Proceedings of the Second International Conference on Press-in Engineering 2021, Kochi, Japan – Matsumoto et al (eds)

Case study of oval shaped foundation using the Gyropress Method under overhead restrictions

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ABSTRACT: This paper describes the press-in piling method of steel pipe piles to form steel pipe foundations for the expansion of bridge piers to widen an existing bridge on the expressway. In this project, it was necessary to install steel pipes under girders/beams of a road bridge while keeping the bridge in service. It was also necessary to embed piles in a gravel layer having a maximum extrapolated SPT *N*-value of more than 70. The Gyropress Method using a type of machine capable of low headroom operation was adopted. In this method, steel pipe piles with pile toe ring bits are rotationally pressed-in to cope with hard ground and steel pipe piles can be pitched using a hoisting system for low headroom. By welding short segmental piles together in vertical position under overhead restrictions, it was possible to press in steel pipe piles until reaching the supporting layer.

1 OVERVIEW OF CONSTRUCTION

The construction site is located beneath the Oppe River Bridge, which spans the Oppe River, on the East Japan Expressway of East Nippon Expressway Company Limited. The bridge connects Tsurugashima City, Saitama Prefecture and Higashi-Matsuyama City, Saitama Prefecture (see Figure 1). The purpose of this project is to widen the lanes in the section between the Tsurugashima Junction and the Higashi Matsuyama Interchange on the Kan-etsu Expressway. As regards the press-in piling to form foundations in the bridge substructure for road widening, this article reports the selection of specifications, the procedure of press-in piling, and the outcome of construction.

It was decided to install additional foundation piles near the existing piers in the substructure.

The project involved construction of 12 additional piers: the piers P1 to P6 for both up and down bound lanes.

2 CONSTRUCTION AND SOIL CONDITIONS

2.1 *Construction conditions*

It was necessary to meet the following conditions in this project.

– Maintain safe overhead clearances from the in-service road bridge. (See Figure 2)
– Complete piling during drought seasons.
– Restore the revetment to its original state by each flood season.
– Minimize noise and vibration in consideration of neighboring residents.
– Install piles into a gravel layer that serves as a support ground.

In installing additional piles for the existing piers, two methods were investigated and compared: installation of additional cast-in-place piles, and installation of steel pipe sheet piles. As a result, steel pipe sheet pile foundations were adopted because of their advantage in terms of the ease of construction and short construction period.

Up to three Gyro Pilers were used simultaneously to shorten the construction period and complete work within drought seasons. Moreover, some sections were arranged for continuous work during the day and night (See Figure 3), and a maximum of six teams were employed for the piling operation.

2.2 *Soil conditions*

Among the 12 piers worked on, this paper describes the pier P2.

Figure 4 shows a borehole log obtained on the site. Below the surface layer of the Kanto Loam, the section from the top of an installed pile to a depth of 12.0 m consists of a gravel layer with weathered conglomeratic clay, with SPT *N*-values ranging from 2 to 47. Below an intermediate clayey layer, there is a very dense layer of clayey gravel, with a maximum extrapolated SPT *N*-value exceeding 70.

DOI: 10.1201/9781003215226-49

Figure 1. Location map.

Figure 2. Overhead clearance under the Oppe River Bridge.

Figure 3. Piling at night.

In selecting a press-in piling method, it was found difficult to apply a standard press-in or a press-in piling with water jetting to a very dense

