

COMPARISON OF HSDPT AND SLT RESULTS OF DRIVEN PILES IN MALAYSIAN RESIDUAL SOILS

S. S. Liew ¹, H. B. Ng ² & K. K. Lee ³

ABSTRACT

This paper compiles the test results of high strain dynamic pile tests (HSDPT) and static load tests (SLT) at four piling project sites within Malaysia. Comparisons between HSDPT and SLT have been carried out to reveal the reliability of this indirect pile testing method. During implementation of the HSDPT, it was observed that the data acquisition, data processing and interpretation based on appreciation of the pile design are the three key factors for meaningful diagnosis of pile conditions. Failure in either one aspect can lead to erratic outcome for important engineering decision. HSDPT has also been used to provide useful information for slip-coated piles with negative skin friction.

Keywords : High strain ; Dynamic load tests ; Static load tests ; Preliminary test piles ; Working piles

1. INTRODUCTION

Pile load tests are usually carried out on preliminary test piles and working piles to verify the pile design and to proof load the working piles as quality control testing. In Malaysia, there are two common types of pile load tests, namely static and dynamic load tests. Static load test (SLT) is generally required as a conventional and traditional pile test for piling projects, whilst high strain dynamic pile load test is usually a supplementary testing to the static load test. High strain dynamic pile load test (HSDPT) is comparatively cheap and quick to determine the mobilised capacity as well as to assess structural integrity of the piles. With the proper correlation to SLT, wave equation analysis can be used for prediction of pile performance. Static load tests are usually costly and take longer time for preparation and conducting the test. High strain dynamic pile load test (HSDPT), with its advantages of time and cost savings, hence become popular as quality control measures and verification tests, particularly for the fast track project. Rausche et al. (1985) have reported that the pile capacity tested using HSDPT correlated well with the static load test results. Gue and Chen (1998) showed that HSDPT has over predicted the pile capacity by more than 60%. They commented that HSDPT could only be an effective mean of construction control provided that the proper correlation between the HSDPT and static load tests are carried out. However, there is still lack of good understanding among the geotechnical engineers on the wave equation theory in HSDPT tests. This paper presents the case histories of the high strain dynamic pile load tests (HSDPT) and static maintained pile load tests (SLT) carried out at four piling sites in Malaysia based on the well-documented test results. Comparisons between the HSDPT and SLT are also presented to reveal the reliability of this indirect pile testing method.

Depending on the objective of the test, HSDPT can be implemented at various stages of piling works as follows:-

- (a) Continuous pile driving monitoring : The testing sensors (strain gauges and accelerometer) can be attached to the initial pile and subsequent extension piles to continuously monitoring the force (from strain gauges measurement) and velocity (from integration of acceleration measured from accelerometer) of the pile during driving. Case method can be used to timely predict the pile capacity

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¹ Director, Gue & Partners Sdn Bhd, Kuala Lumpur, Malaysia

² Senior Geotechnical Engineer, Gue & Partners Sdn Bhd, Kuala Lumpur, Malaysia

³ Senior Geotechnical Engineer, Gue & Partners Sdn Bhd, Kuala Lumpur, Malaysia

as the pile penetrates. At the same time, hammer efficiency, pile integrity and the driving stressed (both tension and compression stresses) can be monitored closely. Continuous pile driving monitoring is very useful in detecting but not limited to the following driving problem:-

- (i) Degradation of pile integrity in pile body under hard driving condition when compressive stress is excessive.
 - (ii) Excessive tension stress when a pile penetrates through intermittent hard layer underlying by soft material.
 - (iii) Degradation of pile integrity at the pile joint under intensive driving impacts or bending of pile toe when the toe is being kicked off from the inclined competent material.
- (b) End-of-Drive HSDPT : This will normally give lower bound capacity as the pile setup or thixotrophy effect is not prominent immediately after driving disturbance except for sandy Silt materials which sometimes exhibits decreasing pile toe capacity with time immediately after pile termination. However, with the expected gain in pile capacity based on previous experience in the similar ground condition, one can use the end-of-drive HSDPT results for timely decision. This approach is only recommended particularly for long friction piles if the abovementioned calibration has been carried out.
- (c) Restrike HSDPT test : To compliment the end-of-drive HSDPT test, restrike tests can be carried out at any time after pile termination to indicate changes of pile capacity with time. However, in order to minimise the disturbance by subsequent driving impact during the restrike test, it is suggested to impart sufficient impact energy with as little hammer blows as possible.

