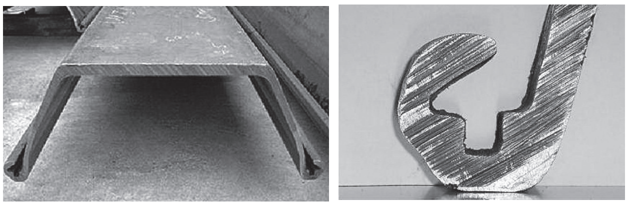

Photo 1 "J pocket pile"

This paper describes the technical features of "J pocket pile" and presents an outline of the various performance confirmation tests carried out in the development and commercialization of this product, together with examples of application.

## 2. Features of "J pocket pile"

### 2.1 Conventional Technology

Steel sheet pile walls, in which waterproof treatment is applied to the joint parts, are used as vertical cut-off walls of final waste disposal sites. As the joint waterproof method, the general practice is to coat the joint part with a sealing material consisting of a special polyurethane resin with a water swelling ratio on the order of 3 to 10, as shown in **Photo 2**. This sealing material has the feature of absorbing the surrounding water after pile

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Photo 2 Previous waterproof of steel sheet pile joints

installation and swelling to fill the spaces in the joint. However, it had been pointed out that some of the waterproofing material may be peeled off by friction with the ground or with the interlocking joint during pile installation, and this deteriorates impermeable performance[1].

### 2.2 Features of “J pocket pile”

“J pocket pile” is an impermeable steel sheet pile with a continuous depression, or “pocket,” approximately 10 mm in width and depth in the longitudinal direction in the claw bottom of the joint, which is filled with a sealing material. This pocket part is formed during hot rolling. The features of “J pocket pile” are described below.

(1) High Reliability Impermeability
- · Swelled natural rubber, which has a record of use in cement joints of shield tunnels etc., is inserted in the pocket, making it possible to avoid damage during installation and construct a cut-off wall with high reliability.
- · It is also possible to select a method in which an injection pipe is inserted after installation of the pile, and a filler (silicone resin) is injected through the pipe.

(2) Stable Quality
- · As this is a hot-rolled product which is manufactured by a JIS certified works, stable quality with minimal deviations is secured.

(3) Excellent Workability
- · Because the parts other than the pocket provide the same performance as conventional steel sheet piles, this product demonstrates excellent economy and workability.

Two types of sealing material can be selected for use with “J pocket pile,” as mentioned in feature (1) above. **Photo 3** shows the appearance of the swelled natural rubber and insertion of the rubber into the pocket. Because swelled natural rubber has a water swelling property, the original outer diameter of 12 mm expands to 18.5 mm when exposed to water, making it possible to fill the pocket completely. During installation, the swelled natural rubber is inserted in the pocket in advance and is then installed together with the pile. **Photo 4** shows the appearance of the silicone resin and injection into the pocket. To prevent infiltration of earth

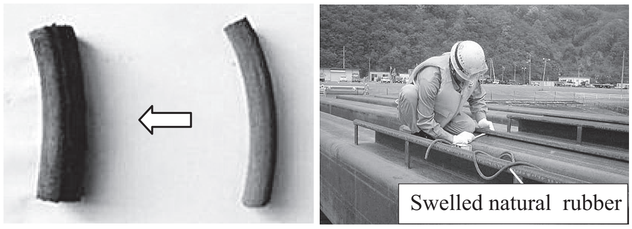


Photo 3 Picture and installation of swelled natural rubber


Photo 4 Picture and injection of silicone resin

and sand into the joint, a prestressed concrete (PC) steel bar is inserted into the pocket during pile installation work. When the silicone resin is injected after installation of the pile, the PC steel bar is removed, the pocket is washed, and an injection pipe is inserted from the head of the pile. Injection work is performed using a high pressure pump, and the injection pipe is extracted as the pocket is filled.

Combinations of sealing materials can also be used, responding to various conditions. It is possible to use a combination of swelled natural rubber, which has a water swelling property, at depths greater than the groundwater table, and inject silicone resin at shallower depths. A combination of swelled natural rubber and silicone resin can also be used in the same section of the pile, as illustrated in Photo 4.