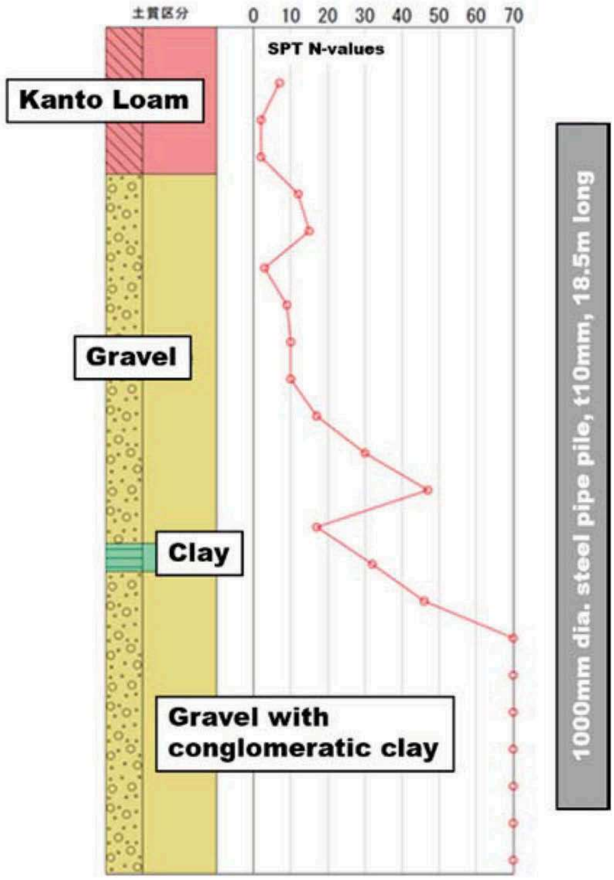

Figure 4. Borehole log.

layer of clayey gravel having a maximum extrapolated SPT *N*-value of more than 70. One method contemplated was to conduct pre-excavation using a full-slewing excavator or the like and then press steel pipe sheet piles into the ground after replacing the existing soil with fine sand, etc. However, this method was judged to be inapplicable because of the lack of certainty in replacing very hard soil. The Gyropress Method (Figure 5) was used in this project, in which steel pipe piles, instead of steel pipe sheet piles, with pile toe ring bits (Figure 6) were rotary pressed-in into the hard soil by rotary press-in piling.

2.3 *Overhead restrictions*

There were overhead restrictions because of the site being under the existing bridge beams and girders. At the pier P2, it was necessary to keep overhead clearances under the road bridge in service: about 7.5 m below a girder, and about 5.3 m below a beam. The piling procedure was therefore restricted to attaching a hoisting system for low headroom to a press-in machine, pitching short segmental piles without using a service crane, and then welding the piles together in vertical position. Therefore, the Gyropress Method using a type of machine capable of low headroom operation was adopted.

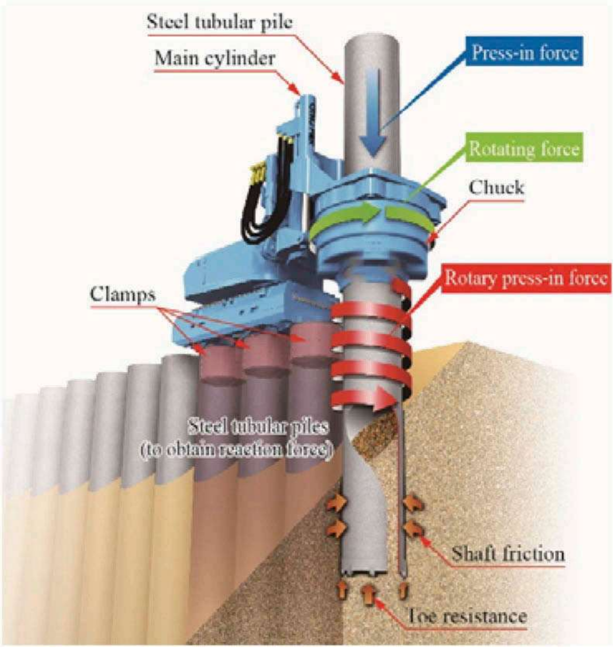

Figure 5. The Gyropress method.

Figure 6. Steel pipe pile with pile toe ring bits.

3 STRUCTURAL TYPES OF FOUNDATIONS

The structural types of foundations considered in this project are described in Figure 7 and 8. The Gyropress Method, which is applicable to steel pipe foundations (without interlocks), was adopted in this project.