For the abovementioned three types of HSDPT tests, the dynamic response of the selected blow can be further interpreted using wave equation theory analysis to show resistance distribution profile between pile shaft and toe, and predict load settlement.

2. CASE HISTORIES

In order to illustrate the application of HSDPT and its comparison with SLT results, the following four case histories are chosen.

2.1 Case 1 : Tangkak , Johore

The site is located at Tangkak, Johore and is a flat ground consisting of thick residual soil and weathered materials derived from the weathering of underlying bedrock of Siltstone. The underlying subsoil generally consists of soft to medium stiff clayey Silt and silty Clay overlying stiff to hard clayey Silt with Sand and Gravels.

The development consists of low to medium rise buildings on filled platform of up to 4m. Owing to the expected downdrag force on the piles induced by the fill, prestressed spun pile with application of slip coating was adopted as foundation system for the structures.

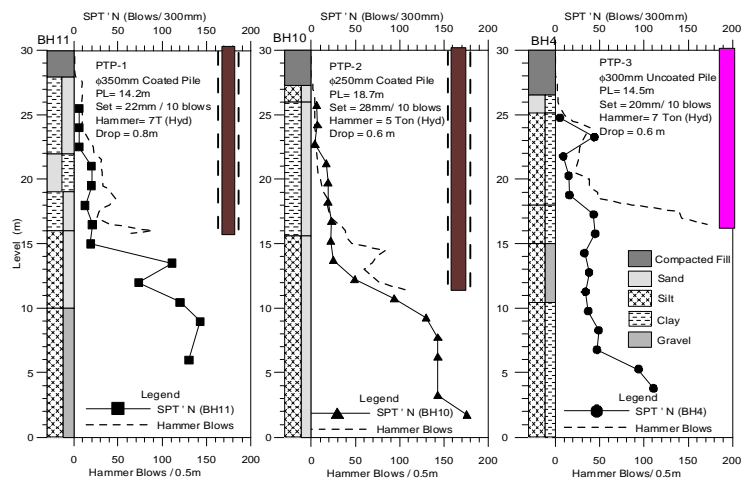


Figure 1 : SPT 'N' Profile With Pile Installation Records of Trial Piles (Case 1)

Three preliminary test piles of different pile dimensions were installed to length ranging from 14.2 m to 18.7 m below the existing ground level prior to the production piling. All test piles were able to achieve the set criteria during installation.

The pile installation records of the three trial piles shown in Figure 1 indicate consistency between the blow count profile and SPT'N profile of the adjacent boreholes. It is also clearly shown that all three trial piles have been terminated at the required hard soil stratum with $SPT'N \geq 50$. HSDPTs were conducted on the three installed trial piles at end of driving. The trial piles were then loaded to failure three weeks after the installation.

Figure 2 presents the load settlement curves of the SLT and those predicted by HSDPT. The load settlement results under the working load indicate a fair agreement in bearing capacity. The variation of the pile capacity determined from SLT and HSDPT is generally within 15% except for PTP-2, in which HSDPT over-predicted the pile capacity by about 36% as compared to the conventional static maintained pile load tests carried out later.

2.2 Case 2 : Gopeng , Perak

The project site is located on a hilly terrain and underlain by sedimentary formation. The overburden materials generally consist of interlayers of Clayey Silt, Gravelly Silt and Sandy Silt derived from the weathering of parent sedimentary rocks. Based on borehole logs, the presence of localized oxidized hardpans or boulders are expected at site.

The development consists of low to medium rise building were located on cut-and-fill platform of up to maximum 4m fill. Prestressed spun piles with application of bitumen coating were adopted as foundation system for the proposed structures located on filled ground with the intention to reduce the potentially large downdrag force on the piles induced by the fill. For structures located on cut ground, uncoated prestressed spun pile was adopted.

