Simple static vertical and horizontal loading tests on small pipe piles using press-in machine

Y. Ishihara
Center Director, Press-in Technology R&D Center, GIKEN LTD., Kochi, Japan
M. Eguchi
Assistant Manager, Scientific Research Section, GIKEN LTD., Kochi, Japan
A. Mori
Assistant Manager, Scientific Research Section, GIKEN LTD., Kochi, Japan
Y. Toda
Researcher, Scientific Research Section, GIKEN LTD., Kochi, Japan

ABSTRACT

In recent years, not only steel pipe piles but also steel sheet piles are increasingly used for non-temporary structures. To further promote this trend, the knowledge on the performance of pipe piles or sheet piles embedded in the ground is essential. This can be achieved by accumulating the results of static vertical and horizontal loading tests on the piles. However, conducting the static loading test requires a certain amount of time and cost, and the accumulation of the results is not easy. If the static loading test is conducted by the press-in machine, the time and cost for the test can be significantly reduced, mainly because it can save temporary works for applying the load and gaining the reaction force. In this study, a series of full-scale field tests were carried out to verify a simple static loading test using a press-in machine (Simple SLT) through comparison with a normal static loading test (Normal SLT). These tests were conducted on small-diameter pipe piles installed by the Rotary Cutting Press-in (RCP) method, assuming the construction on the Moon. As a result, the results of the Simple SLT were confirmed to be equivalent to those of the Normal SLT, provided that the measurement of load and displacement was calibrated in advance.

Key words: *Static loading test, Rotary Cutting Press-in, Small-diameter pipe pile*

1. Background and objectives

In recent years, the steel pipe piles and steel sheet piles installed by the press-in method are increasingly used for non-temporary structures, including underground parking lots (Takeuchi et al., 2018), railway bridge piers (Kasahara et al., 2018), coastal levees (Ishihara et al., 2020), river embankments (Takuma et al., 2021), the stress-cut off wall beside an embankment (Otani, 2021) and architectural buildings (Kondo, 2023). The design of a non-temporary structure is required to be more reliable. To promote this trend, the knowledge on the performance of pipe piles or sheet piles embedded in the ground is essential. This can be achieved by accumulating the results of static vertical and horizontal loading tests on the piles. However, conducting the static loading test requires a certain amount of time and cost, and the accumulation of the results is not easy.

If the static loading test is conducted using the press-in machine (**Fig. 1**), the time and cost for the test can be significantly reduced, mainly because it can save temporary works for applying the load and gaining the reaction force. This advantage will contribute to the construction projects on the Moon as well as on the Earth.

Ishihara et al. (2020) conducted a series of vertical static loading tests on steel sheet piles using a press-in machine. In their tests, the head load obtained by the press-in machine was validated by comparing it with that

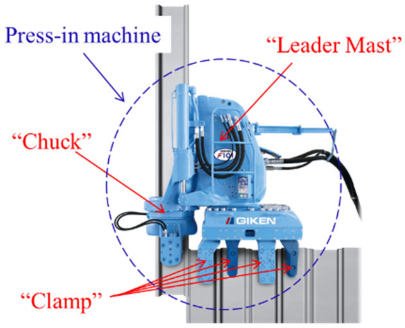

Fig. 1 Typical shape of press-in machine

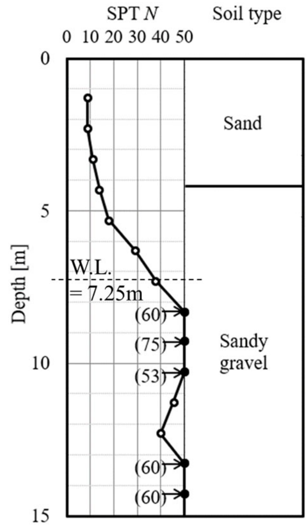

Fig. 2 Ground conditions of field test

obtained by an external load cell. On the other hand, an external displacement transducer was used to obtain the pile head displacement, and the validity of the pile head displacement obtained by the press-in machine was not investigated. In addition, the horizontal loading test was out of their focus.