## 3. Outline of Impermeable Performance Confirmation Tests

In the development and commercialization of the impermeable steel sheet pile “J pocket pile,” the aim was to establish a construction method which enables application at actual sites while satisfying the impermeability performance required in cut-off walls of controlled waste disposal sites. The content of the study in this connection is described below.

### 3.1 Leakage Measurement Test Using Joint Model

Hydraulic conductivity is generally used as an evaluation method for the impermeable performance of joints. A joint order of the Office of the Prime Minister and the Ministry of Health and Welfare in June 1998, which prescribed the structure of final waste disposal sites, set the thickness and hydraulic conductivity of cut-off walls at 50 cm or more and $1.0\times10^{-6}$ cm/s or less, respectively. Therefore, a permeability test was performed using the test equipment shown in **Fig. 1** in order to assess the change over time in leakage and evaluate the hydraulic conductivity of “J pocket pile.” Test specimens (width:100 mm) were prepared by cutting out the joint part of steel sheet piles, and were set in a pressure-proof container. This was placed in a constant temperature water tank, in which the water temperature was controlled to 30°C, so that a water pressure of approximately 0.1 MPa would act on the specimen at all times, and the decrease in the water level in the water-level tubes was measured over a 6-month period. Two types of specimens were prepared: specimen A, which was coated with a commercial water swelling-type sealing material, and specimen B, in which swelled natural rubber with an outer diameter of 18 mm was inserted in a test piece that was prepared by processing the joint part of a steel sheet pile and welding a steel tube with an inner diameter of 17 mm, simulating the structure of “J pocket pile.” **Figure 2** shows the test results. With both test specimens, leakage was kept at a basically constant value after the start of the test. However, leakage decreased sharply and fell to a constant value after 3 weeks with specimen A and after 2 months with specimen B. This is considered to be because fine spaces in the sealing material or between the sealing material and the steel served as water leakage routes immediately after the start of the test, but these paths were closed off as the swelling pressure of the sealing material increased. **Table 1** shows the equivalent hydraulic conductivity of these joints when used in the joints of U-shaped steel sheet piles with a width of 600 mm. The equivalent hydraulic conductivity of specimen B at swelling equilibrium after the inflection point is $3.1\times10^{-10}$cm/s, which showed satisfactory results of the performance requirement of $1.0\times10^{-6}$cm/s. Thus, in this test, it was found that a steel sheet pile with a pocket in the joint, in which swelled natural rubber is inserted, is capable of demonstrating impermeable performance.

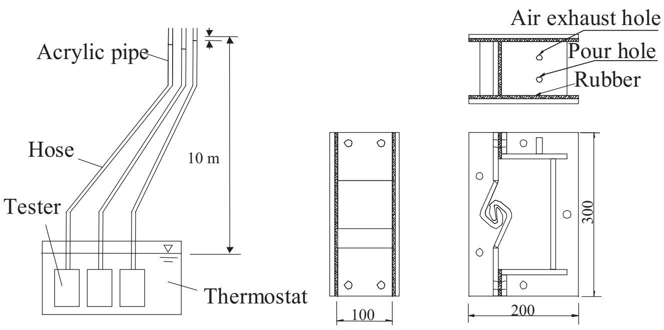


Fig. 1 Test equipment

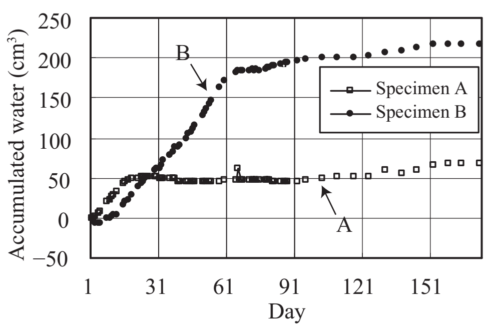


Fig. 2 Accumulated water

Table 1 Hydraulic conductivity of specimens

| | Specimen A | | Specimen B | |
|---|---|---|---|---|
| | Quantity of seepage/day ($cm^3$/d) | Hydraulic conductivity (cm/s) | Quantity of seepage/day ($cm^3$/d) | Hydraulic conductivity (cm/s) |
| After the start | 2.40 | $2.3\times10^{-9}$ | 2.85 | $2.8\times10^{-9}$ |
| Equilibrium | 0.11 | $1.1\times10^{-10}$ | 0.32 | $3.1\times10^{-10}$ |