Prior to construction, three preliminary test piles of different pile sizes were installed to the pile length ranging from 4.5m to 28.5m below the existing ground level. The trials piles were driven to approved set using hydraulic hammer. The

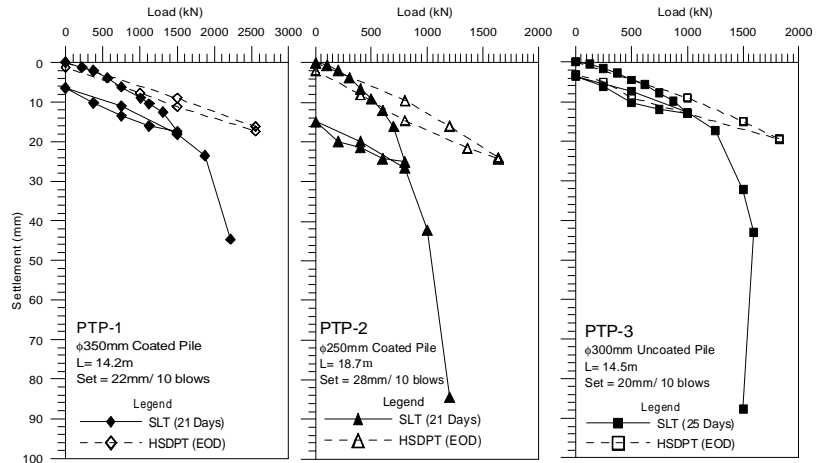


Figure 2 : Results of SLT and HSDPT for Trial Piles (Case 1)

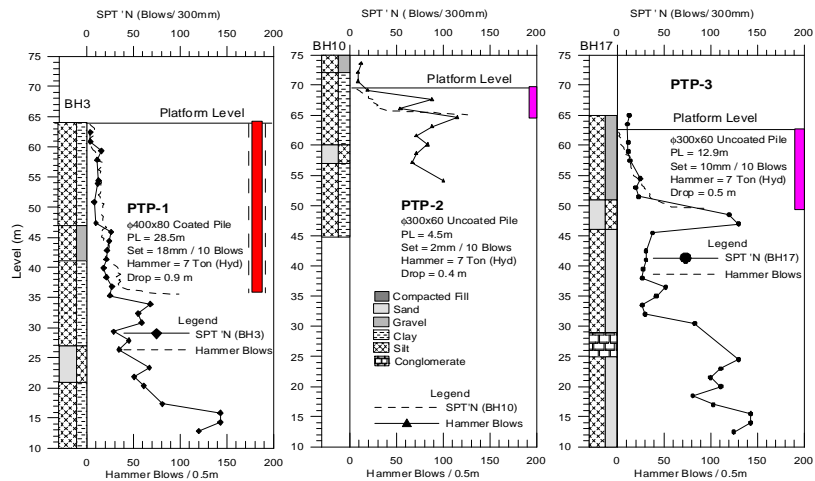


Figure 3 : SPT'N Profile With Pile Installation Records of Trial Piles (Case 2)

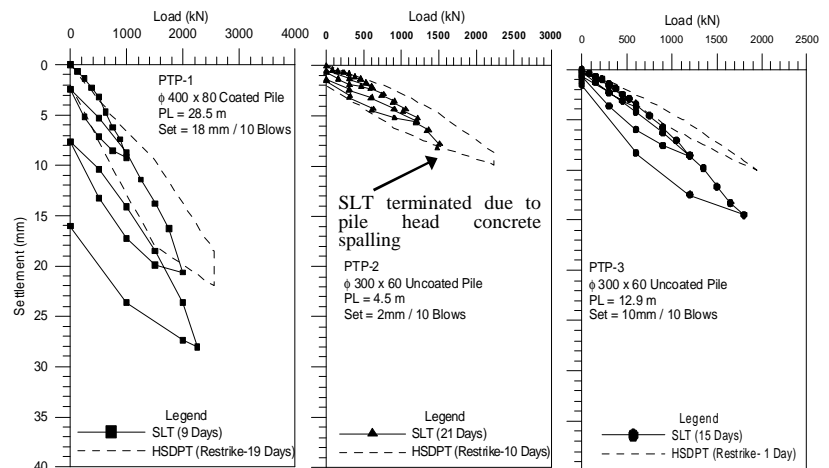


Figure 4 : Results of SLT and HSDPT for Trial Piles (Case 2)

pile installation records shown in Figure 3 indicate similarity in the driving resistance of the three trial piles to the adjacent boreholes. It is clearly shown that all the trial piles had been terminated at the required hard soil stratum with SPT'N ≥ 50 .