This study deals with vertical and horizontal static loading tests, and aims to validate the simple static loading test using a press-in machine (Simple SLT) through comparison with a normal static loading test (Normal SLT). In particular, the vertical displacement of the pile, the horizontal load applied to the pile and the horizontal displacement of the pile obtained by the press-in machine are validated.

2. Methods of field test

The Simple SLT and Normal SLT were conducted on piles installed by the Rotary Cutting Press-in (RCP), both vertically and horizontally. The ground conditions and the test cases are shown in **Fig. 2** and **Table 1**, respectively. The test piles were closed-ended or open-ended steel pipe piles with an outer diameter of 318.5 mm.

Table 1 Test cases

Test case	Pile	Loading test
J2203-03	Open	Simple SLT (vertical)
J2203-04	Open	Simple SLT (horizontal)
J2203-05	Open	Normal SLT (vertical)
J2203-06	Open	Normal SLT (horizontal)
J2301-p-01	Open	Simple SLT (vertical)
J2301-01	Open	Simple SLT (vertical)
J2301-02	Open	Simple SLT (vertical)

Table 2 compares the methods of the Simple SLT and Normal SLT adopted in the field test. The Simple SLT was designed to be completed by the press-in machine, including the securing of the reaction force and the conduction of loading and measurement. As for the Normal SLT, the devices for loading and measurement were external (i.e. not equipped in the press-in machine), while the reaction force was secured by the press-in machine. The test methods for both loading tests were basically in accordance with JGS 1811-2002 (JGS, 2002) and JGS 1831-2010 (JGS, 2010). The time between the end of the RCP installation and the start of each loading test (curing period, t_{LT}) was 7 days for all tests.

Fig. 3 shows the situation of conducting the Simple SLT (vertical). The press-in machine gripped the test pile at its Chuck and applied a press-in force to the pile. The reaction force was secured by the press-in machine, by holding the previously installed reaction piles with its Clamps. The press-in force and pile head displacement were obtained using a measurement system equipped in the press-in machine. In addition, external measurement devices were also used to measure the pile head displacement, to confirm the validity of the measurement by the press-in machine.

Table 2 Methods of Simple SLT and Normal SLT

(a) Vertical loading test

	Simple SLT	Normal SLT
Loading method	Continuous loading	Continuous loading
Loading rate	30 minutes or longer since the start of loading to the end of unloading	30 minutes or longer since the start of loading to the end of unloading
Loading device	Press-in machine	Hydraulic jack
Reaction force	Reaction piles (grasped by press-in machine)	Reaction piles (grasped by press-in machine)
Load measurement	Press-in machine	Load cell
Displacement measurement	Press-in machine	Displacement transducer

(b) Horizontal loading test

	Simple SLT	Normal SLT
Loading method	Continuous loading	Continuous loading
Loading rate	30 minutes or longer since the start of loading to the end of unloading	30 minutes or longer since the start of loading to the end of unloading
Loading device	Press-in machine	Hydraulic jack
Reaction force	Reaction piles (grasped by press-in machine)	Reaction piles
Load measurement	Press-in machine	Load cell
Displacement measurement	Press-in machine	Displacement transducer

The loading rate achieved by the press-in machine is generally much higher than that specified in JGS (2010). In the Simple SLT (vertical), sufficient loading time (30 minutes) was secured by applying the press-in force to the pile intermittently. The pile head load (Q) was obtained by **Eq. (1)**, by considering the press-in force (Q') and the weight of the Chuck of the press-in machine (W_C) (Ishihara et al., 2020).

$$Q = Q' + W_C \tag{1}$$

Fig. 4 shows the situation of conducting the Normal SLT (vertical). The reaction force was secured in the same way as was in the Simple SLT (vertical). A hydraulic jack and a load cell were sandwiched between the pile head and a loading jig gripped by the Chuck of the press-in machine. The head load was applied by the hydraulic jack and measured by the load cell. The pile head displacement was measured using displacement