The shape of a foundation is either circular or oval, and the foundation shape and the number of steel pipe piles were decided according to the shape of the existing pier. For each pier, the foundation type was selected as either the cantilever or

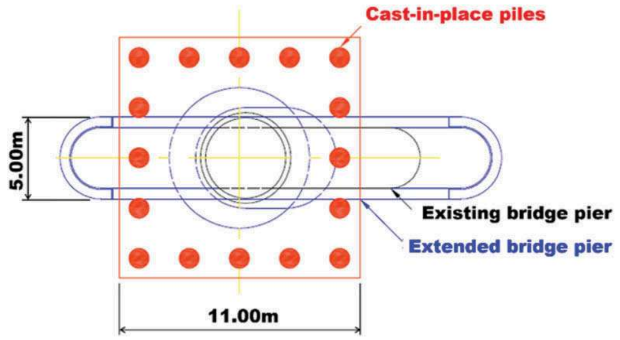

Figure 7. Cast-in-place pile foundation.

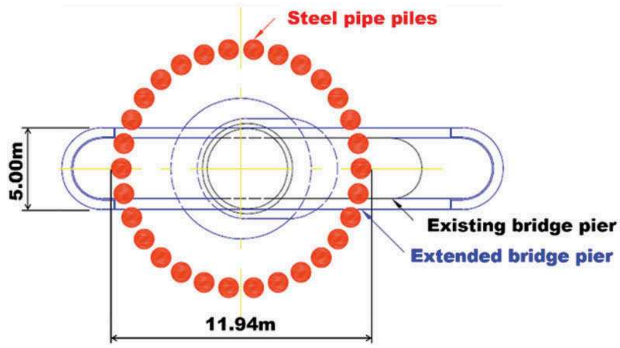

Figure 8. Steel pipe foundation (without interlocks).

supporting type of the earth retaining wall in consideration of penetration into the support layer and stiffness.

For the pier P2 of the down bound lanes, 30 steel pipe piles with pile toe ring bits were rotary-pressed in to form an oval shaped foundation. For the 12 piers worked on in this project, a total of 400 steel pipe piles (See Table 1) were installed by the Gyropress Method.

4 PROCEDURE OF PRESS-IN PILING

4.1 *Selection of applicable machine*

A type of machine that can install steel pipe piles of 1000mm in outer diameter by rotary press-in piling and to which a hoisting system for low headroom (Figure 9) can be attached was selected. The GRAL1015 of GIKEN LTD. was used for press-in piling in this project.

4.2 *Selection of segmental pile length*

The pile length that allows steel pipe piles to be pitched without getting in contact with the existing bridge in a space that satisfies the overhead clearances was investigated. The overhead clearance is most restrictive beneath the beam of the pier P2,

Table 1. Steel pipe piles.

Pier	P1	P2	P3
Foundation shape	Oval	Circle	Circle
Structural type of retaining wall	Supporting	Cantilever	Cantilever
Piles	**Up line** SKK490 1000mm O.D. t12mm 16m long 40 no.	**Up line** SKK400 1000mm O.D. t10mm 18.5m long 30 no.	**Up line** SKK400 1000mm O.D. t10mm 16.5m long 30 no.
	Down line SKK490 1000mm O.D. t12mm 16m long 40 no.	**Down line** SKK400 1000mm O.D. t10mm 18.5m long 30 no.	**Down line** SKK400 1000mm O.D. t10mm 16.5m long 30 no.
Pier	**P4**	**P5**	**P6**
Foundation shape	Oval	Circle	Circle
Structural type of retaining wall	Supporting	Cantilever	Cantilever
Piles	**Up line** SKK490 1000mm O.D. t16mm 16m long 40 no.	**Up line** SKK400 1000mm O.D. t10mm 17.5m long 30 no.	**Up line** SKK490 1000mm O.D. t15mm 18.5m long 30 no.
	Down line SKK490 1000mm O.D. t16mm 16m long 40 no.	**Down line** SKK400 1000mm O.D. t10mm 17.5m long 30 no.	**Down line** SKK400 1000mm O.D. t10mm 12.0m long 30 no.

