Simplified static vertical loading test on sheet piles using press-in piling machine

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ABSTRACT

Although the application of sheet piles has been expanding to non-temporary structures recently, their vertical performance has not been well understood as they have long been used for temporary retaining structures in which their horizontal performance is the main concern. In addition, the extra time and cost required for conducting the conventional load test has been a barrier to improve the situation. In this paper, simplified methods of static compressive and tensile load test using a press-in machine are introduced. Results of the simplified load test on five pressed-in piles in a soft alluvial soil are reported.

Keywords: sheet pile, static load test, press-in piling

1 INTRODUCTION

Recently, the application of sheet piles has been expanding to non-temporary structures such as coastal levees (Ishihara et al. (2019)), railway bridges (Kasahara et al. (2018)), stress cut-off walls (Tanaka et al. (2018)) and so on. However, as they have long been used for temporary retaining structures in which their horizontal performance is the main concern, the number of load tests on sheet piles conducted so far is limited, and methods of estimating vertical performance of sheet piles have not been well developed. In addition, the extra time and cost required for conducting the conventional load test has been a barrier to improve the current situation.

The Press-in Method, which is a piling technique that uses a static jacking force to install a prefabricated pile while gaining a reaction force mainly from the pull-out resistance of previously installed piles (IPA, 2016), has been a major option to install sheet piles in urban areas, owing to its low emission of noise and vibration as well as to its spatially efficient piling system that saves temporary works as shown in Fig. 1. Since a press-in piling machine uses a static jacking force, it has been expected that this piling machine can be used for conducting a static load test.

This paper introduces a simplified method of a static compressive and tensile load test using a press-in machine, and reports a field test to investigate into the vertical performance of pressed-in sheet piles embedded in a soft alluvial soil.

2 METHOD OF SIMPLIFIED STATIC LOAD TEST USING A PRESS-IN PILING MACHINE

As simplified methods of static load test, a simple static compressive load test (Simple SCLT) and a simple static tensile load test (Simple STLT) were adopted in a field test as described in the next section. These simplified methods will be explained here in detail. As shown in Fig. 2, a press-in machine held a test pile at its ‘Chuck’ to apply a hydraulic jacking force to it. At the same time, the press-in machine gripped several piles at its ‘Clamps’ for reaction, which had been installed previously. This saves bulky weights necessary to conduct a formal static load test.
The distance between the test pile and the reaction piles, which can be varied from several millimeters to around 150mm depending on the specification of press-in machines, was set as 15mm. This means that the requirement in JGS standard (JGS (2002)) to secure a pile-to-pile distance of $3D_o$, where $D_o$ is the outside diameter of piles, was ignored in Simple SCLT and Simple STLT.

Displacement of the pile head ($\delta_{Vh}$) was measured by a wire-type stroke sensor, as shown in Fig. 3. The stroke sensor was positioned on the ground surface near the test pile, while the edge of the wire coming from the stroke sensor was tied to a steel bar which was welded to the pile head. The loading condition was chosen to be one cycle continuous loading. Loading was continued until the pile head displacement reached 50mm. This value is greater than $0.1D_o$ if $D_o$ of a sheet pile is interpreted as the outside diameter of a tubular pile that has the same sectional area inside and at the annulus of the pile as shown in Fig. 4 (IPA (2017)). In JGS standard, the pile head capacity ($Q_f$) is defined as the peak value of $Q$ measured when the pile base displacement (rather than head displacement) is smaller than or equal to $0.1D_o$. In Simple SCLT and Simple STLT, the measurement of pile base displacement will be omitted, and $Q_f$ will be defined as the peak value of $Q$ measured when the pile head displacement ($\delta_{Vh}$) is smaller than or equal to $0.1D_o$.

The minimal duration from the start of loading to the end of loading (i.e. when $\delta_{Vh}$ reaches $0.1D_o$) was controlled to be 30 minutes, to satisfy the requirement in JGS standard. To fulfill this, hydraulic pressure was applied intermittently. The minimal duration of unloading was controlled to be the half of the loading duration, as required in the same standard.

