Case Study on Estimation of Ground Information with the Use of Construction Data in Press-in Method

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ABSTRACT

The Press-in Method is a pile construction method in which a pile is statically pressed-in by holding the reaction piles. With the method, it is possible to reduce noise and vibration that usually emanate in conventional pile installations, and to shorten the construction period of temporary works. This construction method is widely adopted especially in urban areas for this advantage. In addition, piles can be installed into hard ground by the Press-in Method assisted with augering, or by the Press-in Method assisted with rotary cutting. The application range of the Press-in Method is spreading more and more. In the Press-in Method, construction data such as time, depth, press-in force and torque can be automatically and continuously recorded, and are used *e.g.*, in construction management.

Using the construction data collected from the three methods (the standard Press-in Method, the Press-in Method assisted with augering and the Press-in Method assisted with rotary cutting), IPA(2017) has compiled methods of estimating ground information at the location of the pile toe. In this paper, validity of the estimation methods was examined, estimating ground information by the three methods with the construction data obtained in the field, and comparing it with the already given ground information. In addition, demonstrated was possibility of extending construction conditions that constitute premise for the application of the estimation methods.

Key words: *Press-in, Press-in Method assisted with augering, Press-in Method assisted with rotary cutting, Ground survey method*

1. INTRODUCTION

1.1. Background

The Press-in Method is one of the pile penetration techniques, where a pile is installed into ground by a static load using a hydraulic pressure. The method has advantages that the press-in operation can be carried out with low noise and low vibration, and that the construction period of temporary works can be reduced. It has been widely adopted for constructions in urban areas. In addition, the construction data such as press-in force during press-in operation of piles can be automatically recorded, and have been used for construction management. The authors term these construction data the Pile Penetration Test (PPT) data, and are trying to use them in the estimation of ground information, optimization of construction conditions and automated operation techniques.

Depending on the piles to be pressed-in and on ground condition, the Press-in Method is divided into several construction methods (**Fig. 1**): the standard Press-in Method; the Press-in Method assisted with augering in which steel sheet piles can be pressed into

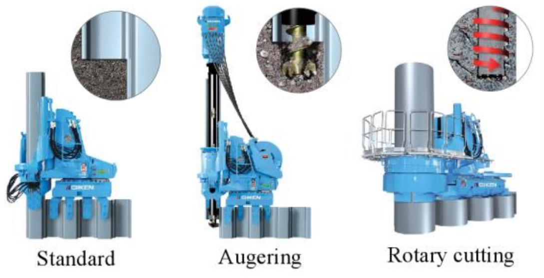

Fig. 1 Various Press-in Methods

stiff ground; and the Press-in Method assisted with rotary cutting in which a steel tubular pile with cutting bits at the toe of the pile is rotated and pressed into stiff ground. IPA (2017) has compiled estimation methods of ground information using these three press-in methods.

1.2. Objectives

If the estimation techniques of ground information by the Press-in Method are used, it is possible to efficiently implement complementation of the given ground information, dealing with unexpected ground conditions and managing embedded length of piles. Note that it is necessary to verify accuracy in these estimation methods, since they have just been developed. In this paper, ground information will be estimated using the PPT data obtained from each of the three press-in methods (the standard Press-in Method, the Press-in Method assisted with augering and the Press-in Method assisted with rotary cutting), and their validity will be verified by comparing the estimated information with the given one.

2. CASE STUDY

2.1. Standard Press-in Method

The standard Press-in Method is used to press-in steel sheet piles and steel tubular sheet piles/piles into relatively soft ground. In the method, using "surging" to move piles up and down during press-in operation, toe resistance of the pile is obtained from the press-in force, and ground information (*N*-value and soil type) is