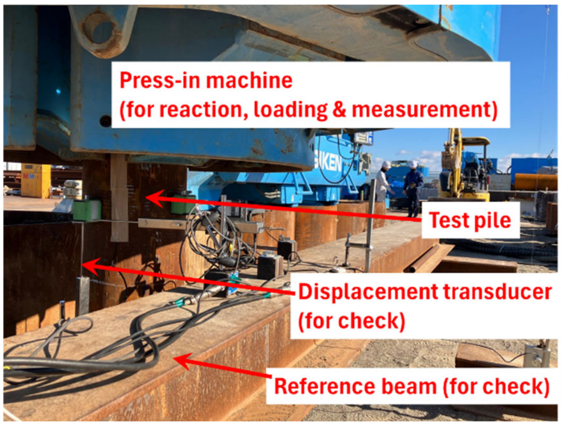

Fig. 3 Conduction of Simple SLT (vertical)

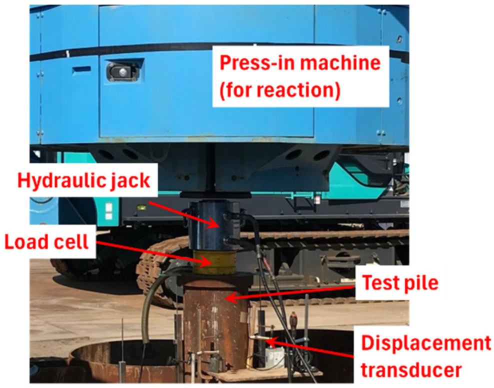

Fig. 4 Conduction of Normal SLT (vertical)

transducers which were fixed to a reference beam.

Fig. 5 shows the situation of conducting the Simple SLT (horizontal). The reaction force was secured in the same way as was in the Simple SLT (vertical). The loading jig, gripped by the Chuck of the press-in machine, was placed in contact with the test pile, and the horizontal load was applied to the test pile by moving the loading jig horizontally using a motion of the press-in machine (swing of the Leader Mast). The loading jig was made of a pile with the same outer diameter as the test pile, and a protrusion was placed at the contact point with the test pile to maintain a constant loading height (0.15 m above the ground surface) even if the horizontal displacement or inclination of the test pile progressed. The horizontal displacement of the loading jig or the center of the Chuck ($\delta h'$) was calculated using the following equation, taking into account the measured angle of swing of the Leader Mast (θ_m) and the distance from the center of swing of the Leader Mast to the center of the Chuck ($L_{(m\text{-}c)}$), as shown in **Fig. 6**.

$$\delta_h' = \theta_m \times L_{(m\text{-}c)} \tag{2}$$

In addition, the horizontal displacement of the test pile near the loading height was measured using an external displacement transducer fixed to the reference beam, to verify the displacement obtained by **Eq. (2)**.

In the Simple SLT (horizontal), the horizontal load was calculated using the following equation, taking into account the load calculated from the measured hydraulic pressure of the Swing Cylinder that enables the swinging motion of the Leader Mast and the positional relationship between the Swing Cylinder and the center of the Chuck, as illustrated in **Fig. 6**.

$$P_h' = \frac{P_{cl(l)} \times L_{(m\text{-}cl)} + P_{cl(r)} \times L_{(m\text{-}cl)}}{L_{(m\text{-}c)}} \tag{3}$$

Here, P_h' is the horizontal load calculated by the press-in machine, $L_{(m\text{-}cl)}$ is the distance between the center of swing of the Lader Mast and the Swing Cylinder, $L_{(m\text{-}c)}$ is the distance between the center of swing of the Leader Mast and the center of the Chuck, and $P_{cl(l)}$ and $P_{cl(r)}$ are the loads exerted by the left and right Swing Cylinders, respectively. The validity of **Eq. (3)** was investigated by a calibration test, as shown in **Fig. 7**. A loading jig, which was grasped by the press-in machine at its Chuck, was connected with the reaction wall via a load cell. The Leader Mast was swinged in the same way as in the Simple SLT (horizontal), and the horizontal load (P_h) was measured by the load cell. As a result, as shown in **Fig. 8**, a linear relationship was observed between P_h' and P_h. Based on this result, the following formula was adopted as a calibration method for P_h' to obtain P_h.