Figure 9. Hoisting system for low headroom in operation.

with the separation between the base surface and the existing bridge being 5.3 m. To join steel pipe piles together safely in this narrow overhead clearance space, the maximum material length of each segmental pile, excluding the bottom pile, was set to 1.5m (see Figure 10).

Beneath the girder in the 7.5 m overhead clearance space, the maximum material length of each segmental pile was set to 4.0 m (see Figure 11).

Table 2 shows the results of consideration into different numbers of joints.

4.3 *Consideration of equipment layout during construction*

The main equipment used for the rotary press-in piling to install steel pipe piles is listed in Table 3.

In this project, press-in piling was conducted by pitching steel pipe piles using a hoisting system attached to a press-in piling machine, without using a service crane for pitching. A 50-ton crane was used to unload piles from a truck, and a 4.9-ton crane was used to move segmental

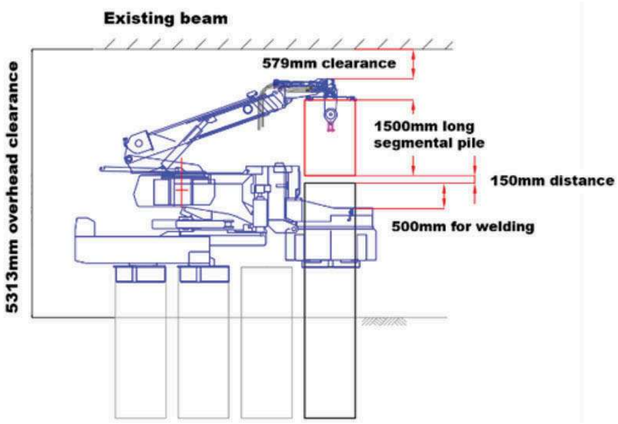

Figure 10. Allowable pile length beneath the beam at pier P2 (5.3m clearance).

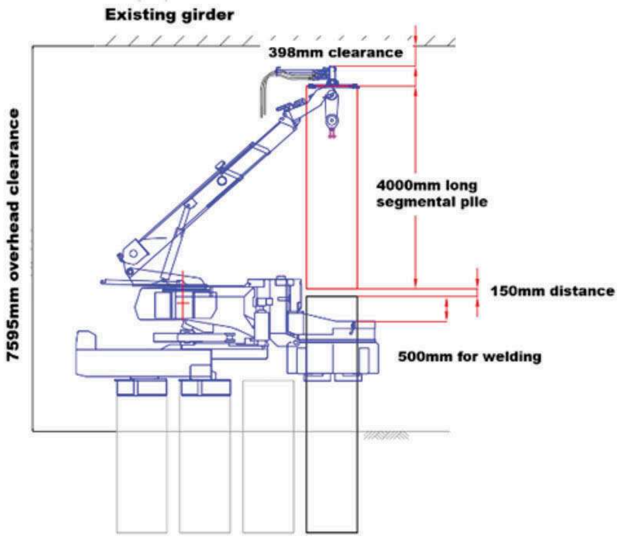

Figure 11. Allowable pile length beneath the girder at pier P2 (7.0m clearance).

Table 2. Specification of segmental piles at the pier P2.

[Under the beam] 5.3m overhead clearance
SKK400, 1000mm O.D., t10mm, 18.5m long
Number of joints: 11 joints
Type-A: 2.5m bottom pile + 10 no. 1.5m piles + 1.0m upper pile
Type-B: 2.0m bottom pile + 10 no. 1.5m piles + 1.5m upper pile
[Under the girder] 7.9m overhead clearance
SKK400, 1000mm O.D., t10mm, 18.5m long
Number of joints: 4 joints
Type-A: 4.5m bottom pile + 4.0m pile + 2 no. 3.5m piles + 3.0m upper pile
Type-B: 4.0m bottom pile + 4.0m pile + 2 no. 3.5m piles + 3.5m upper pile

Table 3. Main equipment.