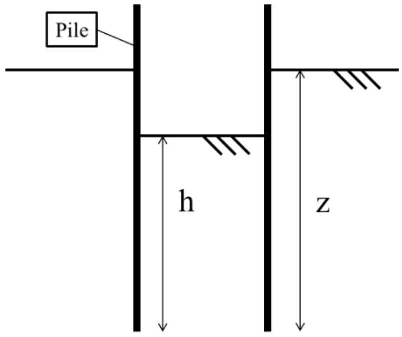

Fig. 2 Definition of plugging

estimated by converting the toe resistance into that in the cone penetration test (CPT) (Ogawa et al. 2012). During the pile installation, a phenomenon called "plugging" occurs, where the inside of an open-ended pile is plugged with consolidated soil. This plugging greatly changes the toe resistance of the pile, so it is necessary to consider incremental filling ratio (IFR) of the pile during pile installation for an accurate estimation of the ground information. IFR is represented by the movement of inner soil during pile installation (**Fig. 2** and **Eq. 1**).

$$IFR = \frac{dh}{dz} \cdots (1)$$

where z: penetration length, h: Penetration length inside the steel tubular pile. IPA (2017) has defined the IFR values uniquely, depending on the shape of the sheet pile. These values were used in the analysis. In the following sections, a couple of case studies at two different construction sites will be introduced.

2.1.1. Case 1

In Case 1, the standard Press-in Method was once tested, in the soft ground consisting of alternating layers of sand and silt. The construction condition is listed in

Table 1. Construction condition of standard Press-in Method

Case No			Case1	Case2	
Test No			J17-01_96	P14-01_No1	P14-01_No2
Machine			F111	F201	F201
Pile	Type		SP-III	SP-IIIw	SP-IIIw
	Width	m	0.4	0.6	0.6
	Thickness	m	0.013	0.0134	0.0134
	Length	m	15	17.5	17.5
Downward	Displacement	m	0.4	0.4	0.4
	Rate	m/min	2.5	1.3	1.3
Upward	Displacement	m	0.2	0.2	0.2
	Rate	m/min	1.9	3.7	3.7
Upper limit	Installation Force	kN	350	300	500
	IFR		0.5	0.9	0.9

