Design and construction of driven piles over soft marine clay

Peir Tien Lee[1], Y.C. Tan[1], and J.G. Bok[1]

[1] G&P Geotechnics Sdn Bhd, Kuala Lumpur, Malaysia.

ABSTRACT

A university college is proposed to be constructed over a 10 acres land situated at Batu Kawan, Seberang Perai, Penang, Malaysia. The proposed site is located at water ponding low lying terrain of soft alluvium clay. In this paper, the design, installation and verification processes of floating pile (pile to length) is discussed. Maintained Load Test (MLT) with and without fully instrumentation were carried out to reveal the performance of the piled foundation. The test results reveal that the pile ultimate capacity increased significantly after 2 weeks of installation. In addition, the tests shows unit shaft friction resistance of 3 x SPT-N (in kPa) can be adopted for driven pile. As the piles were installed after ground treatment with prefabricated vertical drain and temporary surcharge, the gain in strength of the subsoil after ground treatment is presented in this paper as well.

Keywords: driven pile; soft marine clay; pile to length

1 INTRODUCTION

An university college is proposed to be constructed over a 10 acres land situated at Batu Kawan, Seberang Perai, Penang Malaysia (Figure 1). The proposed site is located at water ponding low lying terrain as shown in Figure 2. The subsoil mainly consists of 15m to 20m thick soft CLAY.

Fig. 1. Site Location.

In view of low lying terrain and existence of soft compressible CLAY, ground treatment of Prefabricated Vertical Drains (PVD) with temporary surcharge is utilised to expedite the dissipation of excess pore water pressure generated from filling works and to eliminate the long term consolidation settlement. The performance of the PVD can be referred to paper by Lee et. al (2017). The piling works commenced after removal of the temporary surcharge. Therefore, the piles will not be subjected to negative skin friction.

Fig. 2. Water Ponding Before Site Clearance.

This paper presents the design, installation and verification processes of floating pile (pile to length). Maintained Load Test (MLT) with and without instrumentation were carried out to evaluate the performance of the piled foundation. The load distribution along the pile is discussed in this paper. As the piles were installed after ground treatment with prefabricated vertical drain and temporary surcharge, the gain in strength of the subsoil after ground treatment is presented in this paper as well.

2 GENERAL GEOLOGY

The Geological Map of Peninsular Malaysia, 8th

Edition published by Director-General of Geological Survey Malaysia in 1985, indicates that the site is underlained by Alluvium with Quaternary aged as shown in Figure 3. Alluvium deposits generally consist of mix clay, silt and sand material and generally very soft.

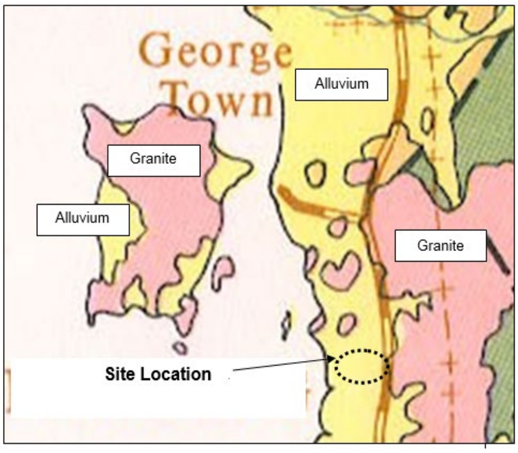

Fig. 3. General geology of the site.

3 SUBSOIL CONDITION

The subsurface investigation (S.I.) works of 4 boreholes, 2 piezocones and 6 penetration vane shear were carried out. The subsoil generally consists of 15m to 20m thick very soft to soft CLAY/SILT overlying loose to medium dense silty SAND to SAND as shown in Figure 4. The piezocones KPZ1 and KPZ2 were carried out adjacent to penetration vane shears KVS3 and KVS4 respectively. KPZ2 was terminated at shallow depth which may be due to intermediate hard layer. It can be seen that the undrained shear strength obtained from the penetration vane shear and piezocone (adopting empirical correlation factor on total cone resistance (N_{kt}) of 13.5) shows matching results (refer to Figure 5).

4 PILE CONSTRUCTION

4.1 Pile Installation

The circular pre-stressed spun piles of diameter 350mm and 450mm having wall thickness of 70mm and 80mm respectively with 80MPa concrete strength have been adopted as foundation pile system for the entire project.

The estimated design pile lengths for 350mm and 450mm diameter are 48m and 54m respectively. The capacities of 450mm and 350mm are 1620kN and 900kN respectively. No pile head hacking is required as all the piles have been installed with the pile head reaching within certain tolerance of the designated pile cut off level. However, during construction, the pile lengths were revised after satisfactory maintained load test (MLT) was carried out on sacrificial pile which will be discussed in the section below.