It may be noted that, Darcy’s law is essentially not considered applicable to the leakage rate from joints of steel sheet piles, but for convenience, the hydraulic conductivity was obtained for a wall comprising ground material with a 50 cm thickness, at which the leakage rate is the same, and that value was used as equivalent hydraulic conductivity $k_e$.

$$Q/B = k_e\cdot(\Delta h/T)$$

$Q$: Leakage from joint per unit of time (per unit of length)
$B$: Interval between joints in steel sheet pile wall (generally, 40–60 cm)
$k_e$: Equivalent hydraulic conductivity
$\Delta h$: Difference in head
$T$: Thickness of equivalent permeable wall (= 50 cm)

### 3.2 Water Tank Test of Impermeable Steel Sheet Pile

The development of a method of filling the pocket in “J pocket pile” with silicone rubber as a sealing material was described above. However, assuming conditions in which oscillation of the steel sheet pile wall occurs after waterproof treatment, for example, in earthquakes, an impermeable steel sheet wall with waterproof treatment was placed in a water tank, and repeated forced displacement was applied to the head with a jack. The impermeable performance of the joint was evaluated under this condition[2)].

In this experiment, a permeability test of steel sheet piles was performed by placing a steel sheet pile specimen in the center of a water tank, as shown in **Fig. 3**, with a difference of 3 m in the water levels on the land

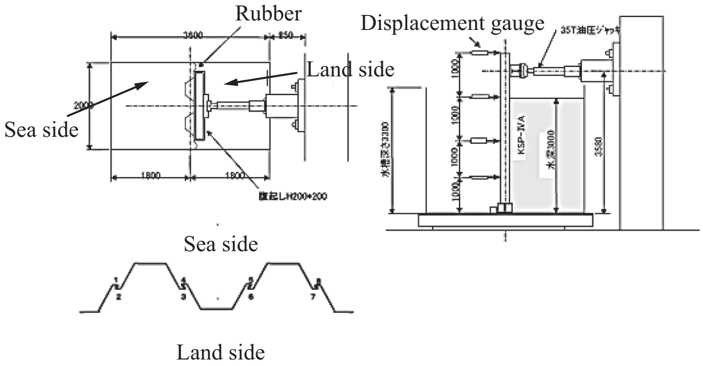


Fig. 3 Test equipment

side (disposal site side) and the sea side. Tests were performed for three cases: Case 1, in which swelled natural rubber was inserted in the pocket part in advance and the piles were then interlocked; Case 2, in which silicone resin was injected after interlocking the piles; and Case 3, in which swelled natural rubber was inserted in advance on one side, and silicone resin was injected from the other side after pile installation. In this test, the water level on the disposal site side has kept constant after installation of the cut-off wall, and the test specimens were left in place until the swelled natural rubber reached swelling equilibrium or a hardened condition (natural swelled rubber: 14 days, silicone resin: 4 days), after which the water which permeated from the steel sheet pile joint to the sea side was measured. Measurements were performed for 24 hours in a static water pressure condition after installation of the cut-off wall. Following this measurement, water was supplied to the sea side again, the steel sheet pile was vibrated for 24 hours with a hydraulic jack (displacement from load point: ±25 mm, cycle: 5 s), and measurements were performed once again for 24 hours.

