Press-in Piling: Field Testing of Cell Foundations

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Abstract

A series of load tests on jacked tubular piles are reported. These tests examine the capacity of cell foundations comprising tubular piles installed using the press-in method. Press-in piling machines are capable of installing large tubular piles with up to 4.6 MN of static jacking force, gaining reaction from adjacent piles within the cell. This technique permits the installation of, for example, bridge foundations, with minimal temporary works. By using static jacking force alone, environmental disturbance through noise and vibration is minimized.

Since the press-in method provides a measurement of jacking resistance during installation, this value can be used to estimate the long-term capacity of the completed foundation. However, group effects and time effects must be accounted for. This paper discusses possible design approaches and suggests that conventional serviceability design methods may be over-conservative when applied to this novel construction method.

Introduction

The press-in method is a modern piling technique by which piles are installed using static force alone, with reaction being provided by previously installed piles. Compared to conventional dynamic methods, press-in piling creates minimal noise and vibration (White et al., 2002). Furthermore, the jacking resistance can be measured during installation, and used to estimate long-term capacity. Since press-in piling machines ‘walk’ along the pile wall under construction, all piles must necessarily be installed at close centres, or indeed touching. This geometry is in contrast to conventional design guidance, which requires a separation of typically two diameters between axially loaded piles, to prevent harmful interaction effects (BS8004, 1986). Research is required to establish the load carrying capacity of pressed-in piled foundations since they lie within this low spacing range.

This paper presents the results of field tests that were carried out in Kochi, Japan, to examine the load carrying capacity of cell foundations installed using the press-in piling technique. The term cell foundation is used to describe a foundation constructed by jacking piles around an enclosed soil block at close centres. Each pile displaces soil, increasing the lateral pressure in the surrounding soil and on the adjacent piles. The load carrying capacity of the cell might thus be expected to exceed the sum of the capacity of the individual piles. However, conventional design approaches do not permit displacement piles to be installed closer than two diameters apart, to avoid possible negative group efficiencies caused by interaction of the piles. This approach may be overly conservative, preventing the use of the press-in method, which requires close pile spacing since the piler uses adjacent piles to provide reaction.

This paper firstly examines how the installation load of a single pile relates to subsequent bearing capacity, in order to establish whether installation force provides a useful indicator of long-term behaviour. Secondly, the relationship between installation force of a single pile, and the installation force for piles within a cell is investigated, to establish whether such close pile spacing leads to driveability problems. Finally, the bearing capacity of the completed cell is compared to the capacity of the single pile to establish the efficiency of the cell foundation.

Background

Previous testing of pressed-in pile foundations is reported by White et al (2003). A series of load tests on rows of 400x400mm steel H-piles was carried out at Shinagawa, Tokyo, to study the design of a foundation system consisting of rings of H-piles forming 20m deep caisson cells. The H-piles were installed in contact with each other, forming closed box sections. These tests demonstrated that:

- A positive time effect was observed, i.e. the ultimate capacity of a single pile was found to be greater than the installation load.
- A positive group effect was observed, i.e. rows of H-piles when loaded simultaneously showed a greater capacity than the sum of the individual capacities of each pile in the group. The positive group efficiency factor, ζ_{GROUP}, defined by Equation 1, was found to be in the range of 1.6 – 2.0.

$$z_{GROUP} = \frac{Q^{n}_{GROUP}}{n \cdot Q_{SINGLE}} \quad (1)$$

Q_{SINGLE} and Q_{GROUP} are the capacity of a single pile and a group of n piles respectively, where n is the number of the piles in the group.

The measured positive group efficiency is in contrast with historic experimental data (e.g. Vesic, 1969), which has lead to design advice requiring a centre-to-centre separation of at least 2D (BS8004, 1986). Subsequent to the

Shinagawa testing, the programme of fieldwork reported in this paper was conducted, with the aim of examining the behaviour of cell foundations constructed from tubular, rather than H-section, piles.

Fieldwork

Two small-scale cell foundations (Fig.1) were installed and tested at the Takasu Research Centre in Kochi, Japan. Additionally, a single pile, and walls of two and three adjacent piles were installed nearby to the same founding depth.

