Time Effects on The Bearing Capacity of Driven Piles

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ABSTRACT: Two case histories where the changes in pile capacity were observed with time are presented. The first case shows the increase in pile capacity especially the shaft friction for piles driven into clayey deposit. The average unit shaft friction, determined from the high strain dynamic pile test, has increased from 33 kPa to 57 kPa from 3 days to 33 days after the installation of piles. The second case shows a tendency of increase in pile capacity for pile driven into sandy deposit over a period longer than needed for complete dissipation of excess pore water pressure induced by the driving process.

1 INTRODUCTION

The geotechnical capacity of pile is normally estimated by static pile formulas and later confirmed by pile load test. Very often the pile load test was carried out shortly after the installation of pile. The pile capacity obtained from the load test is often assumed to be the long term pile capacity. However, during the pile driving process, soils which surround the pile shaft and underneath the pile tip are highly disturbed. Excess pore water pressure builds up as the result of pile driving. Depending on the permeability characteristics of the subsoil, the duration for the complete dissipation of excess pore water pressure varies. The pile capacity could be underestimated if pile load test was carried out while significant excess pore water pressure still remains. The pile capacity increases as the strength of the surrounding soil increases by re-consolidation. This is common phenomenon for low permeability soils such as silt and clay. For granular soil which has higher permeability, the complete dissipation of excess pore water pressure is normally within few hours to few days. However, literatures have shown that there is a tendency of increase in pile capacity even complete dissipation of excess pore pressure has achieved.

This paper shall present two cases to illustrate the time effect on pile capacity for driven pile. In case I, piles were driven into very soft marine clayey deposit. Test pile A has been tested using high strain dynamic pile tests 3 days and 19 days after pile installation. A static pile load test was performed on the same pile 16 days after pile driving. Test pile B was tested by dynamic pile tests 7 days and 33 days after pile installation. In case II, piles were driven into silty sand deposit. A total of 19 numbers of conventional static pile load tests were carried out 30 days to 150 days after piles installation. A tendency of increase in pile capacity with time was observed.

2 MECHANISM OF CHANGE IN PILE CAPACITY WITH TIME

2.1 *In Clay*

During the installation of a driven pile, a volume of clay equal to the volume of pile will have to be displaced in one way or another. The displacement will take place in the direction of least resistance. A remolded zone, up to 100mm to 150mm from the pile surface (Flaate, 1972), was formed after the pile driving as shown in Figure 1. There is also a transition zone where the soil properties changes slightly outside the remolded zone. The extent of this transition zone depends on the soil properties, driving method, pile dimensions and pile density. Beyond this transition zone, the soil remains its original properties. The driving of pile sets up high pore water pressure in the remolded zone. The water flows away from the pile surface and the remolded zone is re-consolidated. This re-consolidation process can lead to higher undrained shear strength and give higher pile capacity. In some cases, the remolded zone which is of higher strength than the surrounding soil will adhere onto the pile surface and move together with the pile after re-consolidation. As the result, the effective perimeter of pile increases so does the pile capacity.

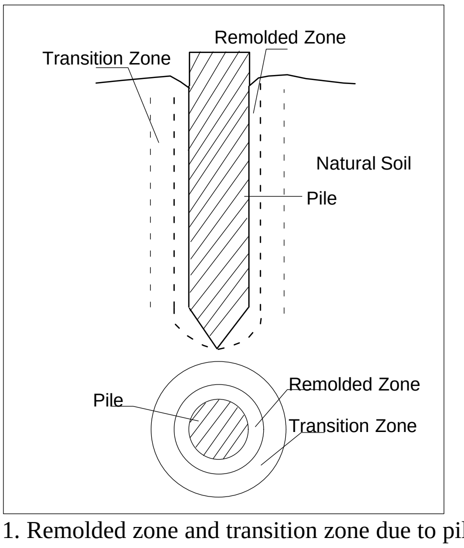

Figure 1. Remolded zone and transition zone due to pile driving

2.2 *In Sand*

The increase in bearing capacity of pile driven into sandy deposit is generally expected to occur shortly after the installation of pile. This is because the complete dissipation of the excess pore water pressure caused by the pile driving process generally took place in few hours or just few days after installation of pile. However, substantial increase in capacity of pile driven in sand over a long term period has been reported by many researchers. Tavenas and Audy (1972) noticed this phenomenon and have reported an increase of about 70% in pile capacity within 20 days for foundation piles of retaining wall at both sides of St. Charles River, Quebec. Samson and Authier (1986), York et al. (1994), Tomlinson (1996) and others have also observed the similar time effects. The most recent case was reported by Chow et al (1998) that an increase of 85% in shaft capacity during the time interval between six months and five years after installation of an open-ended piles into dense marine sand.

