Development of rapid load test device and its applicability to piles installed by Rotary Cutting Press-in

K. Okada
Construction Solutions Development Department, GIKEN LTD., Kochi, Japan
T. Murata
Construction Solutions Development Department, GIKEN LTD., Kochi, Japan
A. Mori
Construction Solutions Development Department, GIKEN LTD., Kochi, Japan
Y. Toda
Construction Solutions Development Department, GIKEN LTD., Kochi, Japan
Y. Ishihara
Construction Solutions Development Department, GIKEN LTD., Kochi, Japan

ABSTRACT

The press-in method is one of the construction techniques for pile foundations, in which piles are penetrated statically by hydraulic force. With this method, it is possible to reduce noise and vibration that usually emanate in conventional pile installations. The press-in method also allows efficient installation as all machinery and equipment can be placed on the installed pile wall and temporary works can be omitted. In recent years, the "Rotary Cutting Press-in" method, which is applicable to hard ground, has been increasingly used for installing pipe piles (RCP piles). However, as this is a relatively new technology, loading test cases have yet to be accumulated, although design methods are currently being developed. Among several loading test methods, the static load test (SLT) is the most reliable but is costly and time-consuming, while the rapid load test (RLT) has advantages in terms of time and cost. The problems with conventional RLT are: 1) an additional equipment frame for dropping weights is required, which is not compatible with the characteristics of the press-in method that allows the omission of temporary works; and 2) although comparative verification with SLT has been carried out as a test method, it is unclear whether it is similarly applied to RCP piles. To overcome these problems, we have developed a new RLT apparatus that can be fixed on the pile without the need for a large equipment frame. This research aims to 1) confirm that the tests can be successfully carried out on RCP piles, and 2) to carry out SLT for comparison and verify the validity of the RLT on RCP piles. The test pile used was the pipe piles with a diameter of 1000 mm and a thickness of 12 mm.

Key words: *Rapid load test, RCP pile, press-in*

1. Introduction

1.1. Background

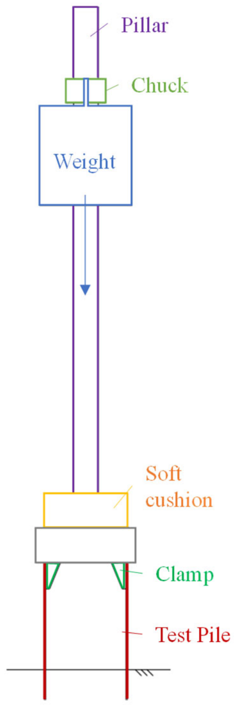
The Press-in Method is one of the pile penetration techniques, where a pile is installed into the ground by applying static load using hydraulic pressure. In this method, the press-in machine grips previously installed piles and installs the next pile, making the machine is lightweight and compact. It also has the advantage that all system equipment can be placed on the installed pile, eliminating the need for temporary work. The press-in method includes a technique called "Rotary Cutting Press-in (Gyropress Method^{TM})" which can be applied to hard ground that is difficult for Standard Press-in method. In recent years, the use of Rotary Cutting Press-in piles (RCP pile) constructed with this technique as bearing piles has been increasing. Although design methods are being developed (JSCE., 2020, Ishihara., 2023), the accumulation of load test cases is insufficient because this is a relatively new technology.

Loading test methods for piles can be classified into two categories: static load test (SLT) and dynamic load test (DLT). In SLT, a static load is applied to the test pile using a hydraulic jack or similar device. It needs a large device to secure a reaction force, which is expensive and time consuming. On the other hand, in DLT, a dynamic load is applied to the test pile using methods such as dropping weight. DLT can be carried out with relatively compact equipment, reducing cost and time compared to SLT. However, a data analysis is required to cancel dynamic effects in order to obtain the bearing capacity value.