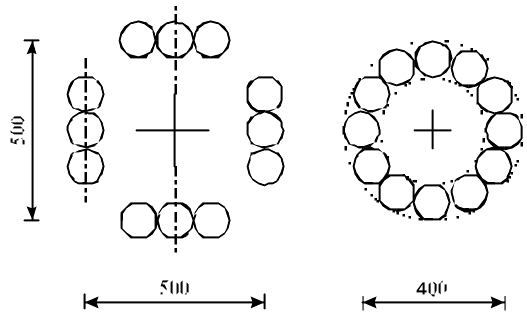


Figure 1: Dimensions of the cell foundations

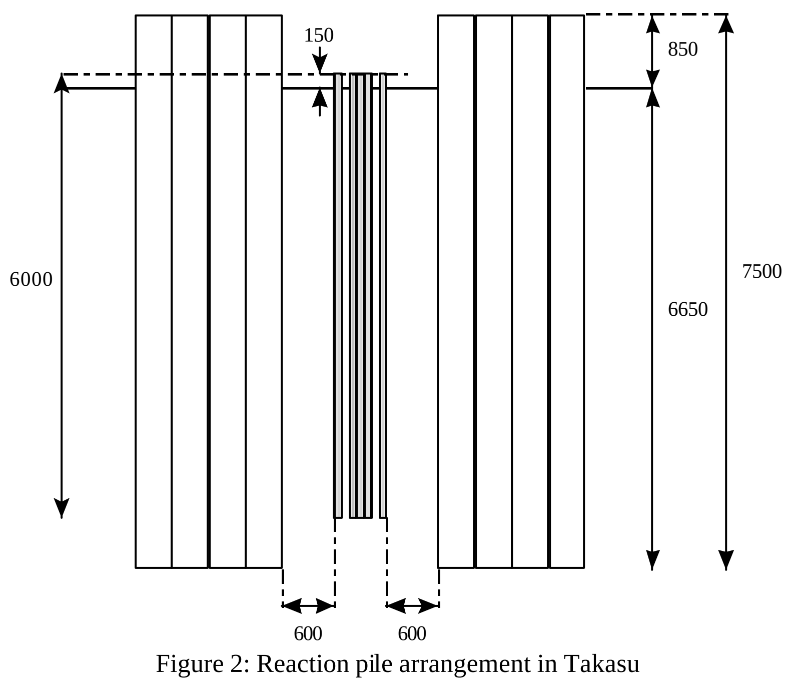


Figure 2: Reaction pile arrangement in Takasu

Each cell foundation consisted of twelve, 6m long, tubular steel piles with an external diameter *D* of 101.6 mm and a wall thickness *t* of 5.7 mm. Reaction sheet piles were installed 600 mm (~6*D*) from the nearest test pile (Fig. 2).

The ground conditions in Takasu consist of made ground overlying layers of silt, silty sand and sand (Fig.3) (White et al., 2000). Prior to installation of the piles, the made ground was removed and replaced by sand.