The mechanism of increase in pile capacity for pile installed in sand cannot be explained by the dissipation of the excess pore water pressure caused by the pile driving process as the complete pore pressure equalization is expected within few hours or the most within few days. The specific mechanisms of the increase of pile capacity are not fully understood at present. There are three possible reasons (Chow et. al., 1998):

(1) Chemical effects which may cause bonding of sand particles to the pile surface,

(2) Soil aging effects which could increase the stiffness, dilation and strength (Schmertmann, 1991, Mitchell & Solymar, 1984).

(3) Long term changes in the stress regime surrounding the pile where the creep behavior of sand particles leading to the breakdown of arching around the pile shaft. As the result, the radial stress on the pile shaft increases.

3 CASE I

3.1 *Site Conditions*

The site is located on very thick marine clay deposit. Six numbers of exploratory holes were drilled and the results showed that the subsoils are quite consistent. In general, the subsoil can be simplified into two major soil strata as follows:

(a) Very soft to stiff silty clay. The thickness of this layer is about 44m to 51m. At the top 20m, the clay layer is very soft with standard penetration test (SPT-N) values normally less than or equal to 1. The clay becomes soft to medium stiff with SPT-N values increase to the range of 2 to 4 between 20m to 40m below the ground surface. At about 40m and below, the SPT-N values normally range from 10 to 15. Thin layers or lenses of dense silty sand could be encountered occasionally at about 30m to 35m below ground surface.

(b) Dense silty fine sand interbedded with silty clay layer could be encountered at depths of 44m to 51m below the ground surface. The SPT-N values are generally greater than 50.

The groundwater level at the site was about 1m to 2m below the ground surface.

The soil profile close to the test piles is shown in Figure 2.

3.2 *Tested Piles*

The piles tested were 400mm by 400mm square precast reinforced concrete piles (R.C. pile) with design concrete strength of 45 MPa. The hammers used for the pile driving were seven tonnes hydraulic hammers.

3.3 *Pile Testing*

Two piles, namely Test Pile A and Test Pile B, have been tested twice by means of high strain dynamic pile test carried out at different time after installation. A seven tonnes hydraulic hammer was used to apply the impact force on the pile top to generate stress waves in the tested piles and the signals recorded by the pile driving analyser (PDA). CAPWAP analyses were performed to assess the pile capacity. One of the tested piles was also tested by conventional static pile load test.

3.3.1 *Test Pile A*

Test Pile A was installed on 1 July, 1996 driven to a depth of 57.5m. At the end of initial driving, the penetration at pile termination of about 8mm/blow (with 7 tonnes hammer and 1m drop) was recorded. Dynamic pile test was carried out 3 days after the pile installation.

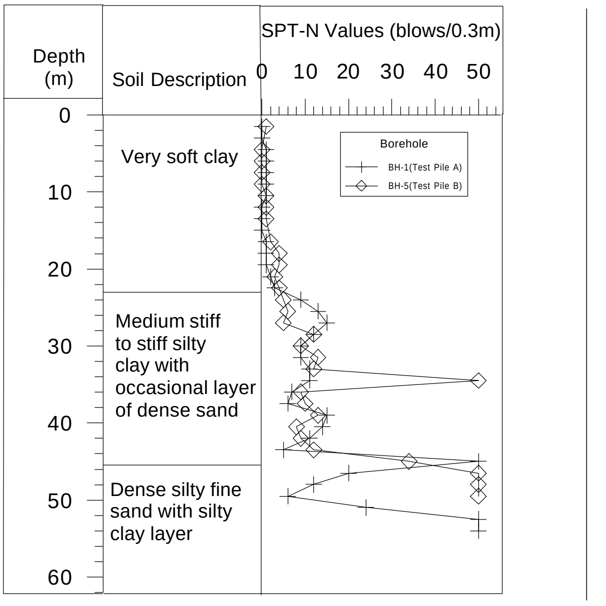

Figure 2. Typical subsoil profile for Case I

CAPWAP analysis result indicated that the pile capacity was 404 tonnes with shaft friction of 305 tonnes and end bearing of 99 tonnes. Static pile load test was performed 16 days after pile installation. The result was interpreted using Davisson's method which is more suitable for quick maintained load test. The obtained pile capacity was about 400 tonnes. Second dynamic pile test was conducted 19 days after pile installation and the CAPWAP analysis showed that the pile capacity has increased to 522 tonnes with 462 tonnes of shaft friction and 60 tonnes of end bearing.