Head load ($Q$) was obtained by Eq. (1), where $Q'$ is the jacking force calculated from the hydraulic pressure measured by a pressure sensor equipped in the press-in machine and $W_C$ is the weight of the Chuck of the press-in machine. Regarding the sign convention, compression or downward direction is taken as positive.

$$Q = Q' + W_C$$

The validity of Eq. (1) was confirmed by a preparatory experiment using a press-in machine F301. A load cell was positioned in between the Chuck and the pile head, and a vertical compressive load was applied to the pile head by the Chuck via the load cell. Fig. 5 is the comparison of $Q$ measured by the load cell and that obtained by Eq. (1), where $Q'$ was arithmetically averaged over 90 seconds before the point of time in
3 FIELD TEST

To investigate the vertical performance of pressed-in sheet piles, a field test was conducted in Osaka, Japan. Two influential factors on the pile capacity – (1) tensile loading history after the end of installation while serving as one of the reaction piles and (2) elapsed time from the end of installation to the start of the load test (called ‘curing period’, \( t_c \)) – was studied.

3.1 Site profile

Fig. 6 is the result of SPT (Standard Penetration Test). The test site consists of soft alluvial soils. A relatively hard layer of fine sand, with SPT \( N \) value exceeding 10, exists from 5.5m to 9. This layer is sandwitched by soft layers of silty sand or silty clay with SPT \( N \) smaller than 3.

3.2 Test layout and procedure

As shown in Fig. 7, a total of 14 U-shaped sheet piles with the width of 400mm (SP-III) were installed in a raw by Standard Press-in (press-in without the use of installation assistance such as water jetting or augering). Of these, Simple SCLT was conducted on five piles (No. 2, 5, 6, 9 and 10), and Simple STLT was conducted on three piles (No. 2, 6 and 10). The five piles were not connected with adjacent piles (i.e. were installed without interlock connection), so that the interlock resistance (frictional force in the interlocking parts in two adjacent sheet piles) could be ignored in the load tests. The embedment depth of the five piles before Simple SCLT was 11.95m, while that of the other piles were 12.00m.

The test procedure and test conditions, as summarized in Table 1, was as follows.

Piles No. A, B, C, D and 1 were previously installed. By gaining a reaction force from piles No. A, B, C and D, the pile No. 2 was pressed-in without interlock connection. With the curing period \( t_c \) of 21 minutes, Simple SCLT was conducted on this pile. Immediately after the completion of Simple SCLT (i.e. after unloading), Simple STLT was carried out. After that, the pile No. 2 was extracted completely, followed by the installation of piles No. 2, 3, 4, 7 and 8 with interlock connection.

For piles No. 5 and 6, the following procedure was adopted. Firstly, the pile No. 5 was pressed-in without interlock connection, while gaining a reaction force from piles No. 4, 3, 2 and D. Secondly, the pile No. 6 was pressed-in without interlock connection, with...
reaction piles being No. 5, 4, 3 and 2. Thirdly, Simple SCLT was conducted on the pile No. 5, with reaction piles being No. 4, 3, 2 and D. Forth, Simple SCLT was conducted on the pile No. 6, gaining a reaction force from piles No. 5, 4, 3 and 2. The curing period \( (t_c) \) was 24 hours. Finally, immediately after Simple SCLT on pile No. 6, Simple STLT was conducted on the same pile.

The above-mentioned procedure for piles No. 5 and 6 were also adopted for piles No. 9 and 10, with reaction piles being No. 8, 7, 1, A and No. 9, 8, 7, 1 respectively. The curing period before Simple SCLT on pile No. 6, Simple STLT was approximately 44 days.

The installation of the five piles were conducted by a press-in machine F111 \((W_C = 19.7\text{kN})\). The installation process was associated with ‘repeated penetration and extraction’ which is usually adopted in press-in piling. In other words, upward and downward displacement \((l_u\) and \(l_d)\) were alternately applied to the pile. When the penetration depth \((z)\) was smaller than 2m, a manual operation with arbitrary values of \(l_u\) and \(l_d\) were adopted, to ensure the verticality of the pile while coping with some large gravels and stones contained in the ground surface. When \(z>2m\), \(l_u\) and \(l_d\) were controlled as 200mm and 400mm respectively, and the rate of penetration and extraction was set as approximately 30mm/s.

The methods of Simple SCLT and Simple STLT were as explained in section 2. Press-in machines used in these load tests were F111 \((W_C = 19.7\text{kN})\) in piles No. 2, 5, 6 and F101 \((W_C = 15.2\text{kN})\) in piles No. 9 and 10.