Rapid load test (RLT) is one of the DLT methods (JGS., 2002). In RLT, a shock-absorbing soft cushion is placed on the pile head and a weight is dropped against it to load the pile. Advantages of this test method include: (1) simple equipment and no need for a large device for a reaction force, (2) short test time, and (3) no need for complex analysis. These advantages make it widely used in on-site construction. Because these advantages are compatible with the press-in method, we developed a new loading device for RLT (Fig. 1). The features of this device are: (1) it is possible to grip the weight with a chuck using hydraulic pressure and lift and drop it freely along the pillar, and (2) the loading device can stand on the pile by clamping the test pile head using hydraulic pressure. The reaction force to lift the weight is obtained from the test pile. It is necessary to confirm the operation of this newly developed testing device and the validity of the test results.

1.2. Objectives

The objectives of this study are to confirm that the new loading device is capable of conducting RLT on a RCP pile and to assess the validity of the RLT result by comparing it with the SLT result.



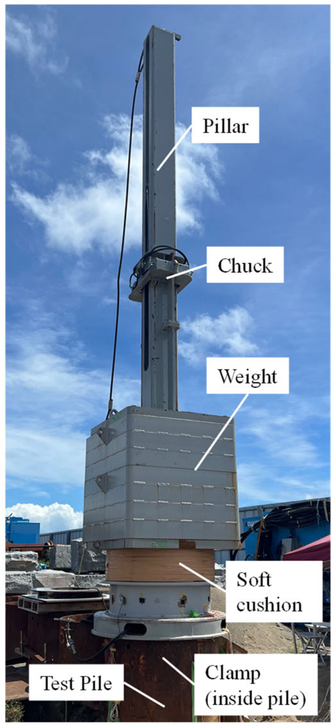


Fig. 1 Loading device

Table.1 Specification of Loading device

Height	m	7
Weight	kN	20
Dropping mass weight	kN	50, 100
Maximum dropping height	m	4
Applicable pile diameter	mm	800, 1000, 1200

2. Test methods

2.1. Loading device

The newly developed loading device for RLT has a total height of 7 m including the pillar and has the capability to drop a weight of up to 100 kN from a maximum height of 4 m (Table. 1). The feature of this loading device is that it can clamp the pile head of the test pile using hydraulic pressure, allowing the entire device to stand on its own on the pile. By adjusting the clamping section, it can be attached to piles with diameters of 800, 1000, and 1200 mm. Two weights, 50 and 100 kN, can be selected according to the magnitude of the bearing capacity to be checked. The weight was selected to be 100 kN in this test.

In according with the JGS standard JGS1815-2002 (JGS., 2002), the duration of the rapid load would lie in the range of,

$$5 \leq T_r < 500 \cdots (1)$$

where relative loading duration T_r is the ratio of the loading duration (t_L) to the time necessary for the wave to travel once along the pile length, so that influence of the wave propagation phenomenon in the pile is negligible. T_r is defined as,

$$T_r = \frac{t_L}{2L/c} \cdots (2)$$

where L is the pile length and c is axial stress wave velocity travelling in the axial direction of a pile. t_L is considered to be equal to the half period of a single vibration of the spring of this device.

$$t_L = \pi\sqrt{\frac{m}{K}} \cdots (3)$$

where m is dropping mass weight and K is the spring constant of soft cushion. The loading capacity F is expressed from the law of the conservation of energy as,

$$F = \sqrt{2mghK} \cdots (4)$$

where g is acceleration of gravity and h is dropping height. Using equation (1) ~ (4), K and F can be determined. For example, the maximum F of this device is approximately 6500 kN for a 20 m long pile.

2.2. Method of calculating ground resistance (JGS., 2002)

To estimate the SLT result from the RLT result, the equation (5) is used,

$$R_{soil} = R_w + R_v \cdots (5)$$

Here, R_{soil} is the total ground resistance obtained directly from RLT, R_w is the static resistance that depends mainly on the displacement of the pile, and R_v is the dynamic resistance that depends mainly on the velocity of the pile. To get R_w from R_{soil}, R_v must be excluded.

