

Performance of high capacity jack-in pile for high-rise building with preboring in weathered sedimentary rock formation

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ABSTRACT

High capacity jack-in piles with working load of up to 3000 kN were successfully designed and constructed for a proposed residential apartment of up to 24-storey high in East Ledang, Nusajaya, Johor, Malaysia. The installation of jack-in pile was carried out after preboring works to ensure a minimum pile length of 5.0 m below cut-off level due to the shallow hard layer (SPT-N > 50) of the weathered sedimentary rock formation. The prebored hole was backfilled with loose soil and jack-in spun pile was installed with termination criteria of minimum two (2) times working load, with the maximum jack-in pressure maintained for at least 20 seconds and the procedure repeated three (3) times for each pile. The termination criteria includes pile head settlement not exceeding 2.0 mm for each pile set / termination reading and the set readings were taken at least three (3) times with an interval of not less than three (3) minutes between each set. The above procedure was adopted to minimize the effect of excess pore-water pressure which may cause premature termination of the pile. The performance of the jack-in pile system was validated based on results of pile static load tests and instrumented test pile. The obtained load test results are discussed in this paper.

Keywords: jack-in pile, preboring, spun pile, sedimentary rock, shaft friction, end-bearing

1 INTRODUCTION

Jack-in pile foundation systems are popular in urban areas due to the low noise and low vibration which are attributable to the pseudo-static jacking force applied to install the piles, as oppose to conventional percussive dynamic methods. Advantages of the jack-in pile foundation include faster installation rates, better quality control, less pile damage and cleaner site conditions. However, as with all foundation systems, the jack-in pile foundation system also has disadvantages such as the need for a larger and stronger working platform to support the large and heavy piling machinery (Chow *et al.*, 2010). Moreover penetration depths of the jack-in piles are limited to the depth of the initial stiff subsoil stratum encountered during installation.

In East Ledang, Nusajaya, Johor, Malaysia, high capacity jack-in piles with working load of up to 3000 kN were successfully designed and constructed for a proposed residential apartment of up to 24-storey high. In this project, the installation of jack-in pile was carried out after preboring works to ensure minimum

pile length below cut-off level of 5.0 m due to the shallow hard layer (SPT-N > 50) of the weathered sedimentary rock formation. This method required the prebored hole to be backfilled with loose soil. Consequently, the piles were installed using jack-in method with termination criteria of jacking to a minimum of two (2) times working load, with the maximum jack-in pressure maintained for at least 20 seconds and the procedure repeated for three (3) times for each pile.

A series of static load tests were carried out at site to evaluate the performance of the installed piles. Results from a fully instrumented test pile were used to validate the design criteria and performance of the jack-in piles system adopted at site.

2 DESIGN METHODOLOGY

2.1 Subsurface information

The proposed residential apartment situated in East Ledang, Nusajaya, Johor, Malaysia is underlain by sedimentary rock formation of Triassic age, consisting of interbedded sandstone, siltstone and shale (according

to Geological Map of Peninsular Malaysia, 8th Ed., 1985). Based on the borehole profiles, overburden materials mainly comprise sandy SILT / silty SAND with increasing SPT-N with depth as shown in Fig. 1. Hard layer (SPT-N > 50) was encountered at shallow depths, ranging from 3.0 m to 9.0 m below the ground surface. Furthermore, weathered sandstone and siltstone were encountered at approximately 8.0 m to 15.0 m below the surface.