HSDPT tests were conducted on the three installed trial piles at end of driving and about 1 to 19 days after the installation respectively. The trial piles were loaded to three times the design working load at 9 to 21 days after the installation. Figure 4 presents the load-settlement curves of the SLT and the interpreted load-settlement prediction of restriking-HSDPT for the test piles. Except for test pile PTP-2 showing lower test load due to the spalling of concrete at pile head during the SLT, all the test piles show satisfactory agreement in pile bearing capacity. Generally, the variation of the pile capacities determined from the HSDPT and SLT ranges from 7% to 13%, in which the HSDPT has overpredicted the pile capacity.

2.3 Case 3 : Kota Bahru, Kelantan

Four numbers of working test piles of different pile dimensions (400mmx400mm RC piles and $\phi 450\text{mm} \times 80\text{mm}$) were installed at this site. The piles had been installed to length ranging from 46.8m to 56.4m below the piling platform. The pile installation records shown in Figure 5 indicate good agreement in the driving resistance of the test piles to soil consistency of the respective adjacent boreholes. The piles were installed reaching the very stiff to hard soil layer as friction piles.

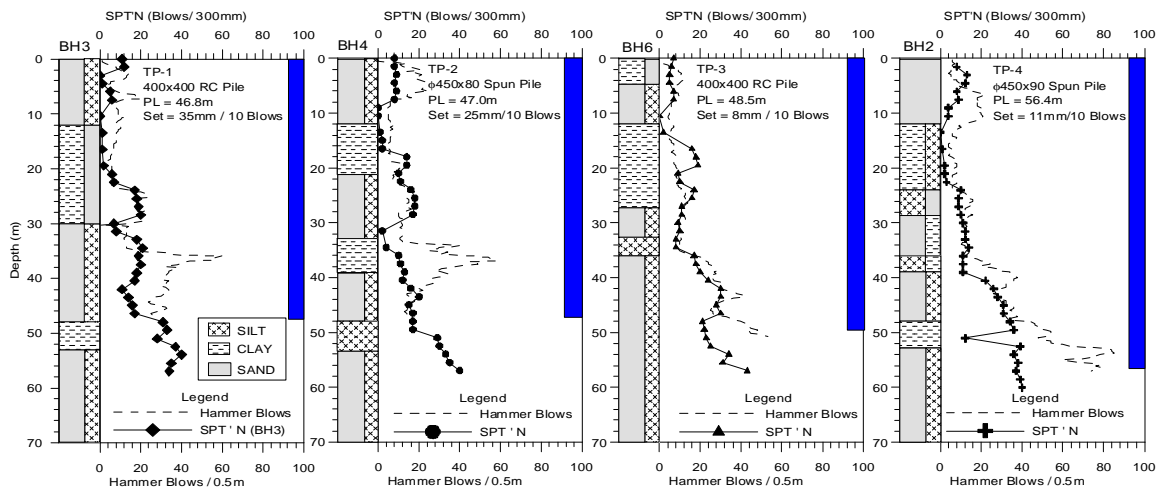


Figure 5 : SPT'N Profile With Pile Installation Records of Test Piles (Case 3)

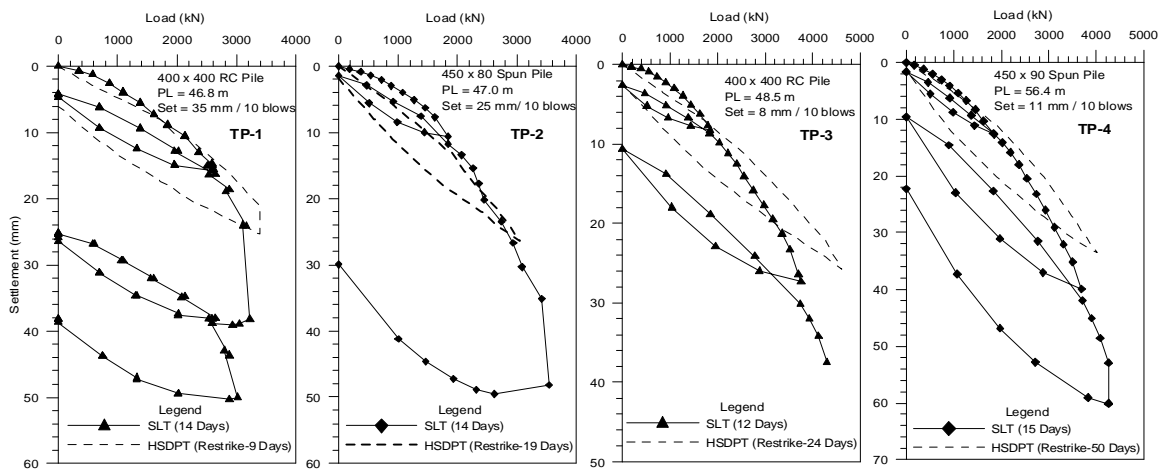


Figure 6 : Results of SLT and HSDPT for Test Piles (Case 3)