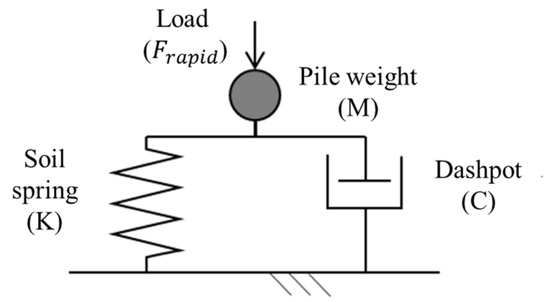


Fig. 2 Model of ULP method

The Unloading Point Method (ULP method) models the pile behavior as a single-degree-of-freedom system with pile mass M, dashpot C, and soil spring K, assuming that the pile is a rigid body of a one-mass system (Fig. 2). This method assumes that the pile head load F_{rapid} measured by RLT is equivalent to the sum of the total ground force R_{soil} and the inertia force of the pile $M \cdot \alpha$.

$$F_{rapid} = R_{soil} + M \cdot \alpha \cdots (6)$$

Here, α is the acceleration of the pile. If R_v is assumed to be proportional to the velocity of the pile v,

$$R_{soil} = R_w + C \cdot v \cdots (7)$$

When the pile is at maximum displacement, R_{soil} is equal to R_w because v is zero. This point is called the unloading point. Since the loading device used in this study is integrated with the test pile by clamps, the mass $M + m_d$, which is the pile weight M plus the loading device mass m_d, is used to calculate the R_w at the unloading point.

$$R_{w,ULP} = R_{soil(v=0)} = F_{rapid} - (M + m_d) \cdot \alpha \cdots (8)$$

By calculating $R_{w,ULP}$ for each cycle with increasing the drop height of the weight, a load-displacement curve corresponding to SLT can be obtained, and this method is called the unloading point connection method (ULPC method). In this study, ULPC method was used to analyze the results of the rapid load tests.

2.3. Test pile

Two open-ended steel pipe piles with an outer diameter of 1 m (=D), thickness of 12 mm, and length of 12 m were used as the test piles for this test. Details of the specification of the test piles are shown in Table. 2. One of the test piles was instrumented with the strain gauges at several sections for measuring axial strains (1, 2, 4, 5, 7.5, 11 m away from pile base, Fig. 3).

2.4. Test layout

The ground at the test site consists of sand and gravel layers, and the test pile are installed into the layer with an N value greater than 40 (Fig. 3). Steel pipe piles were installed in a single row layout, and the same length of piles were pressed-in on both sides of 2 test piles to model the conditions in the actual press-in piling projects (Fig. 4). 44 steel sheet piles (SP-III, 12 m long) were installed as reaction piles in SLT on the both sides of the test pile row. Sheet piles were placed at least 2.5 D away from the surface of the test pile.

2.5. Measurement system

During the installation of the test piles, the pile penetration length, press-in force, torque, rotation rate, flowrate of water, and depth of soil inside the pile were measured. In SLT, measurements included pile head load, axial strains at each section, settlement at the pile head and pile base, and depth of soil inside the pile. The pile settlements were measured by displacement meters. Pile base resistance was measured at a distance of 1 m from the pile base. In RLT, measurements included pile head load, pile head acceleration, and pile head settlement. Strain gauges were used to measure pile head load, displacement gauges to measure pile head settlement and accelerometers to measure pile head acceleration. These sensors were installed 1 m below the pile head. The values of pile head acceleration were smoothed before applying the ULP method to eliminate fluctuations.

2.6. Test procedure

Test piles were installed by a press-in machine using the usual RCP method. The press-in conditions are shown in Table.2. During installation, water was injected from the pile tip in order to reduce pile shaft resistance. At the end of press-in, the water injection was stopped and terminating jacking force was applied