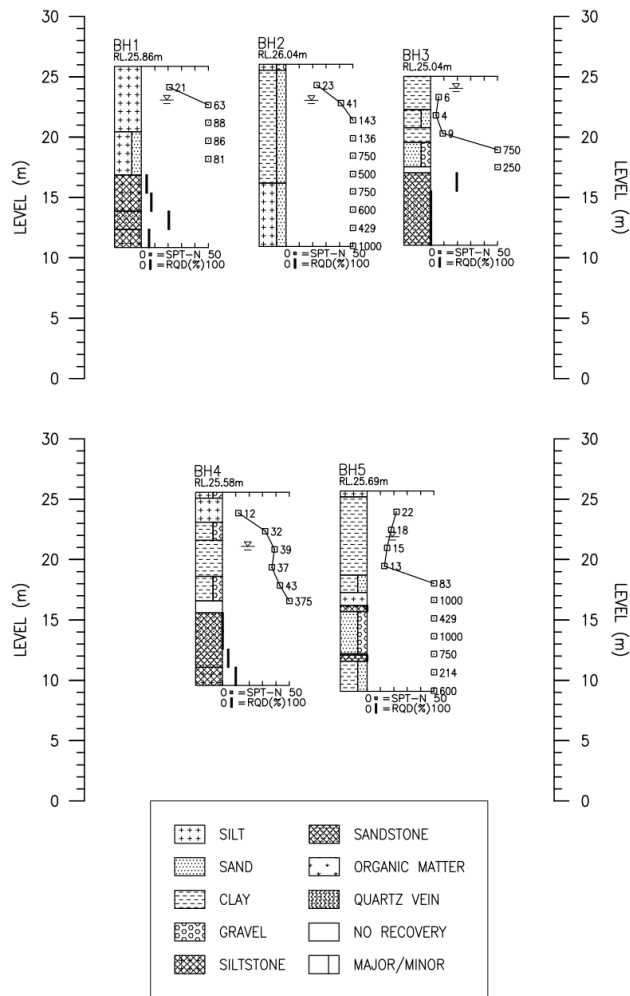


Fig. 1. Borehole profiles at site location.

2.2 Pile installation

A direct jack-in approach cannot be implemented for the proposed development due to the shallow hard layer of the weathered sedimentary formation encountered at site, as shown in Fig. 1. Therefore, preboring of the subsoil is deemed necessary in order to achieve minimum pile penetration length below cut-off level of more than ten times the pile diameter. The minimum pile length of ten times the pile diameter ensures that the pile behaves like a long pile if it is subjected to lateral loads (Fleming *et al.*, 1998). This further ensures that the foundation system is robust and is able to withstand nominal lateral forces due to pile eccentricity.

To facilitate pile installation, preboring works were carried out to predetermined depths depending on the estimated pile length and pile cap thickness. The specified prebore size is equal to or no larger than 50 mm of the diameter of the pile to be installed. Upon completion of preboring, the prebored hole was loosely filled with the excavated material up to no less than the pile cut-off level. Accurate setting out for prebore and jack-in locations is crucial to minimize eccentricity between the two. Furthermore, additional preboring depth of up to 2.0 m was specified to accommodate for compression of the backfill material during installation.

Subsequently, spun piles were installed into the loosely filled prebored holes using high capacity jack-in (injection) machines. The termination criteria adopted for the proposed development was to jack the pile to two (2) times of the design working load and the procedure repeated three (3) times for each pile. For each set of repetition, the corresponding maximum pressure was held for a minimum of 20 seconds with pile head settlement not exceeding 2.0 mm. The pile set / termination readings were taken for all three (3) sets of repetition with an interval of not less than three (3) minutes between each set. This is to minimize the effect of excess pore-water pressure which may lead to premature termination of the pile.

3 STATIC LOAD TEST

One (1) preliminary instrumented ultimate pile load test and three (3) un-instrumented working pile load tests were carried out at site to evaluate the performance of the adopted pile foundation system. The static load was applied to the pile head via a hydraulic jack using kentledge reaction blocks system. The preliminary instrumented pile load test was tested to three (3) times the design working load (or until failure) in three (3) load cycles to obtain the load transfer behavior at ultimate / failure state. The remaining three (3) working pile load tests were carried out to two (2) times the design working load in two (2) load cycles to verify the pile performance after installation.

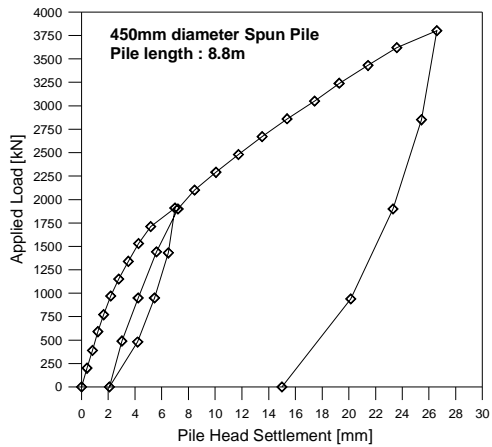
Calibrated load cells were used to measure the applied axial force and pile head settlements were measured using calibrated Linear Variable Displacement Transformers (LVDT) mounted onto independent reference beams. The instrumentation scheme of the instrumented preliminary test pile utilized the proprietary Global Strain Extensometer (GLOSTREXT) system (Krishnan *et al.*, 2006) to determine displacements along the pile shaft and at the pile base level, which is discussed further in the following section. The results of the pile static load tests are tabulated and summarized in Table 1 whereas Fig. 2 presents the load-settlement curves for the static load tests.

Table 1. Results of static load tests.