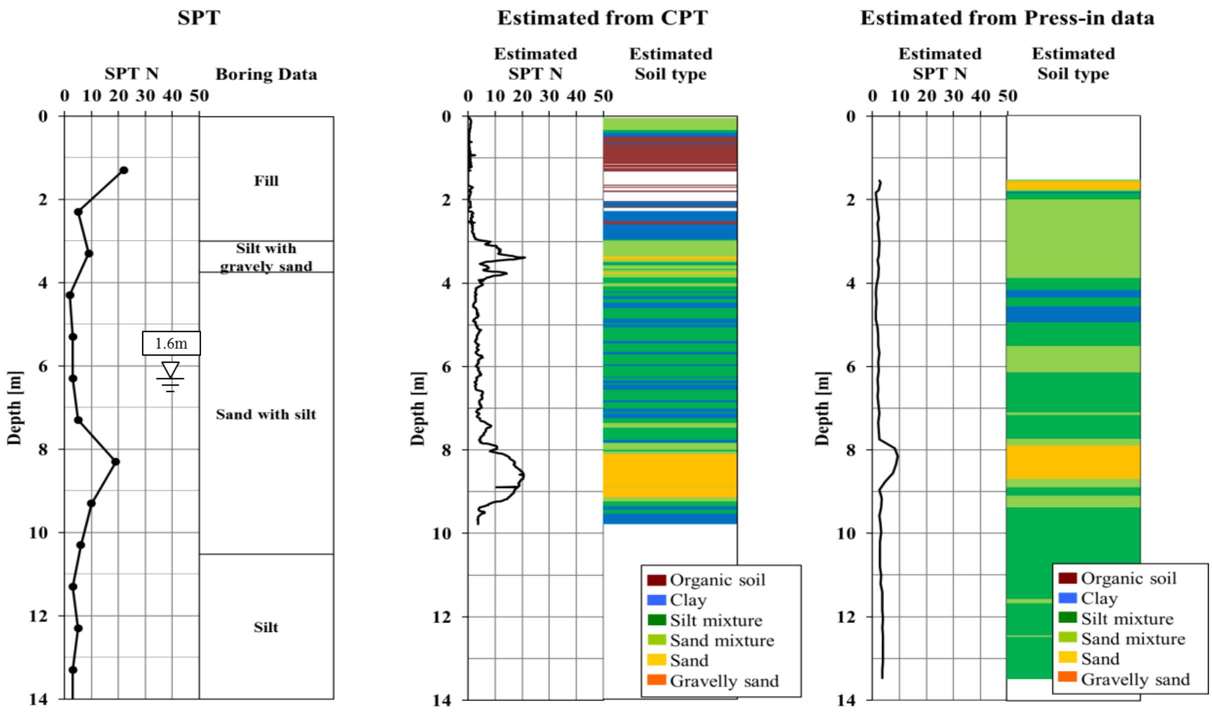

Fig. 3 Estimated result (Case 1)

Table 1. It may be noted that the standard penetration test (SPT) and CPT considered as the given ground conditions were carried out in the vicinity of the Press-in Method test location. According to the estimation result shown in **Fig.3**, the estimation result by the PPT data is generally consistent with those by SPT and CPT. However, the *N*-value at a depth of about 8 m is evaluated somewhat lower than those from SPT and CPT. The following factors might affect the estimation result:

1) IFR is smaller than expected, and the toe resistance was evaluated lower, leading to a smaller estimated *N*-value.
2) Compared with CPT and SPT, the estimation of the ground information using the PPT data is less sensitive to depth. Therefore, *N*-value of a thin layer that might actually have a high *N*-value was estimated lower.
3) The rate effect occurred and the toe resistance was lower, thereby the *N*-value of the ground was evaluated lower.

As for the factor 1) above, calculation was carried out, taking IFR = 0.5 in the estimation equation. In reality, however, indentation of the ground surface is small, and no plugging likely happened (IFR≒1). This led to a lower estimated *N*-value. As for the factor 2), the thickness of the layer with a high *N*-value is 3 to 4 times the width of the pile. This cannot be called a thin layer, and this factor is unlikely. For factor 3), the rate effect is that higher penetration rate will make the drainage condition of soil around a pile worse (more undrained). This will lead to the generation of higher excess pore water pressure, and smaller effective stress in a soil. It is likely that a rate effect occurred since the section in question is below the groundwater table, and the drainage condition was different from that in CPT. According to Okada et al. (2013), the maximum reduction of toe resistance due to the rate effect is about 35 %, and this might have been the reason for the N-value being evaluated lower. It is difficult to rigorously evaluate the soil type, but it may be said that the estimated result by the PPT data is in good agreement with that by CPT.

2.1.2. Case 2

In Case 2, the standard Press-in Method was tested twice in the ground with soft layer consisting of alternating sand and silt, and a gravel layer with a high *N*-value. The construction condition is listed in **Table 1**. Note that SPT was carried out in a location about 200 m away from the test site of the Press-in Method. According to the estimation result by PPT data shown in