Machine type	Specification	Notes
Gyro Piler	Press-in force 1500kN, Extraction force 1600kN	Rotary-press-in piling
Power Unit	221kW (300p s)/ 1800min-1	Power source for the Gyro Piler
Telesco-Crane	50 ton class	for loading/unloading
Water lubrication system	60 ℓ/min, 2no.	Reduction of inner friction of steel pipe piles
Welder	600A, 2no.	Splicing segmental piles
Generator	150kVA	Power source for the welder

piles within the space of overhead restrictions. (See Figure 12, 13 and 14).

4.4 *Confirmation of reaching the support layer*

The Gyro Piler is equipped with a system that acquires press-in data; this system measures and records the press-in force and rotation torque applied to each steel pipe pile during piling. Press-in data was obtained for all the piles on the site, and the horizon at which soil characteristics change was estimated from measurement data to estimate whether the pile has reached the supporting ground.

4.5 *Loading test (IPA, 2014)*

To check the vertical reaction force of the pressed-in piles, a vertical loading test was carried out by using the Gyro Piler.

At the end of piling after making sure that a pile reached the support ground, the pile was pressed into the supporting ground by a distance of 1D or more without toe lubrication using the water lubrication system. As the outer diameter of the steel pipe pile

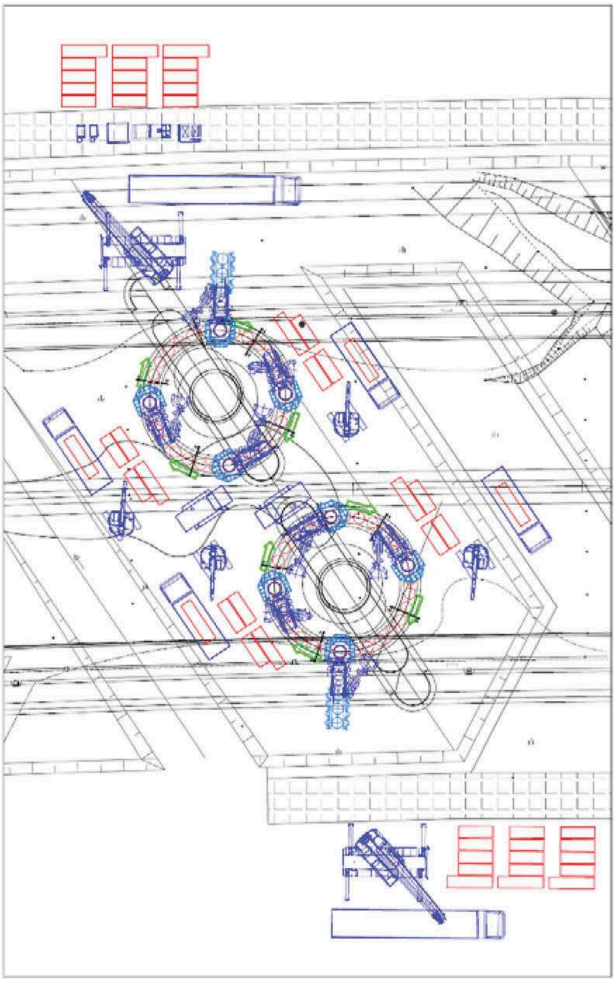

Figure 12. Machine layout for the down bound lane.

Figure 13. Piling work at the open place.

was 1000 mm, a spliced steel pipe pile was pressed in without water by 1.0m or more.

The load applied was set to 1.5 times the maximum normal vertical reaction force stipulated in the design, and the loading test was conducted by applying the press-in force to the pile top by the Gyro Piler for low headroom. For some piers, it was necessary to apply a test load exceeding the upper limit of the press-in force of the Gyro Piler for low headroom. Therefore, the loading

Figure 14. Piling work beneath a girder.