### 4 RESULTS AND DISCUSSION

#### 4.1 Results of press-in piling

Fig. 8 shows the variation of jacking force \((Q')\) in kilo-newtons with penetration depth \((z)\) in meters. In general, \(Q'\) remained low (less than 5kN) when \(2m<z<5m\), increased to around 10kN in \(5m<z<8m\), maintained its peak maximum \((10kN<Q'<15kN)\) in \(8m<z<10m\), and slightly decreased to less than 10kN when \(z>10m\). These trends well correspond to the variation of SPT \(N\) with depth. The only exception was found in \(z>10m\) in the pile No. 2, where the slight decrease in \(Q'\) in \(z>10m\) was not found. This will presumably be because the extent of the increase in the soil stress mainly around the pile base, as a result of the arching action associated with the geometrical shape of the sheet pile as pointed out by Taenaka et al. (2010), was greater in the pile No. 2 compared with the other piles for some reason.

#### 4.2 Results of load tests

Fig. 9 shows the load-displacement curves obtained in the load tests, where jacking force \((Q')\) instead of head load \((Q)\) was used for the vertical axes. Significant dispersion in raw values of \(Q'\) was removed by
averaging them over 90 seconds before the point of time in focus, in the same way as discussed in section 2.

In compression, relatively elastic response continued until the pile head displacement ($\delta_{Vh}$) reached approximately 2mm in all the piles. After that, $Q'$ continued increasing with smaller tangential stiffness until $\delta_{Vh}$ reached around 10mm, except for the pile No. 2 where $Q'$ increased only slightly with an almost constant tangential stiffness. For further displacement ($10\text{mm}<\delta_{Vh}<20\text{mm}$), $Q'$ continued increasing with smaller tangential stiffness in piles No. 9 and 10, while the increase in $Q'$ in piles No. 5 and 6 were much smaller. For $\delta_{Vh} >20\text{mm}$, $Q'$ remained almost constant in all the piles. These different trends correspond to the difference in the curing period ($t_c$).

In tension, the absolute value of $Q'$ increased with decreasing tangential stiffness from the beginning of loading, with smaller initial stiffness compared with that in compression. This will be mainly because the tension loading was conducted just after the compression loading. The increase in the absolute value of $Q'$ continued until the end of the tension loading.

### 4.3 Effect of loading history and curing period on pile capacity

Table 2 is the summary of the field test results, where $Q$ was obtained by Eq. (1). As discussed in section 2, the pile capacity in compression ($Q_f$) and in tension ($Q_{sf}$) were taken as the values of $Q$ recorded

![Fig. 8. Variation of jacking force with depth during press-in piling.](image1)

![Fig. 9. Results of Simple SCLT and Simple STLT. (Thin black lines are raw values, while thick red lines are the averages over 90s.)](image2)
When the variation of $\delta V_h$ during loading reached 0.1 $D_o$ (=25mm). On the other hand, $Q_{EOI}$ is the value of $Q$ recorded at the very end of installation.

The effect of tensile loading history after the end of installation, which is encountered when the pile is gripped by ‘Clamps’ and functions as one of the reaction piles, can be studied by comparing piles No. 5 and 6, or piles No. 9 and 10. In both cases of comparison, piles with tensile loading history (No. 5 and 9) exhibited greater capacity and greater normalized capacity. One possible reason will be that the soils around piles No. 5 and 9 were confined more strongly (i.e. these piles were sandwiched by piles No. 4 & 6 or 8 & 10) than soils around piles No. 6 and 10 (i.e. these piles are not sandwiched by two piles) during the static load test. Another possible reason will be that the effective stress in the soils around piles No. 5 and 9 was increased during the installation process of piles No. 6 and 10, while that around piles No. 6 and 10 was not (i.e. no piles were installed after the installation of these piles). In summary, the negative effect of the tensile loading history on pile capacity was not confirmed in this research, as it would be much smaller than the positive effect of greater confinement or increased effective stress that are associated with the adjacent piles installed after the installation of piles to be load tested.

The effect of curing period ($t_c$) is summarized in Fig. 10. The normalized capacity (i.e. the ratio of pile set-up) was greater than 1 and increased with $t_c$. It was greater than 2 when $t_c$ was 24 hours, and became even greater (being around 3.5 for the greatest case) when $t_c$ was 44 days.

5 CONCLUSIONS

As simplified methods of static load test, a simple static compressive load test (Simple SCLT) and a simple static tensile load test (Simple STLT) were introduced. These load tests were conducted on five pressed-in sheet piles embedded in a soft alluvial soil. The results revealed that (1) the tensile loading history experienced when serving as one of the reaction piles did not have any negative influence on the pile capacity and (2) the pile capacity was greater than the load recorded at the end of installation and increased with time after the end of installation.

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