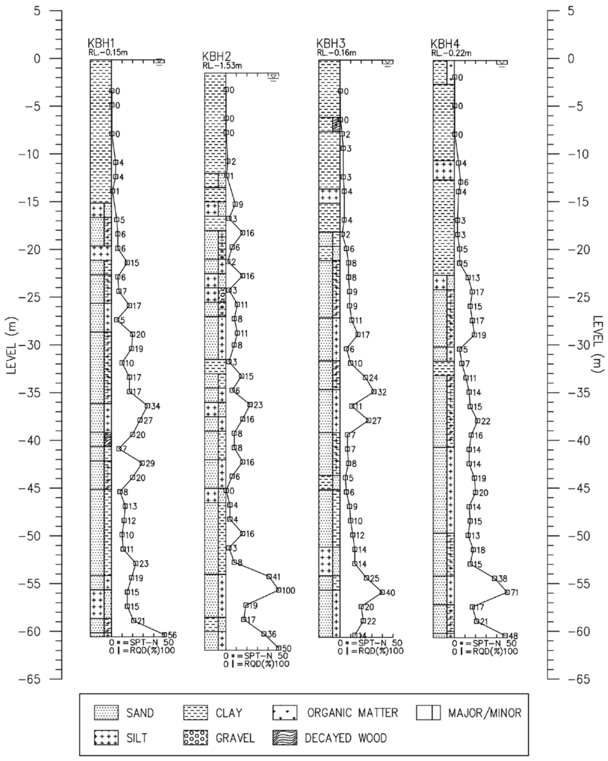

Fig. 4. Borehole profile

4.2 Maintained Load Test

A total of 2 static maintained load tests (MLT) were carried out for this project, which consist of one sacrificial test pile (TP1) and one instrumented working maintained load tests (IMLT) namely P709.

The initial approach is to carry out the instrumented maintain load test on a sacrificial pile. However, the installation of the strain gauges is unable to proceed to the required depth due to improper cleaning of laitance within the annulus of the spun pile. In view of the urgency of the project, the sacrificial pile (TP1) was carried out without instrumentation prior to the commencement of piling works.

TP1 having pile size of 450mm diameter was tested to 2.5 times of the designed pile working load (1620kN). The graphical plotting of the individual pile test result for TP1 is shown in Figure 6. TP1 was tested with three loading cycles. Whilst, Figure 7 show the load-settlement plots of the test pile results for P709, which was fully instrumented and tested to 2 times of the pile working load of 900kN. Table 1 summarises the pile settlement experienced with the load cycle for TP1 and P709. The test results show that all the piles perform satisfactory under one time working with pile settlement less than 12.5mm complying with common practice adopted by Public Works Department of Malaysia.

TP1 was driven with continuous pile monitoring (CPM) and the results are tabulated in Table 2. The high strain dynamic pile tests (HSDPT) during end of

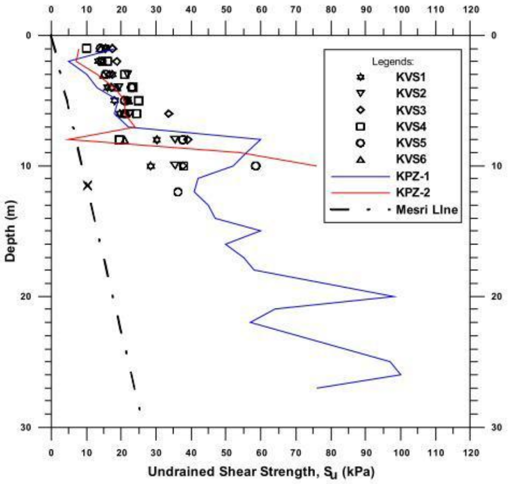

Fig. 5. Undrained shear strength from KVS and KPZ

drive (EOD) for TP1 yielded much lower ultimate pile capacity compared to the MLT result, which was carried out 2 weeks after the pile installation. The MLT result showed ultimate pile capacity of about 4050kN, which increased by almost 100% after 2 weeks. This is in lined with observation by Liew & Kowng (2005).

The much lower ultimate pile capacity at EOD indicating significantly reduced in shear strength of soft clay owing to disturbance during pile installation (i.e driving). Whilst, the significant increase in ultimate pile capacity after 2 weeks demonstrating the gained in strength with time or the commonly known as "set up" effect. This is further verified by subsequent 2 nos of re-strike tests as shown in Table 2. The re-strike tests also yielded that the increase in shaft friction is about 2 times after the first re-strike and 2.2 times after the second re-strike.