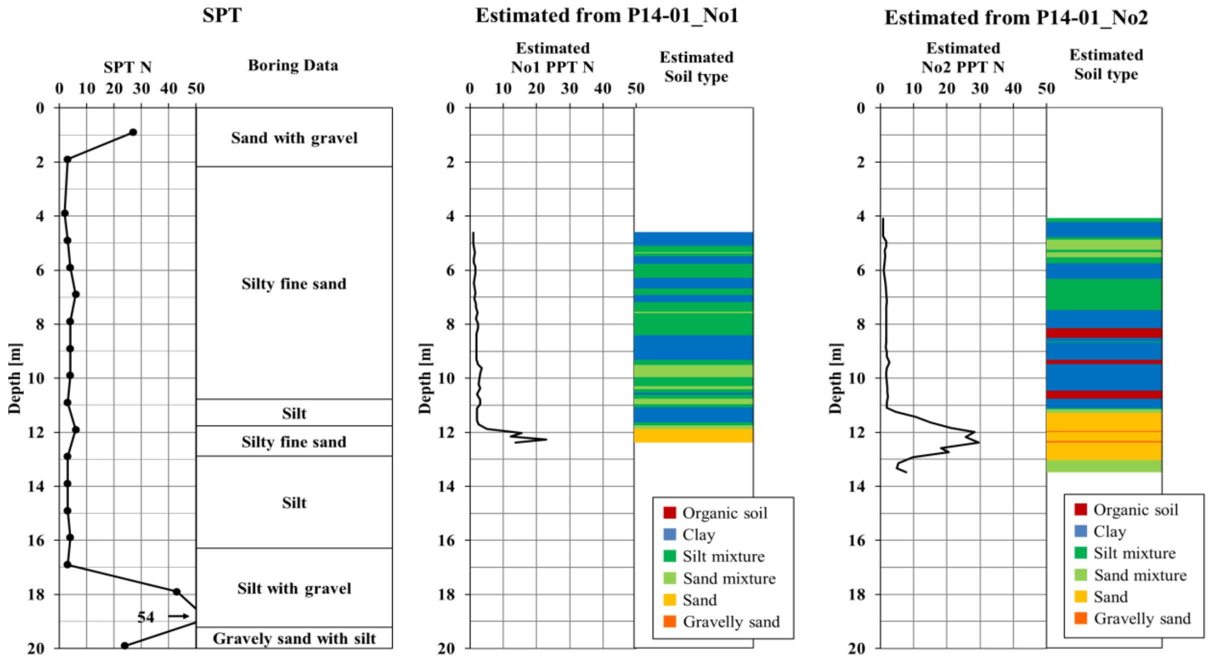

Fig. 4 Estimated results (Case 2)

Fig. 4, there is a relatively stiff sand layer with N-values ranging from 20 to 30 at a depth of about 12 m. This has not been detected in SPT. Since the SPT was performed away from the test site of the Press-in Method, the ground conditions might have been different from each other in the two locations. Originally, piles were to be installed by the standard Press-in Method, based on the SPT data. However, following this test result, the design was changed from the standard Press-in Method to the Press-in Method assisted with water jetting or the Press-in Method assisted with augering, both of which could be applied to stiff ground.

2.1.3. Summary for the Standard Press-in Method

In the estimation of ground information by the standard Press-in Method, the following were clarified:

1) Estimation with the PPT data is fairly consistent with those of the given ground information by SPT and CPT.
2) In the case where the existing ground investigation location is away from the construction site, it is possible to complement the ground information using the PPT data.
3) To improve the estimation accuracy, it is necessary to establish a proper IFR model for steel sheet piles, and to take the rate effect into consideration.

2.2. Press-in Method Assisted with Augering

The Press-in Method assisted with augering is the one used when installing steel sheet piles into stiff ground. In the Press-in Method assisted with augering, there are “pre-augering” method in which the ground is augered prior to installing steel sheet piles, and the “simultaneous augering” method where the ground is augered with press-in operation of steel sheet piles simultaneously. The ground information is estimated from the torque and press-in force exerted to the auger head during pre-augering. The ground information is estimated by two different ways (Ishihara et al. 2015a): a method to use only torque (Power Function Method, **Eq. 2**), and one to use both torque and press-in force (MWD method, **Eq. 3**).

$$N = A\frac{T}{(v/n)^{\gamma}} \cdots (2)$$

$$N = C_n(F + 2\pi nT/v) \cdots (3)$$

where, N: SPT N-value, A, γ, C_n: the parameters, T: rotational torque, n: rotational revolution, v: the penetration rate, F: jacking force during press-in. In the current evaluation, both methods were used. In addition, the parameters used in each case were from the inverse analysis with the PPT data for an auger diameter of 450 mm. Therefore, the application range of the estimation methods is limited to this diameter only. Here, estimation was attempted for an auger diameter of 540 mm, by

Table 2. Construction condition of Press-in Method assisted with augering

Case No			Case3				Case4
Test No			J15-05-1	J15-05-9	J15-06-13	J15-06-15	P16-06-5
Machine			F201	F201	F201	F201	F201
Pile	Type		SP-III	SP-III	SP-III	SP-III	SP-III
	Width	m	0.4	0.4	0.4	0.4	0.4
	Thickness	m	0.013	0.013	0.013	0.013	0.013
	Length	m	15	15	15	15	9
Auger	Diameter		φ450	φ450	φ450	φ450	φ540
	Number of blades		3	3	3	3	3

applying some corrections to the press-in force and torque. Estimation cases for the two different construction sites will be introduced in the following sections.