$$P_h = r_h \times \left(P_h' - \frac{T_{0(m\text{-}c)}}{L_{(m\text{-}c)}} \right) \tag{4}$$

Here, r_h is a reduction factor and $T_{0(m\text{-}c)}$ is a lost torque in swinging the Leader Mast, which are supposed to be specific to each press-in machine.

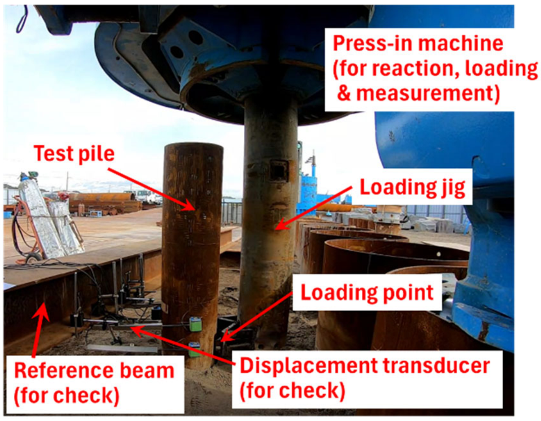

Fig. 5 Conduction of Simple SLT (horizontal)

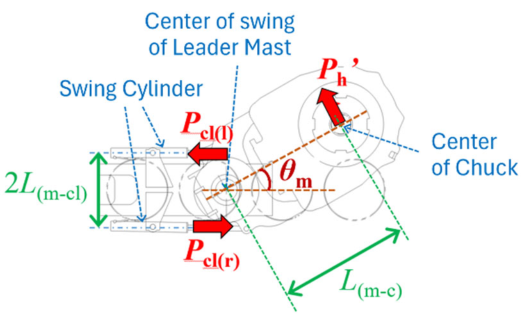

Fig. 6 Information for calculating load and displacement in Simple SLT (horizontal)

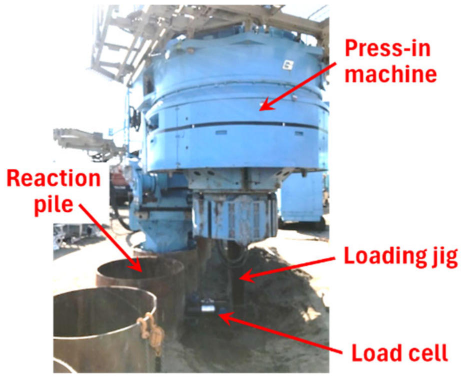

Fig. 7 Conduction of calibration test for horizontal load

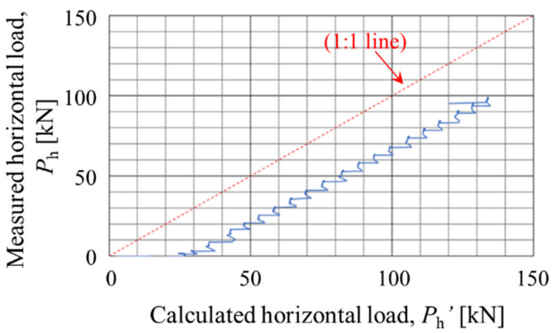

Fig. 8 Result of calibration test for horizontal load

Fig. 9 shows the situation of conducting the Normal SLT (horizontal). The reaction force was secured in the same way as was in the Simple SLT (vertical and horizontal). A hydraulic jack and a load cell were sandwiched between the test pile and the reaction wall, and the horizontal load (P_h) was applied by the hydraulic jack while being measured by the load cell. The loading height was the same as in the Simple SLT (0.15 m above the ground surface). The horizontal displacement was measured using an external displacement transducer fixed to the reference beam.