Table 1. Summary of MLT results

MLT Tests / (Pile Size)	Pile Length	First Cycle Settlement (mm) / (Test Load)	Second Cycle Settlement (mm) / (Test Load)	Third Cycle Settlement (mm) / (Test Load)
TP1 (450mm)	48m	12.46mm 0.98mm* (1620kN)	36.57mm 6.57mm* (3240kN)	52.95mm 11.61mm* (4050kN)
P709 (350mm)	43m	7.19mm 0.28mm* (900kN)	19.74mm 3.29mm* (1800kN)	- -

Note: * Residual settlement.

4.3 Instrumentation Results

The instrumented test pile, P709, was equipped with seven levels of strain gauges as shown in Figure 8 together with the nearest borehole, KBH1 for ease of reference. The strain gauges were installed after pile installation. The mobilised shaft frictions resistance at various depth along the test pile are shown in Figure 9.

The instrumented test results show that the subsoil has mobilised ultimate shaft friction resistance up to about 32m depth (i.e up to Lev F) as shown in Figure 9.

The SPTN values for the first 32m pile length range from 4 to 30 and the mobilised ultimate shaft friction resistances recorded range from 22kPa to 55kPa, which corresponds to about 3 to 11 times of the SPTN values. Therefore, it can be concluded that a conservative correlation of shaft friction of 3 x SPT-N (in kPa) can be adopted for driven pile design in such subsoil condition. Whilst, the mobilised friction resistances at the remaining 10m of pile length (i.e Lev F up to Lev H) are yet to reach the ultimate value.

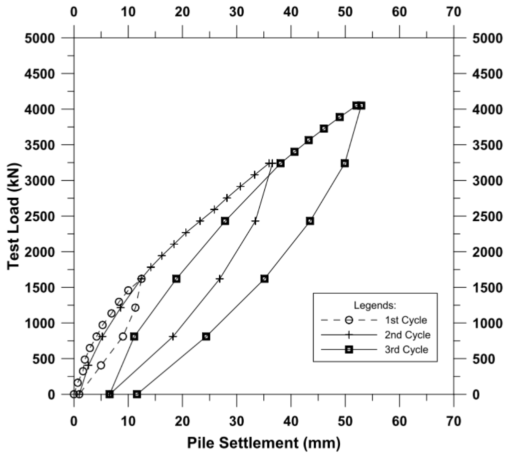

Fig. 6. Load-settlement plot for TP1.

Table 2. Summary of CAPWAP Results for TP1

Date of Installation or Test / (Time lapsed from date of installation, days)	Event Analysed	Shaft Friction (kN)	End Bearing (kN)	Total (kN)
28th March 2016 / (0)	End of drive (CPM)	1780	250	2030
19th April 2016/ (22)	1st Re-strike	3720	300	4020
4th May 2016/ (37)	2nd Re-strike	4040	230	4270

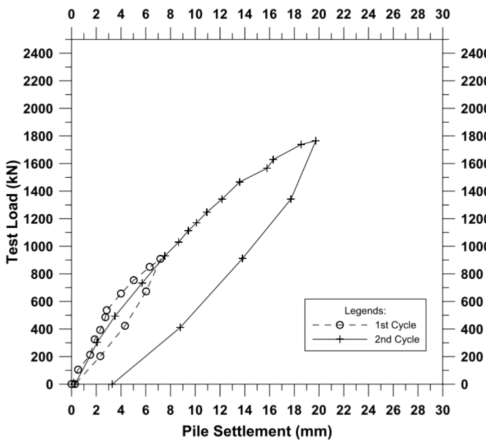

Fig. 7. Load-settlement plot for P709 (fully instrumented)

However, the mobilised ultimate shaft friction resistance for the soft clay layer (Level B – C) is about