2.2.1. Case 3

In Case 3, four tests with the Press-in Method assisted with augering were conducted in the ground consisting of boulders and gravels. The construction condition is listed in **Table 2**. In the four tests, press-in operation was performed under the same condition. It may be seen in **Fig. 5** that the estimation result is in good agreement with the given ground condition by the SPT. Though the closer look at the figure may reveal that the four estimation results are not in agreement at several depths, it seems the reason is due to the difference in ground conditions. Note that SPT shows a large *N*-value at a depth of about 5 m. This is because the *N*-value was evaluated large due to a small diameter of the sampler of SPT, when it encountered obstructions such as boulder or gravel. On the other hand, it is thought that a large increase in *N*-value is suppressed due to the 450mm diameter auger head which is larger than the sampler utilized in the SPT in the Press-in Method assisted with augering. In addition, the Power Function Method shows somewhat higher *N*-value, compared with that in the SPT.

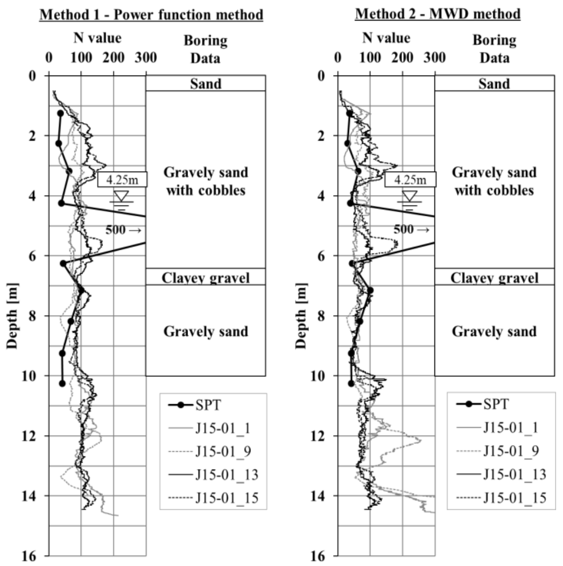

Fig. 5 Estimated result (Case 3)

2.2.2. Case 4

In Case 4, a test by the Press-in Method assisted with augering was conducted in the ground consisting of weathered shale. The construction condition is listed in **Table 2**. In this construction site, the diameter of the auger head used is as large as 540 mm. If the existing estimation equation is used as is, the result will be overestimated. Here, a correction was made to the torque and press-in force measured, and the existing estimation equations were used as were.

Toe resistance and toe torque on the auger head with a radius of R may be given by the following equations, respectively:

$$Q_b = N_w * q_b * R * L \cdots (4)$$

$$T_b = N_w \int r * q_b * tan\delta * dA$$

$$= N_w * q_b * tan\delta * \frac{1}{2} R^2 L \cdots (5)$$

where, Q_b: toe resistance, T_b: toe torque, q_b: unit toe resistance, L: width of wing, N_w: number of wings, and δ: friction angle of the wall.