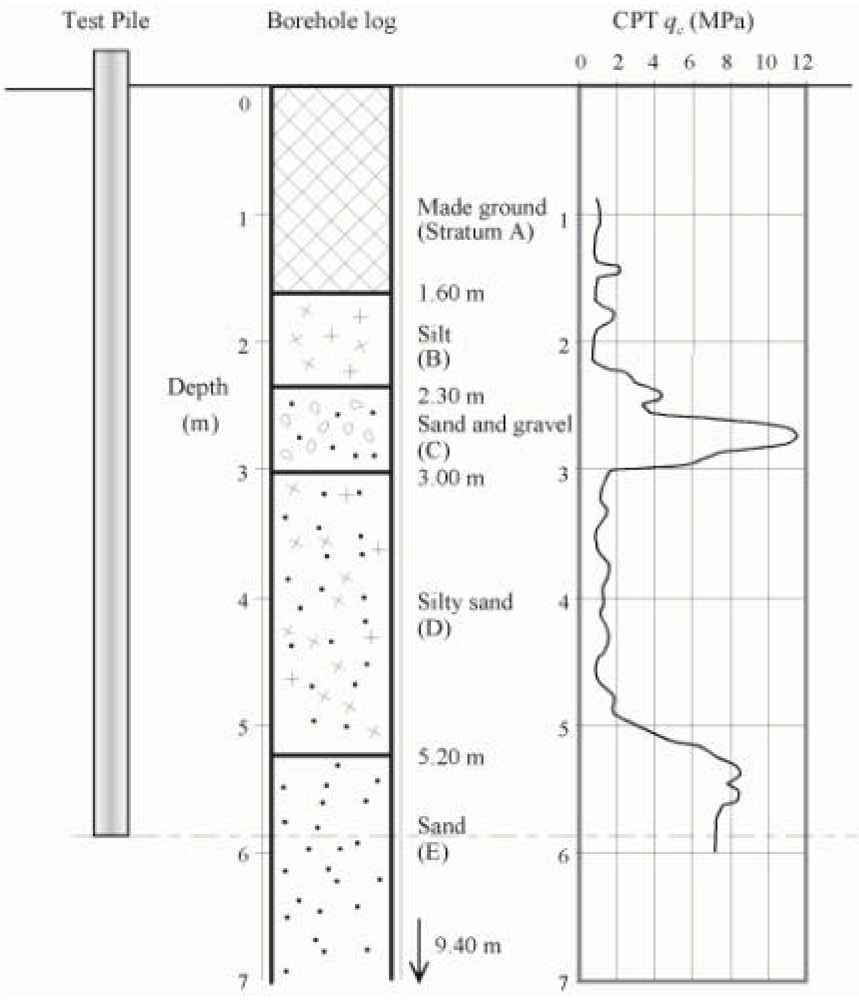


Figure 3: Takasu ground conditions

The final installation force for each pile was recorded by fitting a load cell between the jacking chuck of the piler and the head of the pile during the final installation stroke. To examine the relationship between the installation load of a single pile and the bearing capacity of a group of piles a series of maintained load tests was carried out (Table 1). Separate reaction and reference beams were used. Pairs of displacement transducers were used to monitor the settlement of the single and two- and three-pile walls. A steel cap was welded over the cell foundations with the load cell and load test jack mounted centrally on the steel cap. Four displacement transducers, placed at each corner of the steel cap, were used to monitor the settlement of the pile groups.

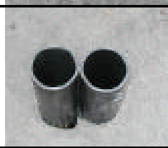
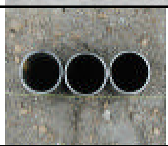
PILE GROUP		**DATE OF INSTALLATION**	**DATE OF LOAD TEST**
Single Pile TK02-P1		05-07-02	17-07-02
Two-Pile Group TK02-P2		09-07-02	22-07-02
Three-Pile Group TK02-P3		05-07-02	18-07-02
Square Twelve-Pile Group TK02-P12sq		08-07-02	19-07-02
Circular Twelve-Pile Group TK02-P12ci		09-07-02	23-07-02

Table 1: Schedule of tests at Takasu Test Site

The load tests were continued until a settlement of $D/4$=25mm was reached except in the case of the cell foundations, which were penetrated to a depth of 80 mm. Unload-reload loops were conducted at a settlement of $D/5$=20mm. The installation and failure loads that were measured during these tests are presented in Table 2, with failure load defined as the load at a settlement of 20 mm.

Pile Group		Installation Load (kN)	Failure Load (Load per Pile) (kN)
Single Pile		49.9	50.0
Two Pile Group	P1	46.3	116 (58)
	P2	56.6	
Three Pile Group	P1	56.3	174 (58)
	P2	74.7	
	P3	70.9	
Square Twelve Pile Group	P1	57.4	700 (58)
	P2	73.2	
	P3	72.9	
	P4	60.4	
	P5	99.8	
	P6	118.7	
	P7	83.3	
	P8	87.7	
	P9	101.8	
	P10	89.4	
	P11	108.2	
	P12	98.5	
Circular Twelve Pile Group	P1	49.2	600 (50)
	P2	71.5	
	P3	83.7	
	P4	79.3	
	P5	90.1	
	P6	89.6	
	P7	88.7	
	P8	115.6	
	P9	105.8	
	P10	109.5	
	P11	116.7	
	P12	128.5	

Table 2: Results of load tests at Takasu Test Site

Single Pile Bearing Capacity

The load-settlement curve for the single pile is presented in Fig.4. A stiff linear response is followed by plunging failure at a load of 50 kN after a settlement of D/50=2mm. The load during this test was increased in steps of 10kN and was kept at each load level until the creep rate was below 1mm/h.

This value of ultimate capacity is comparable to three design predictions following well-known design methods derived for use with conventional (dynamically) installed piles (Table 3).

This good agreement suggests that installation method has only a minor influence on ultimate capacity, and indicates that conventional design methods for ultimate capacity may be applied to pressed-in piles.