3.3.2 *Test Pile B*

Test Pile B was installed on 20 July, 1996 and driven to a depth of 47.5m. A penetration at pile termination of about 13mm/blow was recorded at the end of driving. Seven days later, dynamic pile test was performed. CAPWAP analysis result showed that the pile capacity was about 411 tonnes. The shaft friction and the end bearing were 253 tonnes and 157 tonnes respectively. Second dynamic pile test was carried out 33 days after installation of pile. The pile capacity from the CAPWAP analysis increased to 475 tonnes. About 430 tonnes of the pile capacity was contributed by the shaft friction.

3.3.3 *Summary and Discussion*

The relationship between pile capacities and the time lag after pile installation are shown in Figure 3.

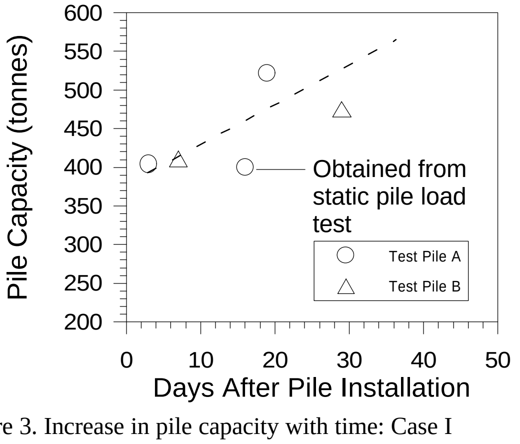

Figure 3. Increase in pile capacity with time: Case I

A trend of increase in pile capacity with time is observed. As described in Section 2.1, the soil surrounding the pile will undergo re-consolidation process after the installation of pile and the soil strength will gradually increase. The pile capacity increased as the result of increased in strength of the surrounding soil. The increase in the pile capacity was mainly from the shaft friction. From the results of CAPWAP analyses, significant increase in the shaft friction was observed. The average unit shaft friction was computed. The relationship between the average unit shaft friction and the time lag after pile installation is shown in Figure 4. A steadily increase in the average unit shaft friction can be observed.

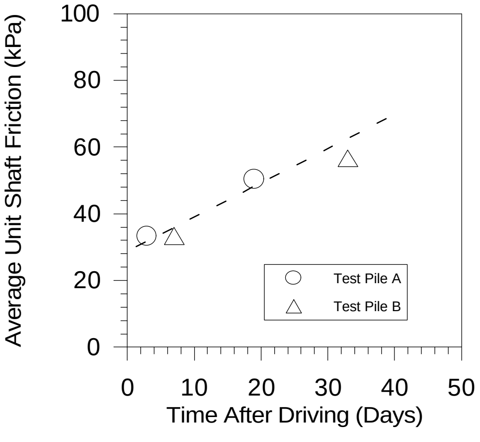

Figure 4. Increase in average unit shaft friction: Case I

4 CASE II

4.1 *Site Conditions*

The site is located at the east coast of West Malaysia and is a flat filled ground. Based on the results of 12 numbers of exploratory holes, the subsoil mainly consists of sand and silty sand. Typical subsoil profile is as follows:

(a) Loose to dense silty sand with occasional sandy clay pockets and gravel. There was a 1m to 1.5m thick fill materials below the ground surface. In general, the thickness of this soil layer is between 45m to 50m. The SPT-N values show an increasing trend with depth. Layers of dense sand were encountered at 12m to 22m below ground surface.

(b) Granite was encountered underneath the sandy deposit.

The typical subsoil profile is shown in Figure 5.

4.2 *Tested Piles*

The piles tested were squared, precast reinforced concrete piles (R.C. piles) with design concrete strength of 45 MPa. The pile sizes vary from 200mm to 381mm. Most of the piles were driven using 7 tonnes hydraulic hammers. For the 200mm by 200mm R.C.piles, 3 tonnes hydraulic hammers were used.

4.3 *Pile Testing*

The tested piles were installed from June 1996 to October 1996 and driven to a predetermined depth of 36m. Conventional static pile load tests were carried out 30 days to 140 days after the installation of piles. The ultimate pile capacity interpreted from the pile load test together with the general information of the tested piles are summarized in Table 1.

