Kochi Chapter

Indian Geotechnical Conference
IGC 2022
15th – 17th December, 2022, Kochi

Offshore Steel Pile Capacity Evaluation Using Static and High Strain Dynamic Tests

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Abstract. In view of the offshore foundation design verification for Duroob Island, offshore of the Abu Dhabi mainland, a program of pile load tests using Static Load Test (SLT) and High-strain dynamic pile testing (HSDPT)/Pile Driving Analyzer (PDA) tests was initiated in the Gravelly, weak Calcarenite, and Mudstone formations. Despite the fact that the SLT is more expensive and time-consuming than the PDA test, most designers use the PDA test as a frequent alternate method for predicting pile capacity. This paper presents the ultimate capacity evaluation of 20.60mm thick offshore steel tubular pile P03, 31.05m long, and 1118mm outer diameter, interpreted from both methods. The SLT result shows a deflection of around 4.30mm and that of 4.00mm from PDA at a load of 1650kN. The ultimate capacity predicated using the Chin and Van der method exhibits good agreement with the PDA result. The findings revealed a higher limit of ultimate pile capacity of 6458 kN, which is reached by pile settlement rather than soil failure. The ultimate capacity calculated from pile driving using CAPWAP shows a value of 6460kN, indicating that both methods are accurate enough to estimate the pile capacity and can be adopted in similar offshore conditions.

Keywords: Static Load Test, Dynamic Pile Capacity, Offshore Steel Pile

1 Introduction

The axial capacity assessment of steel piles has possibly been an area of uncertainty in foundation design over the past few decades. The majority of pile design continues to be dominated by axial capacity estimation in various foundation applications, where the critical issue is more likely to be the magnitude of settlement under operating conditions. In the United Arab Emirates (UAE), steel tubular driven piles are frequently used to support offshore structures [1]. In geotechnical engineering, the accurate measurement of the ultimate pile capacity is a significant mystery. The main objective of static and dynamic load testing is to confirm that the pile can withstand the design load and does not experience any excessive displacements during its design life. Most of the foundation construction standards require the performance of preliminary static tests on a certain percentage of the piles on the site. Similarly, the pile capacity can be evaluated from the dynamic load test by driving piles using suitable hammers.

For some of the offshore projects, a comparison of both test results is performed to identify the ultimate steel tubular pile capacity. The load transfer mechanism of these piles is affected by the soil disturbance caused by driving, the conditions of driving, the frictional resistance of the pile, etc [2]. Various researchers performed predication of the ultimate capacity of piles using different methods [3–6]. The main objective of this article is to compare the static and dynamic load test results of the same steel tubular pile from the Duroob Island (N 2715031.617, E 706324.730) about 140km away from Abu Dhabi, United Arab Emirates, to verify the capacity using traditional numerical methods like Van der Veen [7] and Chin Fung Kee [8].

2 Geological Condition

The geologic description of the ground materials at the site and the approximate average depth at which they were encountered are summarized in Table 1. The subsurface material consists of medium to dense silty gravelly sand followed by very weak Calcarenite and Mudstone.

Table 1. General subsurface condition

Layer no.	Depth Range (m)	Geological Description
1	0.00 to -1.10	Medium Dense, Silty, Very Gravelly Sand
2	-1.10 to -1.60	Loose, Gravelly, Silty SAND
3	-1.00 to -4.10	Loose to Very Loose, Gravelly to Slightly Gravelly, Very Silty Sand
4	-4.10 to -4.53	Very Dense, Silty, Very Gravelly Sand
5	-4.53 to -6.53	Very Weak Calcarenite
6	-6.53 to -19.53	Very Weak Mudstone

3 Methodology

For the Static Load Test (SLT), the reaction system was used as per ASTM D1143-07 [9]. The load is applied through a 4000kN capacity hydraulic jack, and a 5000kN load cell has been mounted in the line of force application to measure the applied load (Fig.1). The details of the steel tubular test pile are provided in Table 2. The test load is applied to the pile in a series of 25% increments of the design load up to 150% of the working load. Settlement of the pile was recorded with four displacement transducers, each positioned at an equal distance around the pile and connected to a data logging system and computer display [1].

Table 2. Test pile details

Pile ID	Pile diameter/ Thickness (mm)	Pile length (m)	Test load (kN)
P03 (Static)	1118/20.60	31.00	1650
P03 (PDA)	1118/20.60	31.00	6460

Fig.1. Typical set up for static load test

In high-strain dynamic pile testing (HSDPT) or PDA, which includes a signal-matching procedure for computed and measured force and velocity at the pile head based on the stress-wave theory [10]. Goble and Rausche [11], Rausche et al. [12], Middendorp [13], and Paquet [14] have discussed the initial major developments of dynamic pile testing and their findings. The pile shafts are instrumented with strain sensors and accelerometers prior to driving. The strain sensor and the accelerometers are set up in two sets, perpendicular to one another. Dynamic pile load testing was done after driving the steel pile to the desired depth in accordance with ASTM D4945 [15], and a typical set up is presented in Fig 2. Pile driving and dynamic load testing are carried out with a hydraulic hammer (IHC S 280) with a maximum nominal energy of 280 KJ. After the test, using the recorded data, an analysis using the Case Pile Wave Analysis Program (CAPWAP) was conducted to estimate the total pile capacity.