	Shaft friction (kN)	Base resistance (kN)	Total capacity (kN)
Meigh, 1987	20.0	34.5	54.5
API Method, 1993	22.2	19.5	41.7
Jardine & Chow, 1996	30.5	24.8	55.3

Table 3: Bearing capacity (Predictions using conventional methods)

The high initial stiffness, with ultimate capacity reached within a settlement of *D*/50=2mm is notable, since the design of urban deep foundations is usually

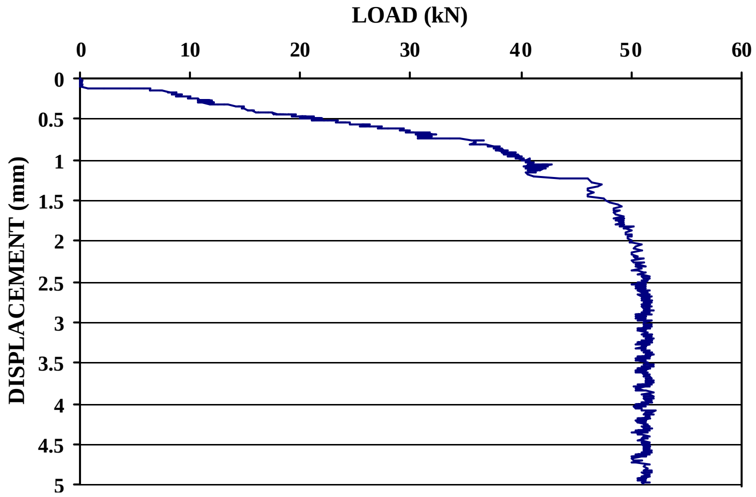


Figure 4: Load test of the single pile

governed by serviceability rather than ultimate limit state considerations (Randolph, 1994; Tomlinson, 2001). Conventionally installed driven piles typically require a settlement of at least *D*/10 to mobilize full capacity with bored piles being even more compliant. This high measured stiffness indicates that the large safety factors applied to ultimate capacity to satisfy serviceability requirements of conventional piles may be reduced when applied to pressed-in piles, with a consequent improvement in design efficiency.

The installation and failure load of the single pile were identical, at 50 kN, indicating that for pressed-in piles in sand, tested within a few days of installation, the jacking force offers a reliable indication of the ultimate capacity (Table 2).

Group Efficiency

The capacities of the circular and square cell foundations, defined by the load at a settlement of D/5=20mm, were 600 kN and 700 kN respectively (Table 2), indicating a group efficiency, ζ_{GROUP}, of 1.02, when Q_{SINGLE} is taken as the installation load of the "weakest" pile in the group. These values of unity indicate that any positive or negative interaction effects balance each other.

In both cases the pile with the lowest installation load, i.e. the "weakest" pile, was the first pile to be installed in the group. Hence, to estimate the capacity of an entire cell foundation, it may be sufficient to install one pile, recording the jacking resistance.

The load-settlement curves of the cells were comparable to the single pile test, with an initially stiff response leading to mobilization of the full capacity at a settlement of D/10=10mm (Fig.5).

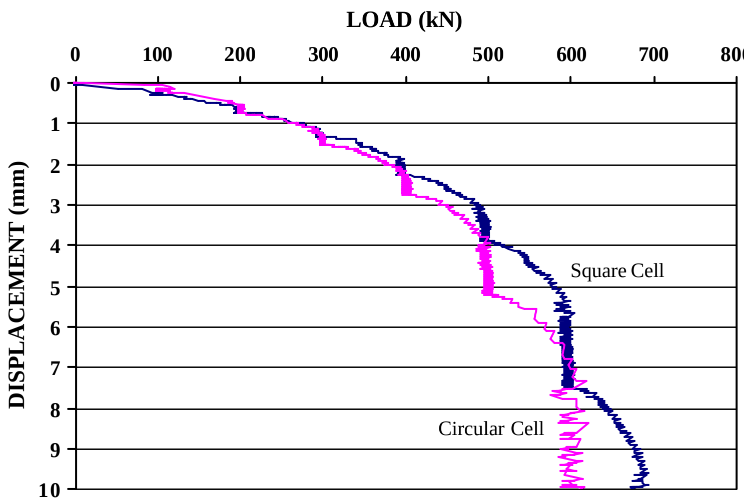


Figure 5: Load test of the square and the circular cells

Enclosure Effects: Driveability

Enclosure effects are defined as the changes in the installation load of individual piles, as the construction of the cell foundations advances. Examining the data from the tests in Takasu it can be seen that increased jacking resistance is encountered as construction progresses (Table 2). This is a well-known effect, which can lead to problems of driveability in close-centred pile groups.