Table 5. Measurements.

Planned ground level	21.41 m
Planned pile top level	22.41 m
Planned pile toe level	3.91 m
Planned level of the support layer	8.56 m
Estimated level of the support layer	10.68 m
Actual ground level	21.68 m
Actual pile top level	22.42 m
Actual pile toe level	3.92 m
Specified embedded length to the support layer	4.65 m
Estimated embedded length to the support layer	6.76 m
Confirmation of the embedded length	OK

test was carried out using a dedicated press-in machine compatible with the test load.

The allowable pile top displacement was set to 1% or less of the outer diameter of the steel pipe pile. As the outer diameter of the steel pipe pile was 1000 mm in this project, it was intended to verify that the pile top displacement was within 10mm.

5 RESULTS

5.1 *Construction process*

The entire construction project was performed during three drought seasons in the years from 2018 to 2020.

The press-in piling of steel pipe piles was completed in a total of nine months over two drought seasons, with the first phase taking approximately five months from late November 2018 to late April 2019 and the second phase taking approximately four months from late December 2019 to late April 2020.

Table 4 shows the cycle time of press-in piling of steel pipe piles at the pier P2 of the down bound lanes. The cycle time was about 300 minutes for each pile beneath a bridge girder and about 540 minutes beneath a bridge beam.

Table 4. Cycle time of piling at the pier P2 of the down bound lanes.

[Under the beam] 5.3m overhead clearance
SKK400, 1000mm O.D., t10mm, 18.5m long
Number of joints: 11 welded joints
Average cycle time: 540 min per pile
[Under the girder] 7.9m overhead clearance
SKK400, 1000mm O.D., t10mm, 18.5m long
Number of joints: 4 welded joints
Average cycle time: 300 min per pile

*Including welding and inspection time

5.2 *Confirmation of reaching the support layer*

The press-in data was used to estimate whether the steel pipe pile toe has reached the support layer. Figure 15 shows an example of investigation at the pier P2 of the down bound lanes and Table 5 shows that results of verifying that the piles have reached the support layer.

At the pier P2 of the down bound lanes, the design length of the pile section penetrated into the support layer was 4.65m. According to the press-in data, the rotation torque started to increase at around 11.5m from the ground.

This implies that the toe of the steel pipe pile reached the dense support layer of clayey gravel and that the press-in force applied to the pile toe ring bits caused a greater resistance against ground cutting in this layer than in the overlying gravel layer.

5.3 *Loading test*

The maximum normal vertical reaction force specified in the design for the pier P2 was 1135 kN. Therefore, the load specified for the loading test using the Gyro Piler was first set to 1702.5 kN (1.5 times 1135 kN), which was then rounded up to 1750 kN. The loading test was conducted by setting the pile top displacement allowance to no more than 10mm, which corresponds to 1% of the steel pipe pile outer diameter of 1000mm. As the upper limit of press-in force was 1500 kN for the Gyro Piler for low headroom, a dedicated press-in piling machine with an upper-limit press-in force of 2600 kN was used in the loading test.

The loading test (See Figure 16) on piles at the pier P2 resulted in a pile head displacement of 9.22 mm, which was within the allowable displacement of 10 mm.