HSDPT were conducted about 9 to 50 days after the piles had been installed. The load settlement curves of the SLT and HSDPT that presented in Figure 6 have indicated fair agreement in the predicted pile capacities. The variation of pile capacities ranges from 5% to 13%.

2.4 Case 4 : Damansara Perdana, Selangor

Two prestressed spun piles with size of $\phi 500\text{mm} \times 90\text{mm}$ (trial pile) and $\phi 400\text{mm} \times 80\text{mm}$ (working test pile) were installed prior to the production piles at this project site. The test piles have been installed to the respective lengths of 24.6m and 22.5m below the existing ground level. The pile installation records shown in Figure 7 indicate fair agreement in the driving resistance of the test piles to the soil consistency adjacent boreholes. The results show that all trial piles have been terminated at the required hard stratum with SPT'N > 50 or granite bedrock.

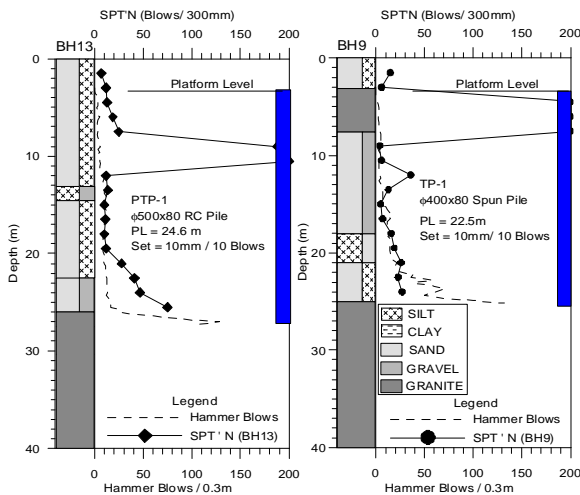


Figure 7 : SPT'N Profile With Pile Installation Records of Test Piles (Case 4)

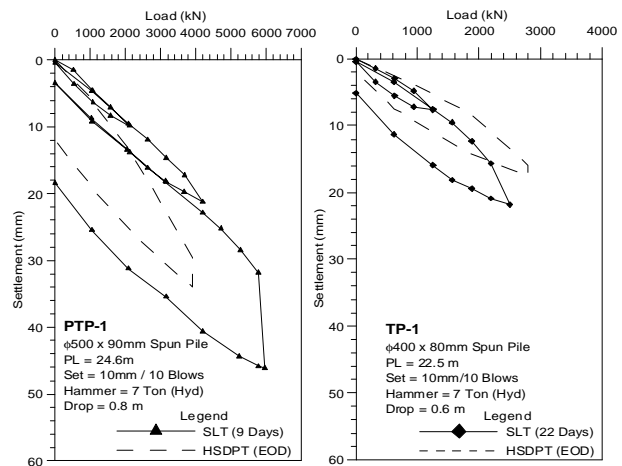


Figure 8 : Results of SLT and HSDPT for Test Piles (Case 4)

HSDPT were conducted at the end of the pile driving and static maintained pile load test (SLT) were conducted 9 to 22 days after the pile installed. The load settlement curves of the SLT and HSDPT as shown in Figure 8 have indicated reasonable satisfactory agreement in pile capacities for working test pile TP-1. But, HSDPT has underestimated the pile capacity of PTP-1 for about 35%. The relatively low estimated capacity obtained from HSDPT could be due to the disturbance of subsoil that mainly consists of sandy materials. However, the restriking test on PTP-1 was unable to be conducted to check the pile capacity after the setup effect as the contractor has cut off the pile head immediately after the SLT.