From **Fig. 6**, the auger diameter of 540 mm is 1.2 times the diameter of 450 mm. Therefore, it is thought that the toe resistance will be 1.2 times, and the toe torque will be 1.2^2 = 1.44 times, when the auger head diameter is increased from 450 to 540 mm. The PPT data obtained with the 540 mm diameter auger head were

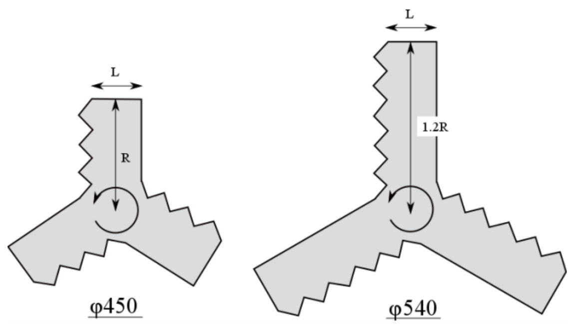

Fig. 6 Conversion of auger head diameter

corrected to those for the 450 mm diameter auger head. It may be seen in **Fig. 7** that the estimation results with corrected values are closer to the *N*-value from the SPT,

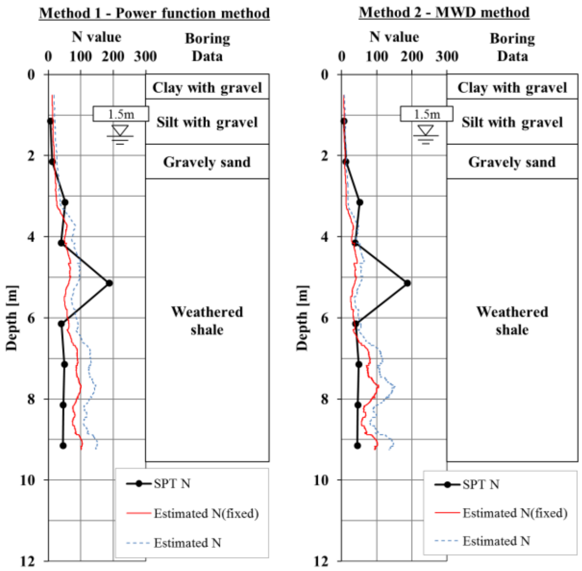

Fig. 7 Estimated result (Case 4)

compared with those without any correction.

2.2.3. Summary for the Press-in Method assisted with augering

The following were clarified in the estimation of ground information by the Press-in Method assisted with augering:

1) Compared with the *N*-value in SPT, instantaneous increase in *N*-value is reduced when the auger head hits gravel or boulder.
2) Both estimation methods give close results to those of existing ground information. The MWD Method gives a closer result than the Power Function Method.
3) For the auger head with a diameter of 540 mm, relatively good estimation result can be obtained, if the torque and press-in force are corrected.

In addition, there is limitation in the application of SPT to stiff grounds with *N*-values over 50. In such cases, the estimation of ground information with the Press-in Method assisted with augering is effective. It appears important to increase case studies, and to improve the estimation accuracy.

2.3. Press-in Method Assisted by Rotary Cutting

The Press-in Method assisted with rotary cutting is used when installing steel tubular piles into stiff ground. With the teeth called cutting bits at the pile toe, the pile is pressed-in while cutting ground, rotating the steel tubular pile. In the method, consumed energy is calculated from the torque and press-in force during the press-in operation, and is converted to the penetration energy in SPT, and ground information (converted *N*-value) is estimated (Ishihara et al. 2015b). In the estimation of ground information by the Press-in Method assisted with rotary cutting, IFR during press-in operation is required. However, there are very few cases where measurements are taken at construction sites. Here, considered was the difference between the result from the easily measurable Plug Length Ratio (PLR, **Eq. 6**) and that using IFR.

$$PLR = \frac{h_f}{z_f} \cdots (6)$$

where z_f: penetration length at the completion of press-in operation and h_f: penetration length inside the steel tubular pile at the completion of press-in operation.

The case studies at the two different construction sites will be presented in the following sections.