**Table 2** shows the equivalent hydraulic conductivity. In all Cases 1, 2, and 3 (after injection of silicone resin), the equivalent hydraulic conductivity tended to be larger after vibration than before vibration. However, a quantitative comparison could not be performed for Case 1 because the degree was such that slight oozing could be observed in the joint. In Case 2, a phenomenon in which the crevices became progressively closed by hardening of the silicone resin itself could be seen. In Case 3, leakage occurred when the joint was interlocked with swelled natural rubber on one side, but this leakage decreased to substantially 0 after injection of the silicone resin. It is considered that the swelled natural rubber swelled and caulked the joint, demonstrating a seal effect as a result of contact surface stress of the rubber on the joint, and the silicone resin also substantially filled spaces, thereby shutting off leakage routes. As a result of this evaluation of impermeability performance, the equivalent hydraulic conductivity was $1.0\times10^{-7}$–$1.0\times10^{-8}$ cm/s or less when converted at a permeable layer thickness of $t$ = 50 cm. This satisfied the target performance requirement of $1.0\times10^{-6}$ cm/s.

### 3.3 Impermeable Performance Confirmation Test in Actual Coastal Environment

The laboratory confirmation tests of the impermeable performance of the impermeable steel sheet pile and the results thereof were described in sections 3.1 and 3.2. This section describes the confirmation test of the workability and impermeable performance of the impermeable steel sheet pile when used in an actual coastal environment. The demonstration experiment was performed from April 2003 to December 2004 at the Marinopolis landfill at Aga Area, Kure City, Hiroshima Prefecture at a location with a water depth of 7.0 m.[3)] The specimen, as shown in **Fig. 4**, was a support structure in which square columns were arranged at the ends of two lines of steel sheet pile walls. The space enclosed by the steel sheet walls and the square columns was considered to simulate a disposal site. Seawater was supplied to the enclosed space to a depth of standard sea level (C.D.L.) +4 m, and that water level was measured at 30 min intervals. Two types of steel sheet pile specimens were used, a “swelled natural rubber type,” in which swelled natural rubber was installed in the full length of the pockets on both sides before installation of the piles, and an “injected type,” in which swelled natural rubber

Table 2 Hydraulic conductivity

| Cace | | Hydraulic conductivity (cm/s) | | | | | Remarks |
|---|---|---|---|---|---|---|---|
| | | Joint 1, 2 | Joint 3, 4 | Joint 5, 6 | Joint 7, 8 | All | |
| 1 | Before vibration | — | — | — | — | — | |
| | After vibration | — | — | — | — | — | |
| 2 | Before vibration | — | — | — | — | — | |
| | After vibration | $3.68\times10^{-7}$ | $1.51\times10^{-7}$ | — | $4.53\times10^{-7}$ | $2.29\times10^{-7}$ | |
| 3 | Before vibration | — | $1.76\times10^{-5}$ | $1.82\times10^{-5}$ | $3.09\times10^{-6}$ | $5.03\times10^{-6}$ | Swelled natural rubber (only one side) |
| | After vibration | — | $1.99\times10^{-5}$ | $9.06\times10^{-5}$ | $2.50\times10^{-6}$ | $3.19\times10^{-5}$ | Swelled natural rubber (only one side) |
| | Before vibration | — | — | — | — | — | |
| | After vibration | $4.92\times10^{-10}$ | — | — | — | $9.68\times10^{-8}$ | After injection of silicon resin |