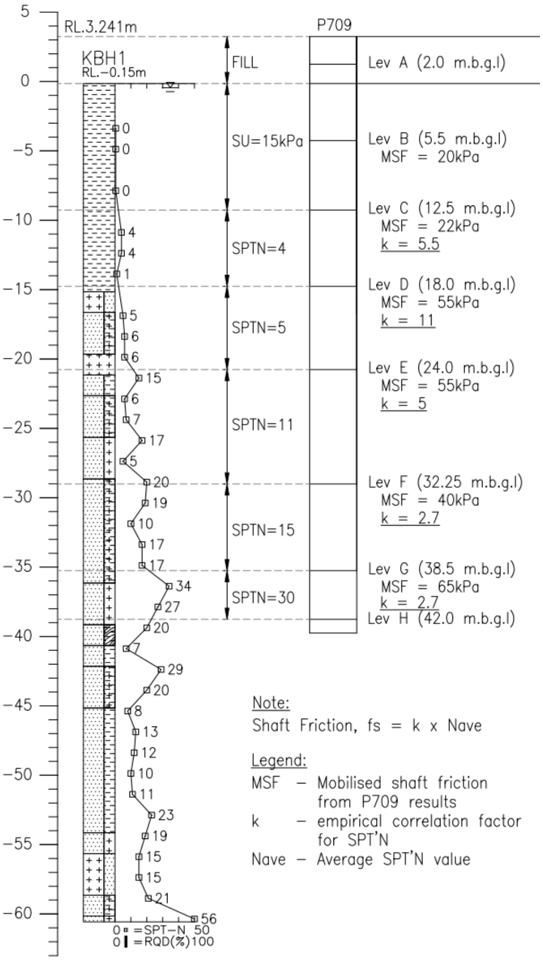

Fig. 8. Location of strain gauges for P709 with KBH1.

20kPa. Whilst, the nearby penetration vane shear (KVS1) which was carried out before the ground treatment works (i.e PVD and temporary surcharge) works indicated undrained shear strength (s_u) of 15kPa for the first 9m soft clay. Generally, the soil friction resistance for soft clay is the function between empirical factor of α and s_u. Based on the instrumentation results, apparently there is insignificant increase in the subsoil s_u after the ground treatment works. Thus, further study is required on this issue.

The load distribution along the pile is shown in Figure 10. It can be seen that the major contribution of shaft resistance is from 16m to toe of the pile. Whilst, there is insignificant base contribution (i.e 100kN) even when the test load achieved about 2 times of the pile working load. This is also in lined with the HSDPT results, which showing the majority contribution of load is from shaft resistance.

5 CONCLUSIONS

Case study on the design and construction of driven piles over soft marine clay has been presented. From the test pile results, it is found that the spun piles, which were installed to 43 to 45m length (without founded on hard layer), have performed satisfactory as friction pile. This is in lined with the test results where majority contribution of load is from shaft friction with insignificant base contribution. In addition, a conservative preliminary correlation for shaft friction resistance of 3 x SPT-N (in kPa) can be adopted for driven pile design in similar subsoil condition. Whilst, the significant increase in ultimate pile capacity after 2 weeks demonstrating the gained in strength with time or the commonly known as "set up" effect.

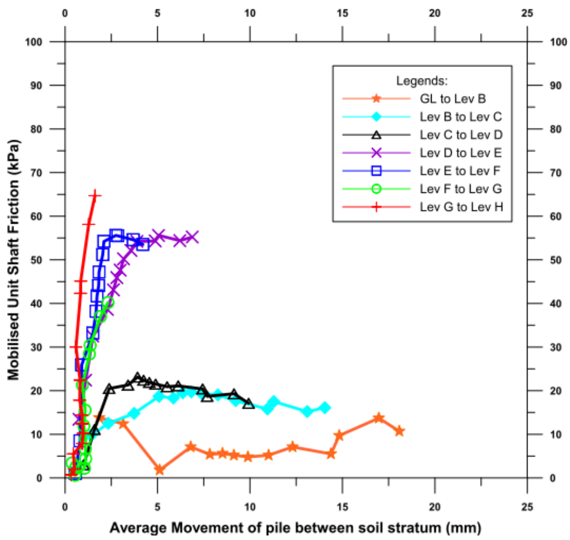

Fig. 9. Mobilised shaft friction resistance along the pile length for P709

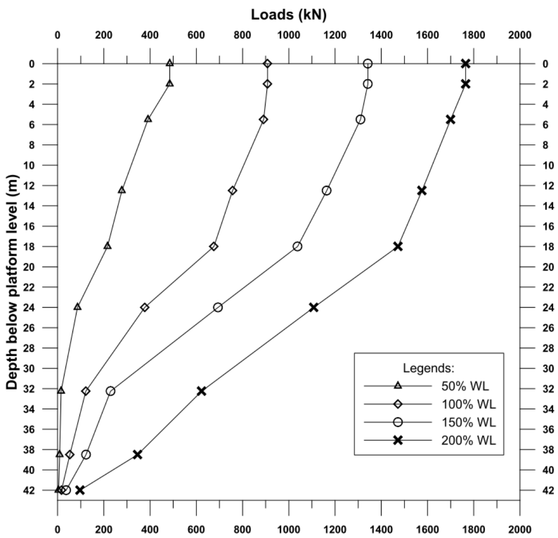

Fig. 10. Load distribution curve with depth below platform level

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