2.3.1. Case 5

One test was performed by the Press-in Method assisted with rotary cutting in a relatively stiff ground consisting of sand and gravel. The construction condition is summarized in **Table 3**. At this site the movement of soil surface inside the steel tubular pile was continuously

Table 3. Construction condition of Press-in Method assisted with rotary cutting

Case No			Case5	Case6
Test No			C15-07	J17-01_No1
Machine			SP10	F401
Pile	Diameter	m	1	1
	Thickness	m	0.012	0.012
	Length	m	12	25
	Number of teeth		6	6
	Flow rate	L/min	60	15
Downward	Installation Rate	m/min	0.6-1.2	0.7~1.5
Upward	Displacement	m	0.05	0.05
	Installation Rate	m/min	0.4-0.9	0.7~1.8
	Rotation Rate	min-1	6.4	9~11
Upper limit	Installation Force	kN	400	200~1000
	Installation Torque	kN*m	?	250~400
	PLR		0.6	1

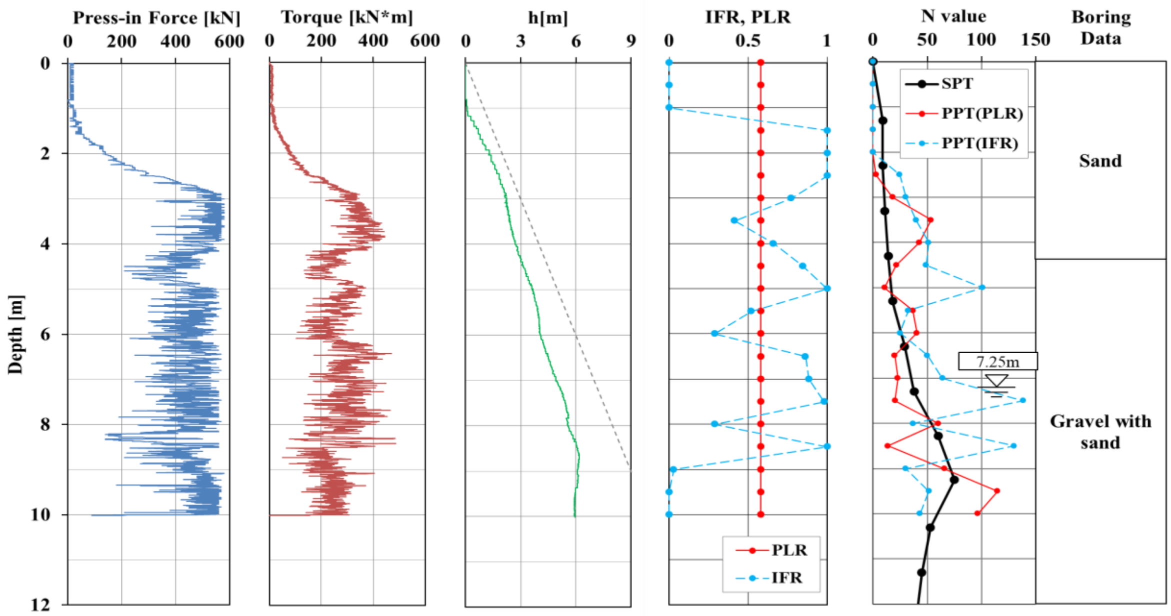

Fig. 8 Estimated result (Case 5)

measured, and IFR was calculated at every 0.5 m. It may be seen in **Fig. 8** that plugging phenomena are repeatedly occurring at depths ranging from 2 to 9 m. Here, the estimation of *N*-value using IFR was compared with that using PLR.

The estimation result using PLR shows similar *N*-values to those by SPT, but the result using IFR is scattered. In particular, in a section at depths between 2 and 9 m, where plugging and unplugging were repeated, the estimation result using IFR tends to largely scatter. The following reasons may be considered :

1) Measurement accuracy of IFR is poor.
2) *N*-values at sections where the pile is not plugged are overestimated.

As for factor 1), the distance from the pile top to the soil surface inside the steel tubular pile is measured using a wire-type stroke sensor with a plumb bob. However, the soil surface tends to fluidize due to existing water, and it is difficult to measure h accurately. Especially in a section where IFR often changes, IFR is calculated differently from the real IFR, which may cause a big error. On the other hand, the result using PLR is close to that of SPT, compared with the result with IFR. This is because overall IFR is averaged, and the estimation result is not extremely off. It may however be noted that PLR cannot adapt to the change in the depth direction. It is therefore inferred that IFR is essential to have an estimation with high accuracy.