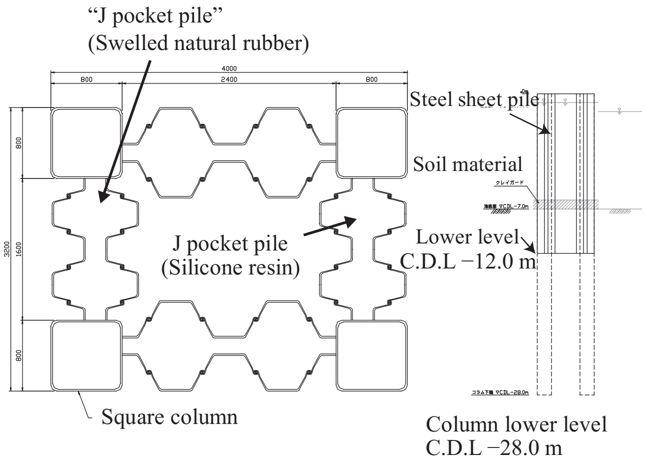


Fig. 4 Apparatus of specimen

was installed on only one side, and the remaining side was filled with silicone resin after pile installation. With the injected type, silicone injection was limited to the part shallower than the sea bottom, and swelled natural rubber was installed in advance in the part deeper than the sea bottom in order to prevent infiltration of earth and sand into the injection holes. Silicone resin injection was performed by inserting an injection pipe in the concave groove from the crown following pile installation, and filling the pocket with silicone resin using a high pressure pump, while extracting the injection pipe from the area near the sea bottom toward the crown part. **Figure 5** shows the variation of the average daily water levels in August and November. With both test specimens, the water level decreased in a substantially linear manner, and the leakage rate was stable. **Table 3** shows the equivalent hydraulic conductivities of the swelled natural rubber type and the injected type during the periods shown in Fig. 5. In all cases, the equivalent hydraulic conductivity is on the order of $10^{-8}$cm/s, confirming that cut-off walls using "J pocket pile" also satisfy the performance requirement for cut-off walls in actual coastal environments.

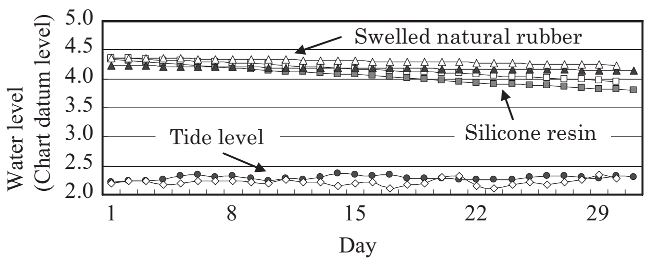


Fig. 5 Variation of average water level

## 4. Test Installation of Impermeable Steel Sheet Piles

In order to evaluate the effect of pile installation work on the sealing material, it was necessary to confirm workability under difficult ground conditions by installation in soft ground and sea bottom installation[4)]. This section describes the results of the pile installation tests.

### 4.1 Installation of Long Steel Sheet Piles

Pile driving was performed using long "J pocket pile" with a length of 26 m as steel sheet piles. As shown in **Fig. 6**, the ground comprised soft reclaimed ground to a depth of approximately 17 m and hard ground with an *N* value of 50 or more at depths greater than 17 m. Installation was performed using a vibratory hammer (120 kW), and natural swelled rubber was adopted as the joint waterproof method.

Regarding the conditions during installation, although the pile driving rate decreased from a depth of around 20 m, installation was completed without trouble. After installation, the steel sheet pile was removed and

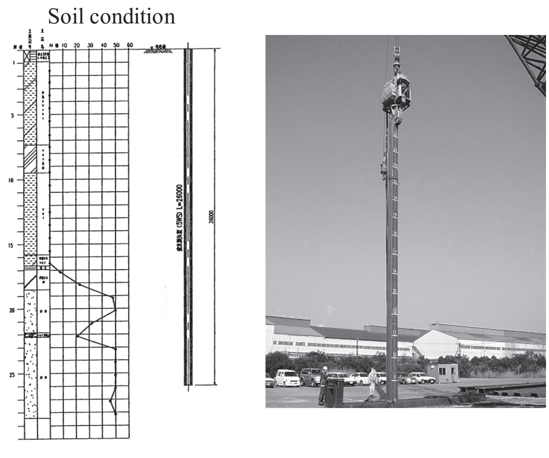


Fig. 6 Installation of long "J pocket pile"