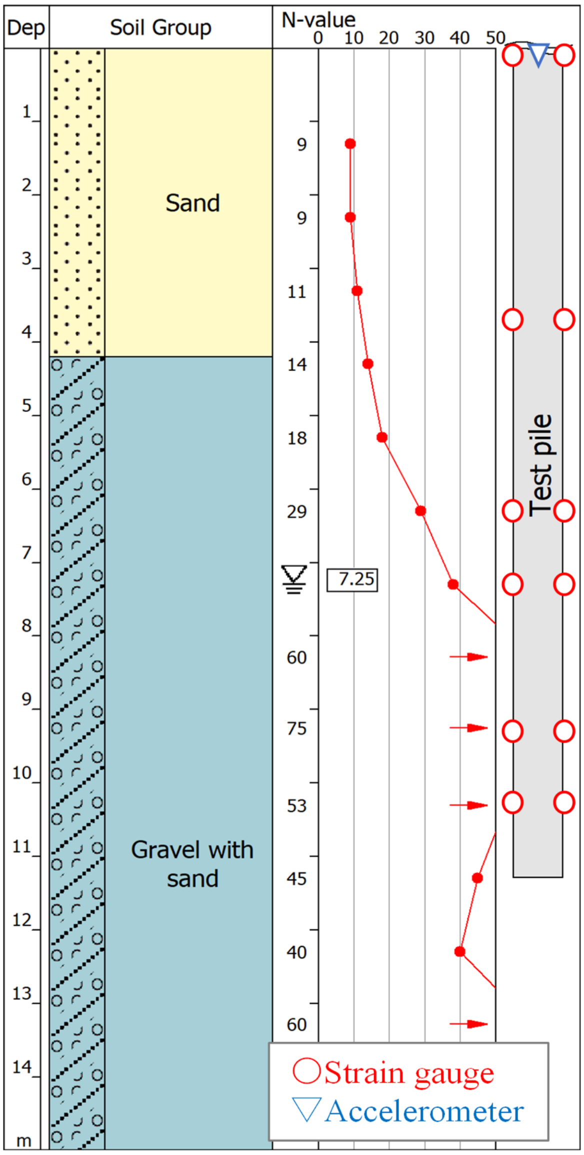


Fig. 3 Ground conditions

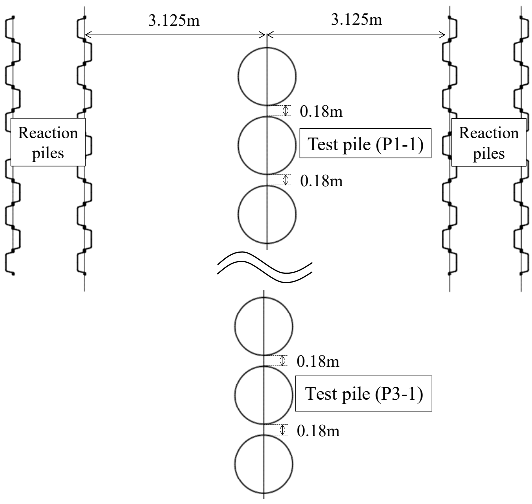


Fig. 4 Test layout

without rotation for 5 minutes.

SLT was performed on the pile P1-1 using the step loading method, consisting of 10 steps over 5 cycles, following the JGS standard. Loading was carried out using reaction piles and hydraulic jacks. The curing period between finishing pile installation and the loading test was 7 days. However, the loading test was prematurely halted during the 9th step due to the insufficient pull-put resistance of the reaction piles.

RLT was conducted on both P1-1 and P3-1 using a new loading device. Loading was carried out by gradually increasing the height of dropping the weight, until the pile head settlement exceeded 0.1 D. RLT on P1-1 was conducted 5 days after the SLT, while for P3-1, it took place 7 days after pile installation.

Table.2 Specification of test piles

Test Pile (Case No)		P1-1	P3-1
Installation method		RCP	RCP
Pile diameter	m	1	1
Pile thickness	m	0.012	0.012
Pile length	m	12	12
Penetration depth	m	11.3	11.3
Pile weight	kN	42	42
Number of cutting teeth	-	6	6
Installation rate	Mode	2	2
Extraction rate	mode	2	2
Rotation rate	rpm	9	9
Flowrate of water (inside)	L/min	30～50	30～50
Flowrate of water (outside)	L/min	20～40	20～40
Upper limit of jacking force	kN	300～450	300～450
Upper limit of torque	kN*m	300	400
Terminating jacking force	kN	1240	1240
Curing period (SLT)	day	6.9 (after Pile installation)	—
Curing period (RLT)	day	4.9 (after SLT)	6.9 (after Pile installation)

3. Test results

Fig. 5. shows the result of SLT. The vertical axis represents the load and the horizontal axis represents the pile head settlement, the black line represents the pile head load, the red line represents the pile base resistance and the blue line represents to pile shaft resistance. The pile base resistance was taken as the value at 2 m from the pile base. Weibull distribution curves using data up to the 8th stage of SLT to estimate the pile head load are shown as dotted lines. This shows that the ultimate bearing capacity was around 6500 kN. The shaft resistance was almost at its maximum value at a pile settlement of about 20 mm, and remained almost constant thereafter.