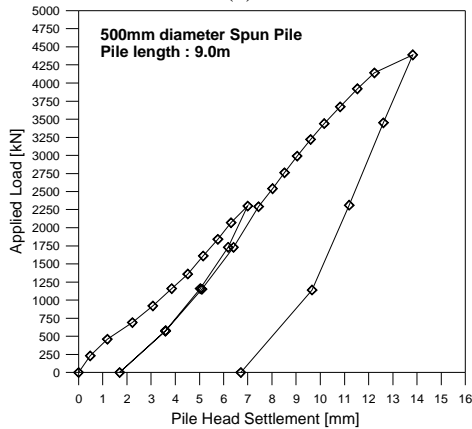
Pile Diameter [mm]	Pile Penetration Length [m]	Prebored Depth [m]	Pile Head Settlement [mm]		Remarks
			1x WL ¹	2x WL	
450	8.8	9.0	7.0	26.6	-
500	9.0	11.0	7.0	13.8	At 1.9x WL ²
600	8.5	11.0	5.8	13.0	At 1.5x WL ²
600	9.5	9.0	7.0	55.6	Instrumented

Note: ¹ WL denoted Design Working Load. The working loads for 450, 500 and 600 mm diameter piles are 1900, 2300 and 3000 kN respectively.

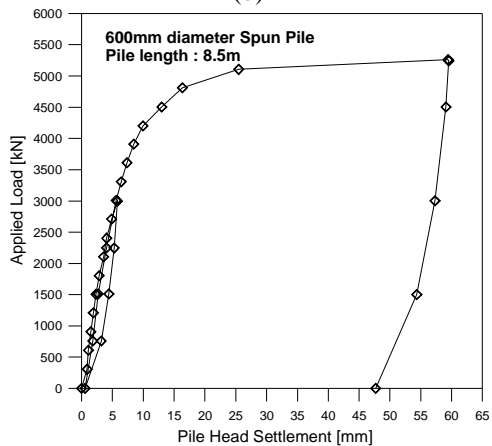
² Static load tests terminated at the stated applied load.



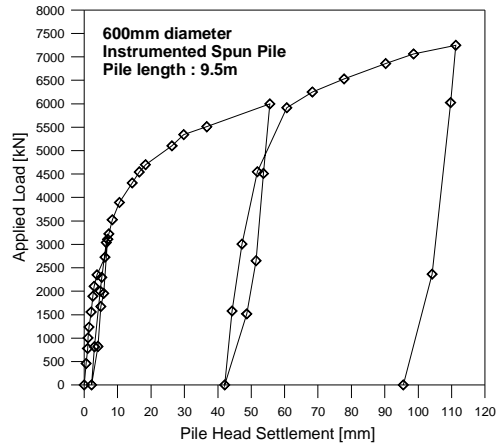
(a)



(b)



(c)



(d)

Fig. 2. Load-settlement curves for (a) 450 mm, (b) 500 mm, (c) 600 mm and (d) 600 mm diameter instrumented pile static load test.

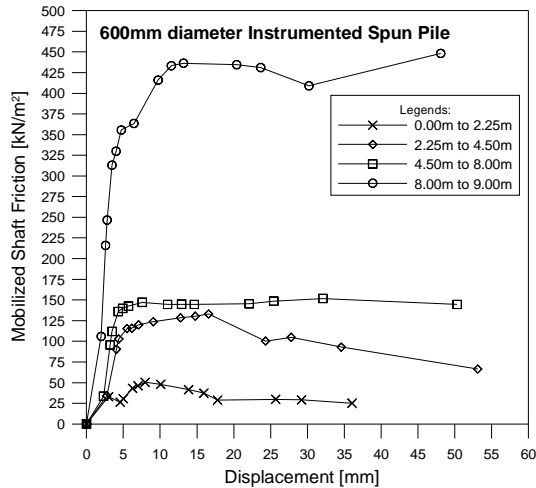
Based on the results of the static load tests conducted at site, the following observations are made:

- The 500 mm diameter spun pile load test stopped at 1.9x WL (4370 kN) due to complications experienced by the hydraulic jack during loading. Nevertheless, the pile head settlement at 1.9x WL was relatively small (13.8 mm) with residual settlement of 6.7 mm after unloading as shown in Fig. 2(b).
- Referring to Fig. 2(c), the un-instrumented 600 mm diameter pile load test terminated at 1.8x WL (5400 kN) with pile head settlement of 59.0 mm. In Table 1, the reported pile head settlement of 5.8 mm and 13.0 mm were at WL and 1.5x WL respectively. The pile was unable to achieve 2x WL as excessive pile head settlement was observed. In retrospect, the pile was expected to undergo excessive settlement as the imposed load approached 2x WL because the pile was designed to a global safety factor (FOS) of 2.0. Therefore, it is deemed adequate to test the pile to 1.5x WL (4500 kN) to prevent pile damage and to be consistent with the recommendations of ICE Specification for Piling and Embedded Retaining Walls (Institution of Civil Engineers [ICE], 2007).
- In general, the results showed that the performances of the jack-in piles were satisfactory, even with preboring. All piles tested to the design working load recorded pile head settlements of 7.0 mm or less with very small residual settlement after unloading. The relatively lower ultimate pile capacity for the un-instrumented 600 mm diameter pile compared to other test piles was possibly caused by the thicker compressed fill beneath the pile toe, resulting in lower end-bearing resistance.