Table 3 Hydraulic conductivity of specimens

| | Average water level C. D. L | Average tide level C. D. L | Average water level difference (cm) | Variation of water level (m/d) | Hydraulic conductivity (cm/s) |
|---|---|---|---|---|---|
| Silicone resin | 4.05 | 2.29 | 176 | $-1.76\times10^{-2}$ | $9.62\times10^{-8}$ |
| | 4.17 | | 188 | $-1.41\times10^{-2}$ | $7.16\times10^{-8}$ |
| Swelled natural rubber | 4.18 | 2.21 | 197 | $-2.76\times10^{-2}$ | $1.40\times10^{-8}$ |
| | 4.30 | | 209 | $-4.40\times10^{-2}$ | $2.08\times10^{-8}$ |

Upper row: Data of August
Lower row : Data of November
C. D. L.: Chart datum level

the natural swelled rubber was observed. Light damage was found in the final 1–2 m at the bottom end of the pile. However, substantially no damage was observed in other parts.

### 4.2 Combined Water Jet Installation in Gravel Ground

In cases where excessive time is required for installation of steel sheet piles due to hard ground, the ground conditions are expected to have a large effect on the swelled natural rubber. Therefore, installation of “J pocket pile” with lengths of 8–13 m was performed in ground characterized by a continuous gravel layer (gravel diameter: 5–15 cm) except in the surface ground, using an electric vibratory hammer (90 kW) in combination with a water jet method.

In all of these tests, the installation rate also decreased temporarily at a depth of 4–5 m, but installation proceeded smoothly at greater depths. After installation, the steel sheet pile was removed and the natural swelled rubber was observed. Although scratches could be observed at the bottom end, this damage was not of a degree which would affect impermeable performance, and substantially no damage was found in other parts.

### 4.3 Press-in Method

Installation of steel sheet piles in urban areas is frequently performed using a low noise, low vibration compact hydraulic press-in machine (silent piler), as shown in **Photo 5**. The load placed on the joint is considered to differ in this method and the vibratory hammer method due to differences in the penetration method with the two installation methods. Therefore, an installation test was performed by the press-in method[5)]. The ground where the test was performed comprised a clay layer with *N* values on the order of 10–15. The test was carried out with “J pocket piles” having a length of 13.0 m. Both swelled natural rubber and silicone resin were used as joint waterproof methods. The results of installation by the press-in method confirmed that installation can be performed under the same press-in conditions as with ordinary U-shaped steel sheet piles.


Photo 5 Installation by silent piler

## 5. Examples of Application

### 5.1 Sangawa Eastern Area Coastal Land Reclamation Project

“J pocket pile” was adopted as the vertical cut-off wall of a controlled final waste disposal site for a seawall (outer revetment) 500×219.5 m in length surrounding the disposal site in the Sangawa Eastern Area Coastal Land Reclamation Project in the City of Shikokuchuo, Ehime Prefecture. An example of the structure of the seawall is shown in **Fig. 7**. The seawall comprises a double steel sheet pile wall with a width of 15.0 m, and the steel sheet pile wall on the inner side of the seawall also serves as the side cut-off wall of the landfill site. As the structure of the landfill, the bottom is made up of a soil-type clay guard material, which consists of dredged marine clay as the main material, to which a void conditioner and gelling agent were added and mixed. The slope joining the side and bottom is covered with a double waterproof sheet.

The specification of the “J pocket pile” used in this project is shown in **Table 4**, and the condition of installation is shown in **Photo 6**. The waterproof method was a combination of swelled natural rubber above the con-

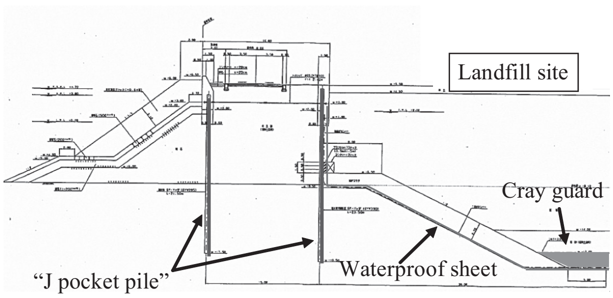


Fig. 7 Cross section of seawall

Table 4 Outline of “J pocket pile”

| Length | Quantity | Weight | Waterproof method of joints |
|---|---|---|---|
| 23–28 m | 1 800 | 6 350 t | Swelled natural rubber and silicone resin |

Photo 6 Installation of “J pocket pile”

trol water level and silicone resin injection a shallower depths than the control water level. The length of the “J pocket piles” was 23.0–28.0 m. Because the ground at this site is gravel with $N$ values of 50 and higher, installation was performed using the water jet method in combination with the electric vibratory hammer (120 kW), enabling smooth installation.