Figs. 6 and 7 show the result of RLTs. The vertical axis represents the load and the horizontal axis represents the pile head settlement since the start of the test. The black dotted line represents R_{soil} of each drop, and the red line represents $R_{w,ULP}$ obtained by the ULPC method. According to this, the piles show elastic behavior up to a pile head settlement of about 10 mm, but after 20 mm the ground yields and settles at a constant value of about 5000 kN. It should be noted that the information of the base resistance during the RLT has not been included in this research, due to the lack of the measurement of the acceleration at the pile base.

4. Comparison of SLT and RLT

Fig. 8. shows a comparison of the load-displacement curves of RLT and SLT. The vertical axis represents the pile head load (R_w in RLT) and the horizontal axis represents the pile head settlement. The black line shows the load-displacement curve of SLT and the black dotted line shows the Weibull distribution curves of SLT. The red lines show the results of RLTs, and the test results of the RLT (P1-1) are presented in terms of continuous settlement since the end of the SLT.

The results show that the load-displacement relationship of the two RLTs is very similar. Compared to SLT results, the RLT results are characterized by (1) higher

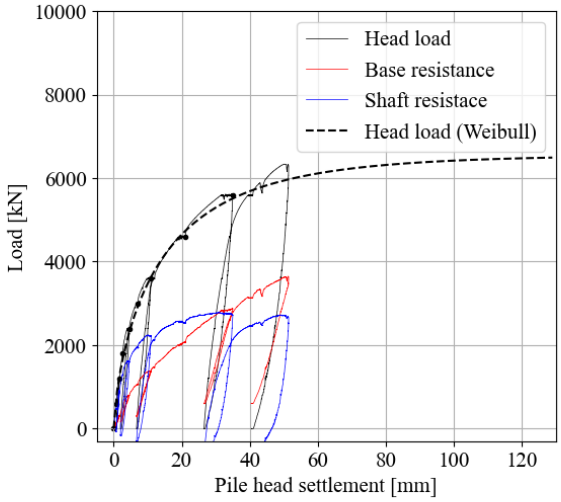


Fig.5 Result of SLT (P1-1)

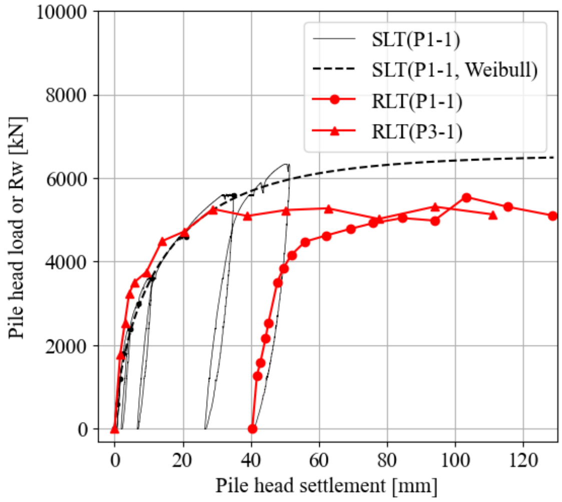


Fig. 8 Comparisons of SLT and RLT

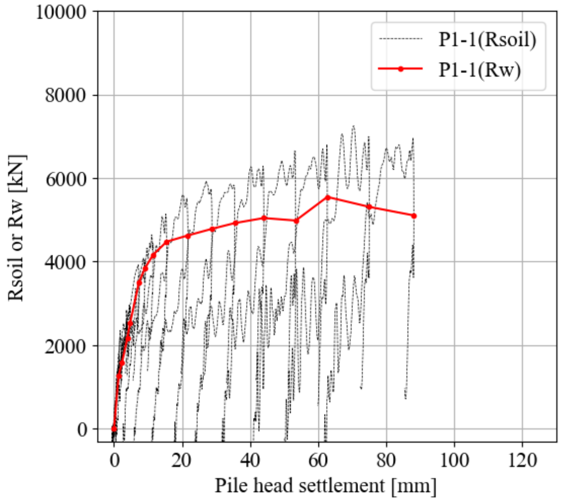


Fig.6 Result of RLT (P1-1)