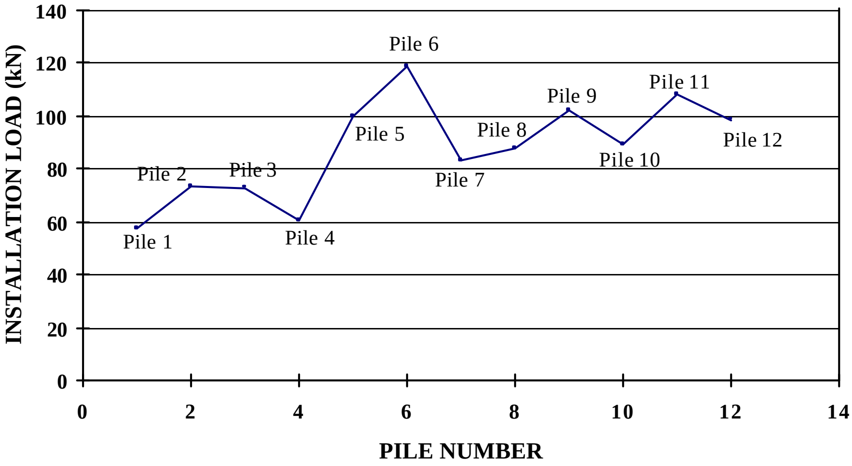


Figure 6: Installation of the square cell foundation

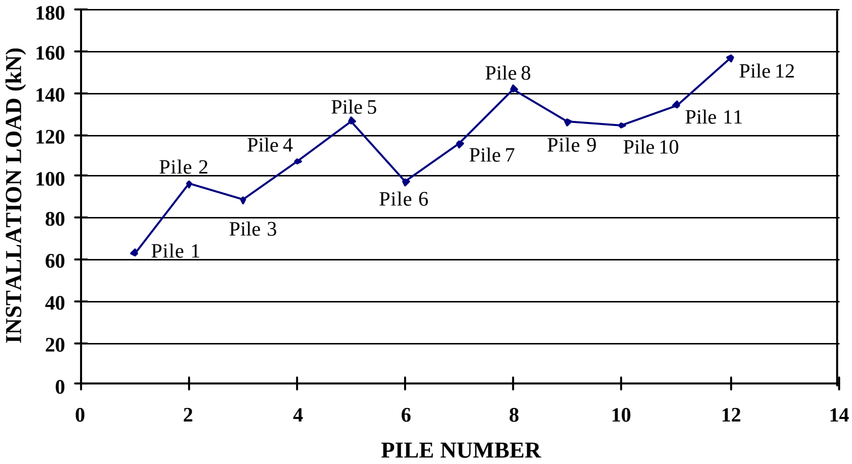


Figure 7: Installation of the circular cell foundation

The progressive increase in jacking force can be attributed to the increase in lateral pressures in and around the soil block that is enclosed as the construction of the cell foundation advances. Fig. 6 and 7 show the increase in installation force as each cell foundation is completed. This recorded increase in resistance has implications for the deployment of press-in piling machines for the construction of cell foundations. It is not sufficient to mobilize a machine with jack capacity greater than the strength of a single pile. Instead, a jack capacity of approximately twice the capacity of a single pile is required to install the final pile in each cell.

Conclusions

The press-in method allows measurement of jacking resistance during the installation of piles. The field tests described in this paper show that this measurement is a useful indicator of the long-term capacity of pressed-in piles in sand.

Piles installed using the press-in method show very high initial stiffness during maintained load tests and the full pile capacity is mobilised at a very small settlement. Consequently, the large safety factors that are normally applied to ultimate capacity to meet serviceability limits can be reduced significantly when using the press-in method and more efficient use can be made of the potential capacity of a piled foundation.

The field tests described in this paper also show that the bearing capacity of a complete cell foundation can be estimated from the installation load of a single pile. No negative group effects on ultimate capacity due to the proximity of the other piles in the group were evident. However, an increase in the installation force of the individual piles was measured as the cell foundation advanced. This observation has implications for machine selection to avoid driveability problems.

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