3. Results of field test and validity of Simple SLT

The results of the Simple SLT (vertical) are shown in **Fig. 10**. For the displacement, both of the information obtained by the press-in machine (δ_v') and that by the external transducer (δ_v) were used. As can be confirmed by the figure, the stiffness of the pile was smaller when δ_v' was used, especially for the smaller displacement where the pile showed a relatively elastic response.

The reason for this was thought to be that δ_v' included a measurement error (δ_v''), as expressed by:

$$\delta_v' = \delta_v + \delta_v'' \tag{5}$$

Fig. 11 shows the relationship between δ_v'' and the pile head load (Q) during the loading tests. A linear correlation is confirmed between δ_v'' and Q, especially when Q is greater than 260 kN. This relationship can be written as:

$$\delta_v'' = \delta_{v0}'' + \alpha_v \times \left(Q - Q_0\right) \tag{6}$$

The parameters α_v, δ_{v0}'' and Q_0 are presumably dependent on the type of the press-in machine, as the main cause for δ_v'' is thought to be the slight inclination of the press-in machine when applying a vertical load to the pile as illustrated in **Fig. 12**. By coupling **Eqs. (5)** & **(6)**, a method of calibrating the vertical displacement can be obtained as:

$$\delta_v = \delta_v' - \delta_{v0}'' - \alpha_v \times \left(Q - Q_0\right) \qquad (6)$$

Fig. 13 shows the results of the Simple SLT (vertical), where the displacement was expressed by δ_v directly obtained by the external transducer or by the calibrated δ_v' (i.e. the δ_v value obtained by **Eq. (6)** based on the measurement by the press-in machine). The two curves show a good agreement in each test. **Fig. 14** compares the load displacement curves obtained in the

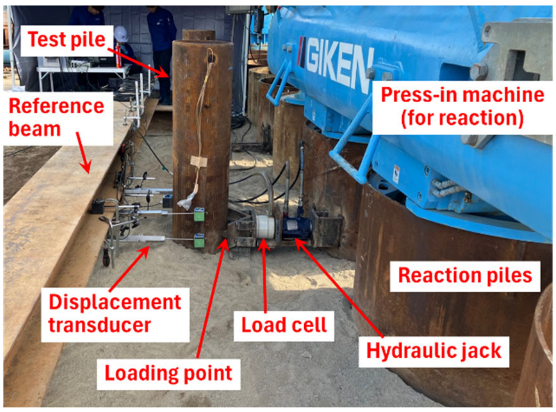

Fig. 9 Conduction of Normal SLT (horizontal)

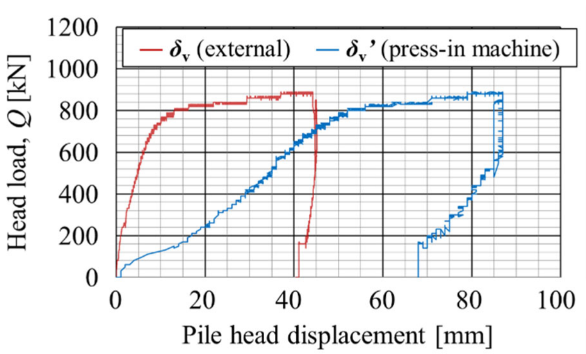

Fig. 10 Results of Simple SLT (vertical) in J2203-03

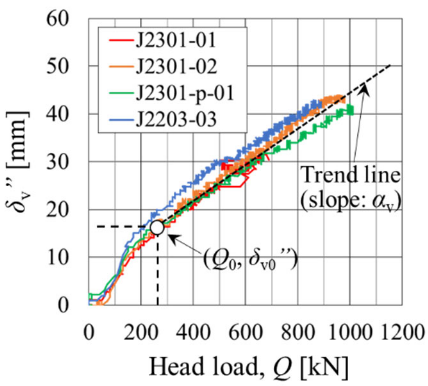

Fig. 11 Relationship between δ_v'' and Q observed in Simple SLT

Simple SLT (vertical) using the calibrated δ_v' and those obtained from the Normal SLT (vertical). The results are consistent with each other. These results suggest the validity of the Simple SLT (vertical) when the calibrated δ_v' is adopted.