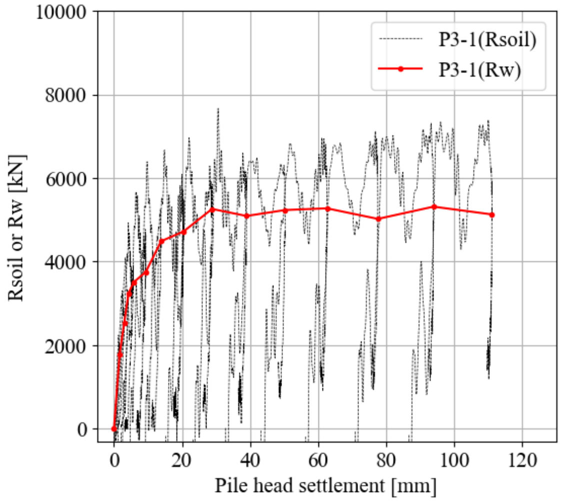


Fig.7 Result of RLT (P3-1)

initial stiffness and (2) a smaller increase in load after yielding. In general, RLT results tend to have similar initial stiffness and greater ultimate bearing capacity compared to SLT results (Brown., 2009, Lin et al., 2023, Sato et al., 2012), but the results of this site showed a slightly different trend. The difference could be attributed to the effect of penetration speed during the RLT. In the ULP method, loads with zero pile velocity are considered equivalent to SLT loads, assuming no effect of velocity. However, the generation of excess pore water pressure, which can become greater with the larger penetration speed, could reduce the effective stress, thereby reducing the soil resistance. According to White et al. (2010) and others, this effect will be especially seen in the penetration in contractile soils with the normalized velocity ($V = v_d * Do/c_v$) being smaller than around 30, where v_d is the penetration speed, Do is the outer diameter of the pile and cv is the coefficient of consolidation. In the RLT in this paper, the values of V were around 10, if c_v is assumed as $1.0 * 10^7\ m^2/year$ (White et al., 2010). Further investigation is required to clarify this issue.

5. Conclusion

Regarding the newly developed rapid load testing equipment, the aims of this research were (1) to confirm that the tests can be successfully carried out on RCP piles, and (2) to carry out SLT for comparison and confirm the validity of the RLT on RCP piles. The results showed that (1) RLT on RCP piles using the new loading device were carried out without problems, and (2) RLT results tended to produce slightly lower ultimate bearing capacity than the SLT result. And further investigation is required to clarify this issue, including on effect of velocity and measurement system.

References

Brown, M. 2009. Chapter 2 Recommendation for Stanamic use and interpretation of piles installed in clay, Rapid Load Testing on Piles, Taylor & Francis Group, pp. 26-36.

Sato, K., Hoshino, M., Takano, K., Kamei, S. and Nishimura, S., 2012. A comparison between static load test and rapid load test for a steel pipe pile installed by water jet vibratory technique., Proceedings of the 9th International Conference on Testing and Design Methods for Deep Foundations (IS-Kanazawa 2012), pp. 581-585.

Ishihara. Y., 2023. Use of press-in piling data for estimating subsurface information and pile performance, Ph.D. thesis., Tokyo University, pp. 385-398.

Japan Society for Civil Engineers (JSCE). 2020. Report of technology assessment of design and construction method for Rotary Cutting Press-in (Gyropress) Method. Technology Promotion Library, No. 25. (in Japanese)

Lin, S., Kamei, S., Yamamoto, I., Watanabe, S. and Matsumoto, T., 2023. Hybridnamic rapid load tests on driven steel pipe piles in sandy ground compared with static load test., Second International Conference of Civil Engineering ICCE 2023, pp.484-492

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.

White, D. J., Deeks, A. D. and Ishihara, Y., 2010, Novel piling: axial and rotary jacking, Proceedings of the 11th International Conference on Geotechnical Challenges in Urban Regeneration, London, UK, CD.