3. DISCUSSIONS

HSDPT is a time and cost effective pile testing method compared to SLT and has gained popularity in the local piling industry. HSDPT can be an effective tool for construction control if the correlation of the HSDPT and SLT is made and the test is conducted and interpreted by qualified personnel. Figure 9 shows the comparison of interpreted pile capacity of the aforementioned test piles from HSDPT and SLT results. The interpreted pile capacity of the test piles from these well-documented load test results at four piling sites in Malaysia are in reasonably fair agreement with the results of static load tests. With some exceptional test results, the variation of the predicted pile capacity generally falls within 15% for the test piles loaded to ultimate state or failure. The variation in over estimation of pile capacity is probably due to the inherent dynamic damping effect in the HSDPT testing. Rausche et al. (1985) reported that any value of damping constant between 0.0 to 2.0 will give results within 20% of the statically measured value. The prediction of pile capacity is usually sensitive to the selection of damping constant unless the pile toe velocity during driving is zero.

In addition, the pile capacity can change with time due to the setup or relaxation effects. Figure 10 shows the changes of the estimated capacity and pile set with time at various piling site. The results indicate that there is a significant increase of the capacity from day 1 to day 18 after the pile installation and the corresponding pile set generally reduces in drastically with time. It is worth to note that the HSDPT only gives capacity at the time of testing. Thus, HSDPT restriking test performed on restriking pile is much desirable as the soil strength changes with time is taken into account.

For HSDPT that has over-estimated pile capacity for more than 15%, the SLT test results obtained were not loaded to the ultimate capacity. It is believed that the pile capacity will be higher if the piles were tested to failure.

4. CONCLUSIONS

From the above, the following conclusions can be drawn:-

- (1) Generally, HSDPT can provide an effective mean of predicting pile capacity, establishing termination criteria for pile installation and construction control if calibration against SLT is properly carried out.
- (2) In order to obtain a meaningful diagnosis of pile conditions, data acquisition, data processing and interpretation are the key factors during the HSDPT implementation. Otherwise, the HSDPT results can lead the foundation designer to make an unsound engineering decision.
- (3) For pile capacity prediction, restriking test after the pile installation is generally recommended. The duration of resting before restriking test will depend on soil type. Fine grained soil will need longer resting period.
- (4) HSDPT can also be used to provide useful information for slip-coated piles with negative skin friction. The interpreted shaft resistance can reveal the performance of bitumen slip coating and the estimated maximum negative skin friction from the shaft resistance above the neutral plane as interpreted from HSDPT results.

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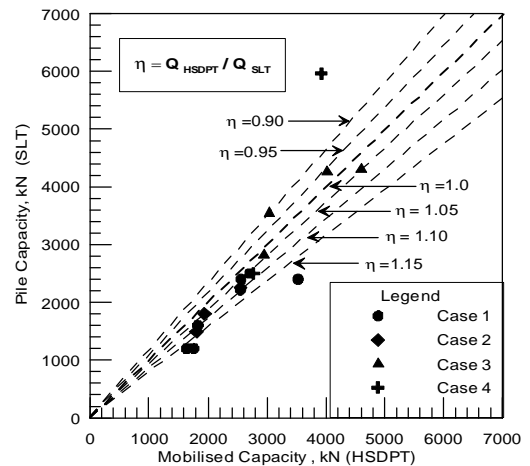


Figure 9 : Comparison of SLT and HSDPT carried out in Residual Soil

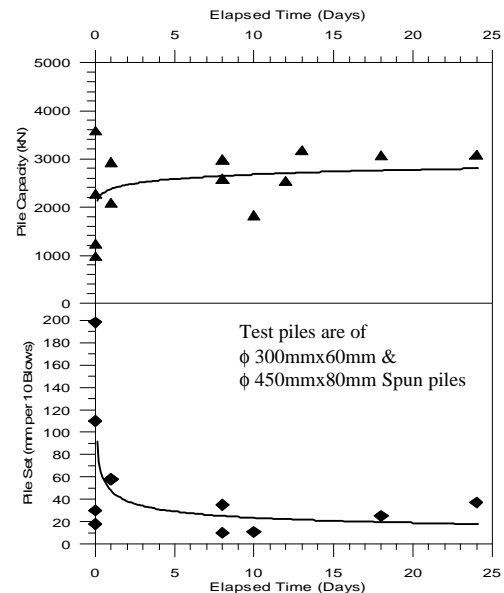


Figure 10 : Pile Capacity and Pile Set with Elapsed Time

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