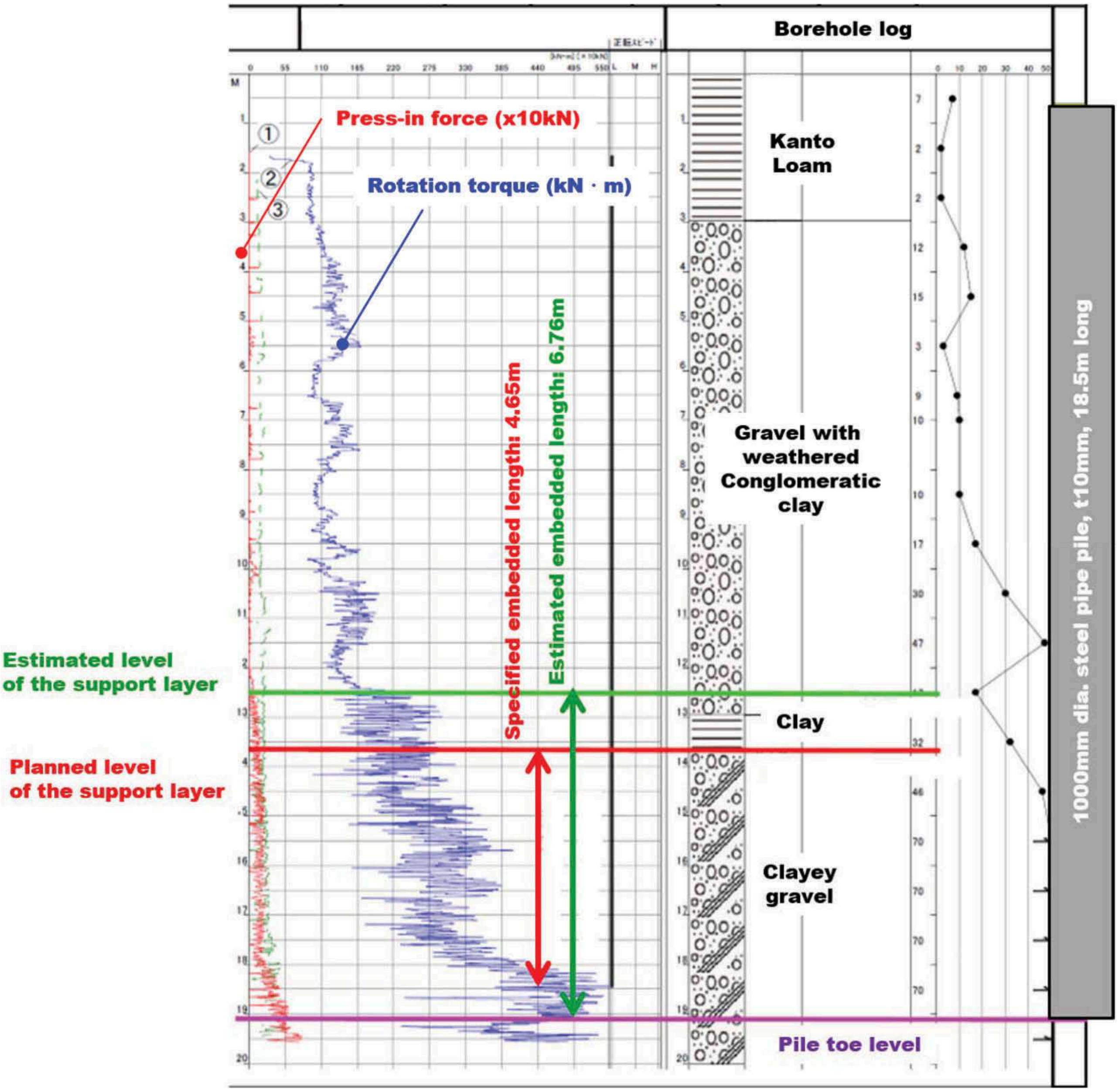

Figure 15. Press-in data.

Figure 16. Vertical loading test.

6 SUMMARY

This paper describes an example of using the press-in pilling method to install steel pipe piles into the hard and supporting ground under overhead restrictions. The applicability of the Gyropress Method has been demonstrated under soil conditions in which the applicability of the standard press-in or the press-in piling with water jetting after replacing existing soil with fine sand by a full-slewing excavator is less certain.

Although many issues arose from the planning to the piling stages under the construction conditions, it was possible to complete the piling for the oval shaped foundation within limited drought seasons by using the Gyropress Method. On the basis of knowledge obtained from this project, the author intends to make technological improvements in the press-in piling method for special conditions, such as overhead restrictions and narrow spaces.

REFERENCES

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