As for factor 2, inner shaft resistance is 0 in calculation, as long as the pile is not plugged. In reality, however, there may be inner shaft resistance in a degree where plugging does not occur. The energy consumed as inner shaft resistance is regarded in calculation as one that occurred in toe resistance, leading to an overestimated *N*-value. It is thought that this trend is likely to happen, especially when there is a high inner

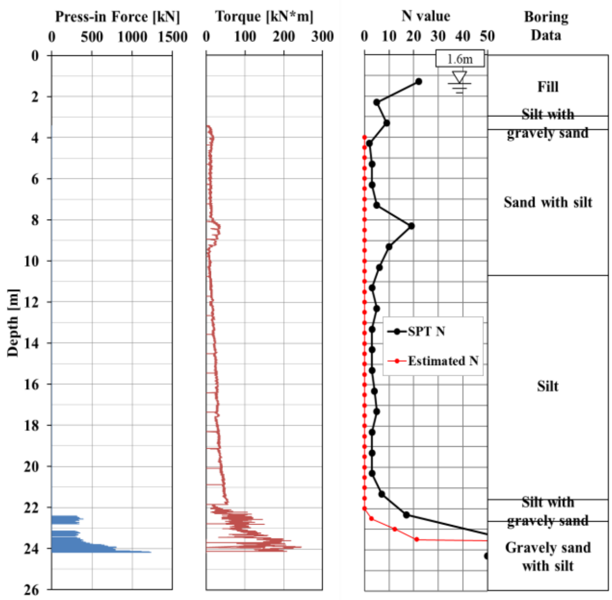

Fig. 9 Estimated result (Case 6)

shaft resistance.

2.3.2. Case 6

In Case 6, a test by the Press-in Method assisted with rotary cutting was conducted in a ground consisting of alternating layers of fairly loose sand and silt, underlain by stiff sand and gravel layer. The construction condition is listed in **Table 3**. In this site, since the measurement of soil surface inside the steel tubular pile was not taken, the ground information is estimated only by PLR. According to **Fig. 9**, the estimation result and the given ground condition have a similar trend. The ground in this site is loose above the 22 m depth and the press-in force is 0. For this reason, estimated *N*-value became 0, which shows underestimation. On the other hand, in the sand and gravel layer below the 22 m depth, *N*-value from SPT quickly increases. This phenomenon is represented in the estimation result as well.

2.3.3. Summary for the Press-in Method assisted with rotary cutting

For the estimation of ground information by the Press-in Method assisted with rotary cutting, the following observations may be made:

1) Since the estimation result largely changes depending on IFR, it is necessary to develop a measurement method of IFR in good accuracy.
2) The estimation method with PLR returns a good estimation results, even when IFR extremely changes.
3) When the *N*-value of the ground is low, and the press-in force is 0, the estimated result is underestimated.

3. CONCLUSIONS

In this paper, with the PPT data obtained at each site, the ground information was estimated using the three different Press-in Methods: the standard Press-in Method; the Press-in Method assisted with augering; and the Press-in Method assisted with rotary cutting. From the examination of each case, the following summary and conclusions may be drawn:

- The standard Press-in Method estimated very similar ground information to the given information. For more accurate estimation, however, it is necessary to establish a proper IFR model and to take the rate effect into consideration.
- The Press-in Method assisted with augering too estimated very similar ground information to the given information. The result by the MWD method is closer to the given ground information than that by the Power function method. In addition, estimation of ground information was tried using an auger head diameter of 540 mm, and relatively a good result was obtained after correcting toe resistance and toe torque. More detailed examinations would be necessary, collecting more data in future.
- In the Press-in Method assisted with rotary cutting, the estimation result largely depends on IFR. It is therefore necessary to have a measurement method with high accuracy. The estimation method with PLR provides good results, even when IFR extremely changes. However, for an estimation with high accuracy, IFR is essential, and it is necessary to review the measurement methods in future.

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