Fig. 15 shows the results of the Simple SLT (horizontal). For the displacement, both of the information obtained by the press-in machine (δ_h') and that by the external transducer (δ_h) were used. In both cases, the pile behavior was elastic, but the stiffness was smaller when δ_h' was used.

Fig. 16 shows the correlation between δ_h' and δ_h during the loading test. This correlation can be approximated by the following equation.

$$\delta_h = \alpha_h \times \left(\delta_h' - \delta_{h0}'\right) \tag{7}$$

Fig. 17 shows the results of the Simple SLT (horizontal), where the displacement was expressed by δ_h directly obtained by the external transducer or by the calibrated δ_h' (i.e. the δ_h value obtained by **Eq. (7)** based on the measurement by the press-in machine). The two curves are in good agreement. **Fig. 18** compares the load displacement curves obtained in the Simple SLT (horizontal) using the calibrated δ_h' and those obtained from the Normal SLT (horizontal). The results are comparable. These results demonstrate the validity of the Simple SLT (horizontal) when the calibrated δ_h' is

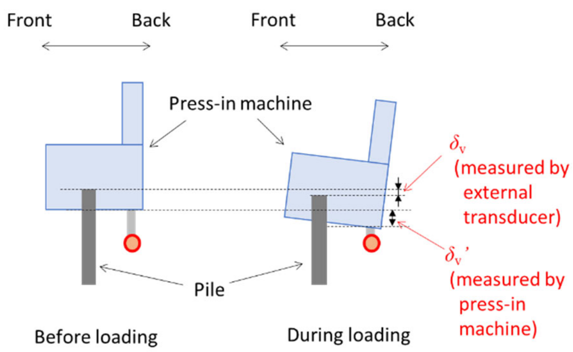

Fig. 12 Conjectured cause for measurement error in vertical displacement

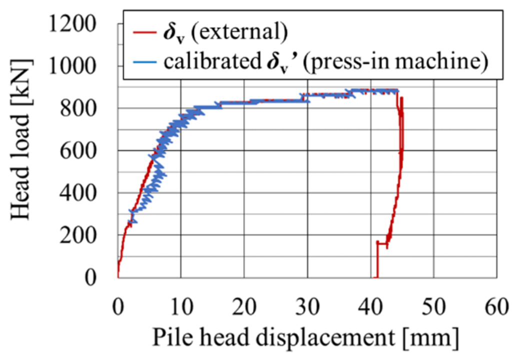

Fig. 13 Results of Simple SLT (vertical) using calibrated δ_v' in J2203-03

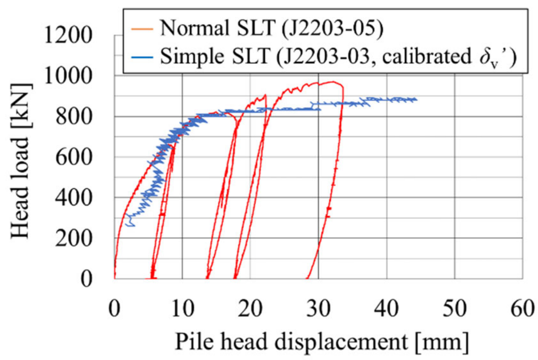

Fig. 14 Comparison of results of Simple SLT (vertical) and Normal SLT (vertical)