### 5.2 Appropriate Closure of Mamio Landfill, Yamakawa Town

Section 5.1 described an example of use of “J pocket pile” in a coastal waste disposal site. Application of “J pocket pile” to landfill sites and containment of contaminated ground is also possible. This section introduces an example of adoption in appropriate closure of a final waste disposal site for municipal waste in Yoshinogawa City, Tokushima Prefecture.

At this landfill, a steel sheet pile cut-off wall was adopted as the method of preventing leaching of retained water and rainwater, etc. from the reclaimed land. “J pocket pile” was used as the steel sheet pile. As reasons for the adoption of “J pocket pile,” due to the steep slope of the site, as shown in **Photo 7**, it was difficult to construct a soil cement diaphragm wall using large-scale machinery in construction, and there was concern that the sealing material might be peeled off during installation if the ordinary method of coating with a water swelling sealing material was used. The specification of the “J pocket pile” used in this project is shown in **Table 5**.

One potential problem in the application of “J pocket pile” in an inland construction project was the possibility that earth and sand might infiltrate the pile joints during installation, making it impossible to insert the injection pipe used to fill the pocket with silicone resin. This problem was avoided by protecting the pocket with a PC steel rod during installation, and then removing the rod before injection of the sealing material. At this site, a large part of the ground consists of rock, and it was impossible to install steel sheet piles under this condition. Therefore, piles were inserted after first drilling holes with a down the hole hammer. As a result, although incomplete pile driving occurred with some piles, injection of the sealing material was possible with no problems.

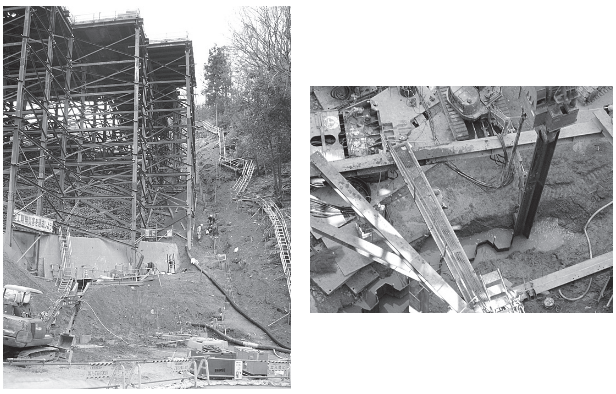

Photo 7 Condition of construction

Table 5 Outline of “J pocket pile”

| Length | Quantity | Weight | Waterproof method of joints |
|---|---|---|---|
| 9–24 m | 130 | 290 t | Swelled natural rubber and silicone resin |

## 6. Conclusion

This paper presented the features of “J pocket pile,” an outline of the various performance confirmation tests carried out in development and commercialization, and examples of application.

(1) To assess impermeable performance, a leakage measurement test in the laboratory and impermeable performance confirmation test in an actual coastal area were performed. “J pocket pile” amply satisfied the hydraulic conductivity value of $1.0\times10^{-6}$ cm/s required in cut-off walls of controlled waste disposal sites, confirming that this product satisfies the impermeable performance requirement.

(2) Workability was assessed in workability demonstration tests by installation of long steel sheet piles using the vibratory hammer method, installation in gravel ground, and installation by the press-in method. The results confirmed that installation of “J pocket pile” is possible with no problems.

(3) As results of actual construction, the use of “J pocket pile” in a coastal disposal site and a landfill site were introduced as examples of application in different environments.

In the future, JFE Steel will continue efforts to popularize “J pocket pile” as an impermeable steel sheet pile which demonstrates high reliability in cut-off walls.

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