The interpreted pile capacities were normalized to the calculated static pile capacities of various pile sizes. The static pile capacity was calculated using the empirical equation as proposed by Meyerhof (1976) as follows:

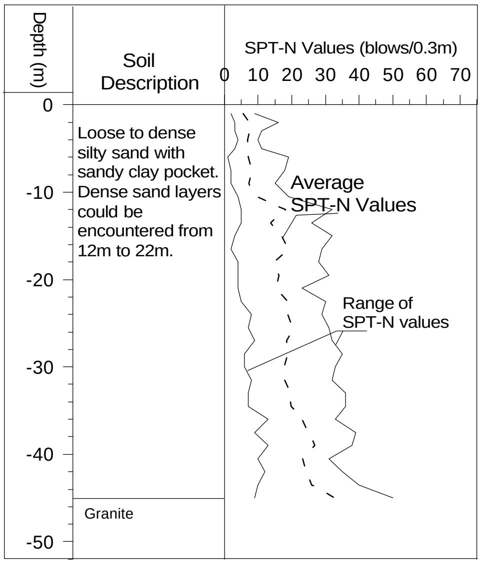

Figure 5. Typical subsoil profile for Case II

Shaft friction $Q_f = 2\ N\ A_s$
End bearing $Q_b = 400\ N\ A_p$
Where N = SPT- N values
A_s = Shaft area of pile
A_p = Cross section area of pile

Figure 6 shows the relationship between the time after pile driving and the ratio of the interpreted ultimate pile capacity of each test pile from the load test to the calculated static pile capacity. A tendency can be observed. The pile capacity increased during the first 60 to 80 days to reach a maximum value of about 150% higher than the calculated capacity. Apparently, the pile capacity does not seem to increase further after 60 to 80 days.

Table 1. Summary of The Tested Piles For Case II

Pile no.	Dimension (mm)	Length (m)	Date Installed	Date Tested	Interpreted Ult. Pile Capacity (kN)
1	200	36	14/07/96	13/08/96	940
2	250	36	09/07/96	12/08/96	1430
3	250	36	17/08/96	08/10/96	1400
4	250	36	20/08/96	21/10/96	2260
5	250	36	07/09/96	25/11/96	3600
6	250	36	31/07/96	04/12/96	2360
7	305	36	25/07/96	05/10/96	4890
8	305	36	30/07/96	12/10/96	4090
9	350	36	06/07/96	05/08/96	3030
10	350	36	21/08/96	21/10/96	4620
11	350	36	06/07/96	23/11/96	3190
12	381	36	24/08/96	16/10/96	6350
13	381	36	11/07/96	28/10/96	4100
14	381	36	02/10/96	30/11/96	5640
15	381	36	12/09/96	04/12/96	6090
16	280	36	11/07/96	08/09/96	3410
17	280	36	30/07/96	08/10/96	3380
18	280	36	19/08/96	12/10/96	2850
19	280	36	18/08/96	16/10/96	2640

5 IMPLICATIONS OF THE CHANGE IN PILE CAPACITY WITH TIME

The observed increase in pile capacity with time implies that substantial cost saving is possible for a project if the preliminary piles can be installed earlier and sufficient time was allowed before carrying out the pile load test. Higher pile

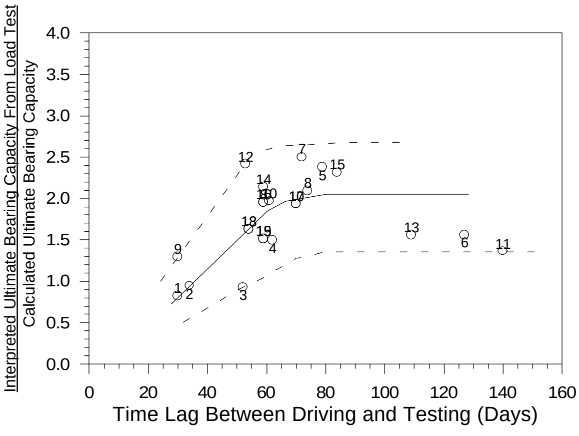

Figure 6. Increase in pile capacity with time: Case II

capacity implies that less number of piles will be required.

The pile capacity estimated from the pile driving formulae does not necessarily lead to a valuable estimate of pile capacity due to the time effect. If pile driving formulae are used for the assessment of pile capacity, re-striking the pile after sufficient resting period is suggested to obtain a more representative result.

Load test program shall be planned in such a way that the test result has considered the time effect and will not significantly underestimate the long term pile capacity.

6 CONCLUSIONS

Very often in a construction project, pile load test is carried out shortly after the pile has been installed due to the time constraint. The obtained pile capacity is then taken as the long term capacity of the pile. As a result, the pile capacity could be underestimated and the total number of piles could be over provided. The time effects not only can occur in clayey deposit but also in sandy deposit. The increase in pile capacity for piles installed in clayey deposit is mainly due to the re-consolidation of the soils surrounding the pile. However, at present the increase in pile capacity for piles driven into sandy deposit are still not fully understood. Further study is needed. In preparing the pile load test program, time effects should be taken into the consideration. Sufficient resting period after installation of pile is recommended whenever possible.

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