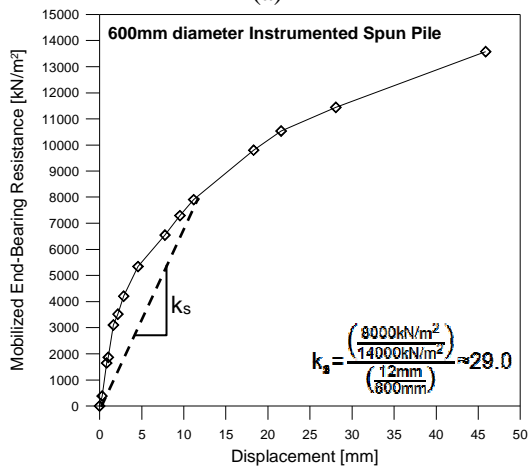
4 MOBILIZED SHAFT FRICTION AND END-BEARING RESISTANCE

The preliminary test pile was instrumented using

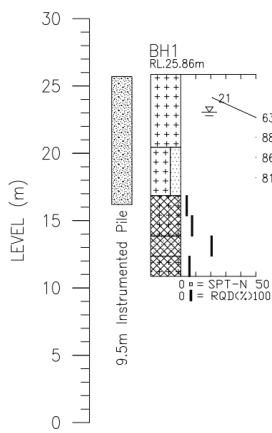
GLOSTREXT's global strain gauges and vibrating wire extensometers. The installed instruments allowed for measurements of mobilized shaft friction and mobilized base (end-bearing) resistance of the preliminary test pile. The load transfer curves for shaft friction and end-bearing resistance measured at two (2) times the design working load (2x WL) are illustrated in Fig. 3.



(a)



(b)



(c)

Fig. 3. (a) Mobilized shaft friction, (b) end-bearing resistance for instrumented 600 mm diameter spun pile at 2x WL and (c) adjacent borehole profile.

From the preliminary instrumented pile load test results, the following observations are made:

- Chow *et al.* (2010) have suggested a shaft friction correlation factor of 5x SPT-N for jack-in piles in weathered granite without preboring. Fig. 3(a) suggests that the ultimate shaft friction was reached with shaft friction correlation factor of approximately 2x SPT-N of the original subsoil, which is fairly high considering the pile was installed into loosely filled prebored hole. Hence, it is evident that the shaft friction is still a function of the original subsoil condition after preboring, but with lower correlation factor.
- Fig. 3(b) shows that larger base resistance was mobilized at smaller base displacements. The characteristic secant base stiffness, k_s , at base displacement of 2% pile diameter and with end-bearing resistance normalized to the ultimate end-bearing resistance is about 29.0. This is consistent with the findings of Deeks *et al.* (2005), where k_s for jack-in piles is more than two and ten times compared to driven piles and bored piles respectively.

5 CONCLUDING REMARKS

High capacity jack-in piles with working load of up to 3000 kN were successfully designed and constructed for a proposed residential apartment of up to 24-storey high in East Ledang, Nusajaya, Johor, Malaysia. The performance of the jack-in piles in weathered sedimentary rock formation was assessed by means of pile static load tests. Based on the test results, the following conclusions can be made:

- Construction challenges were expected due to the nature of the pile installation method, primarily short pile penetration. Approximately 2.5% of the total piles installed were shorter than the targeted minimum length and compensation piles were required. From the authors' experience, short pile penetration is best mitigated by adopting proper and accurate setting out to minimize discrepancies in location (eccentricity) and verticality between the prebored hole and the jack-in pile.
- The termination criteria adopted for the project was found to be satisfactory.
- Based on the instrumented pile load test and nearest borehole profile, a correlation for shaft friction of 2x SPT-N of original subsoil for jack-in piles into loosely filled prebored holes is proposed.
- The presence of residual base load due to the jack-in pile method resulted in high base stiffness, with secant base stiffness, k_s of approximately 29.0. Thus, end-bearing resistance for jack-in piles can be mobilized with relatively smaller base settlement compared to driven piles and bored piles.

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