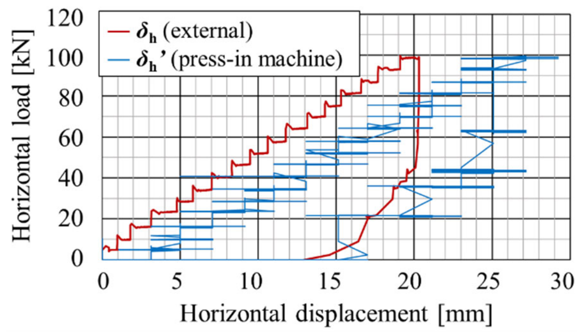

Fig. 15 Results of Simple STL (horizontal) in J2203-04

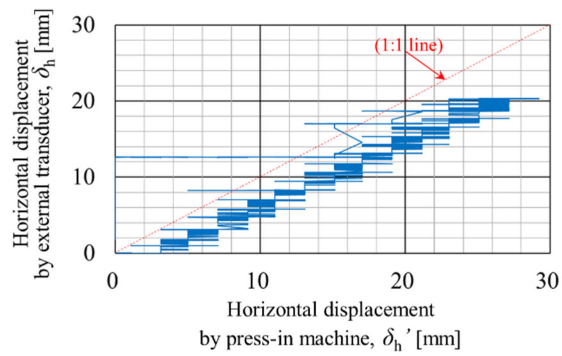

Fig. 16 Correlation between δ_h' and δ_h during Simple SLT (horizontal) in J2203-04

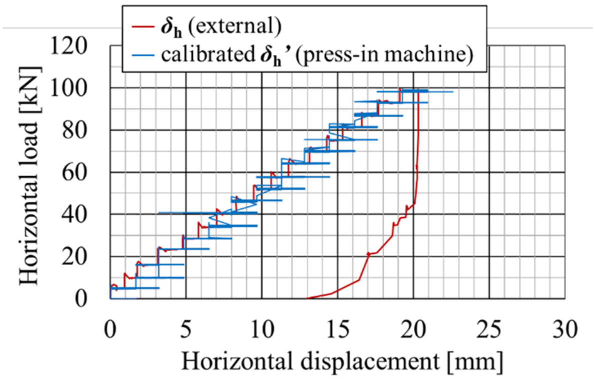

Fig. 17 Results of Simple SLT (horizontal) using calibrated δ_h' in J2203-04

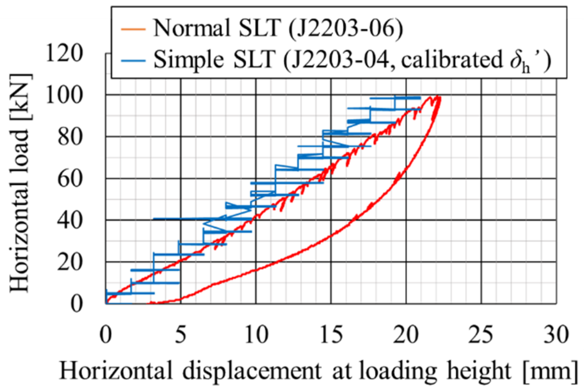

Fig. 18 Comparison of results of Simple SLT (horizontal) and Normal SLT (horizontal)

adopted.

4. Conclusions

A series of full-scale field tests were conducted to verify the validity of a simple static loading test using a press-in machine (Simple SLT) through comparison with a conventional static loading test (Normal SLT).

The Simple SLT and the Normal SLT were conducted, both vertically and horizontally, on a steel pipe pile with an outside diameter of 318.5 mm installed by the Rotary Cutting Press-in method. The results of the Simple SLT were confirmed to be equivalent to those of the Normal SLT, provided that the measurement of load and displacement were calibrated in advance.

5. Acknowledgements

This research was conducted as part of the “Space Construction Innovation Project” of the Ministry of Land, Infrastructure, Transport and Tourism in Japan. The authors would like to express their gratitude to all those involved.

References

Ishihara, Y., Ogawa, N., Mori, Y., Haigh, S. and Matsumoto, T. 2020. Simplified static vertical loading test on sheet piles using press-in piling machine. Japanese Geotechnical Society Special Publication, 8th Japan-China Geotechnical Symposium, pp. 245-250.

The Japanese Geotechnical Society (JGS). 2002. Method for static axial compressive load test of single piles. Standards of Japanese Geotechnical Society for Vertical Load Tests of Piles, pp. 49-53.

The Japanese Geotechnical Society (JGS). 2010. Method for Lateral Load Test of Piles, 63p.