Fig.2. Typical set up for Dynamic test

The ultimate capacity of piles is generally estimated using data from axial static load testing and load-settlement behavior at a particular percentage of test loads. The available literature offers a variety of techniques for calculating pile's maximum carrying capacities [16]. According to the common methods outlined by Van der Veen [7] and Chin Fung Kee [8], the static load test results in the current study were analyzed to determine the pile's ultimate bearing capacity. For the final design check, extrapolation of the static load test results was done in order to compare with the dynamic test results.

4 Results and Discussion

Static and dynamic load tests were conducted on piles embedded into the weak mudstone formation. The results obtained from SLT and the PDA are presented in Fig.3 and Fig. 4.

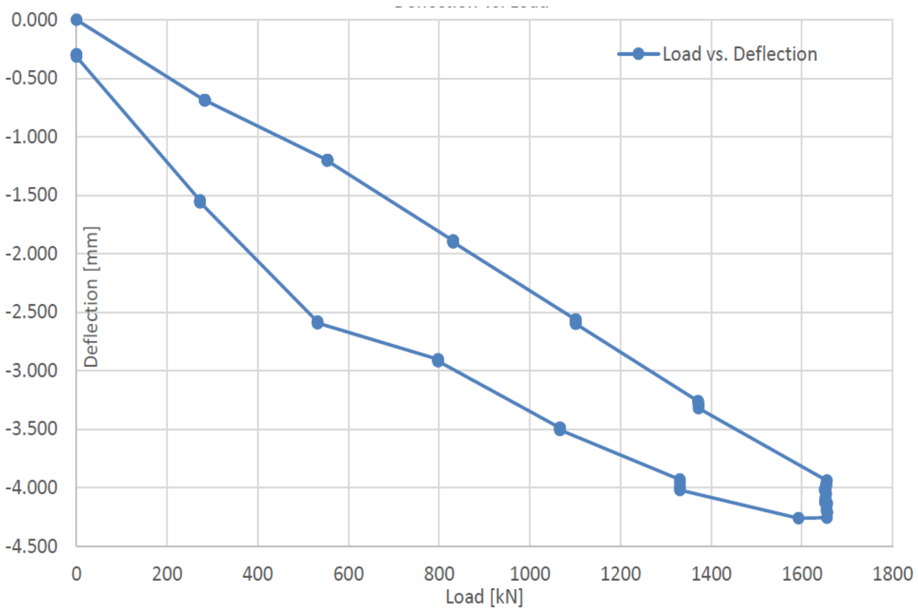

Fig.3. Load – deflection plot from SLT

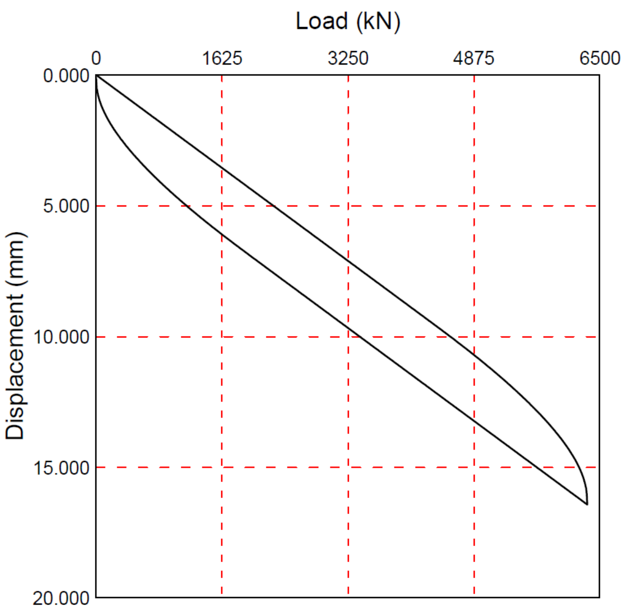

Fig.4. Load – displacement plot from PDA

According to the SLT results, at a test load of 1650kN, there was a 4.30mm deflection. The lesser settlement value shows that the pile is not fully mobilized, and as a result, there is no indication of the pile toe material's bearing capacity. Furthermore, there is no evidence of any plastic soil behavior because the applied load is within the first stage of the pile capacity. During the unloading stage, the deflection-load relation shifts, exhibiting a slightly quicker reversibility at low loads with a residual deflection of less than 0.5mm. According to the CAPWAP analysis, the settlement was 4.00 mm at a load of 1650 kN and 17.00 mm at the ultimate test load of 6460 kN. Based on the similar settlement values observed at 1650kN, it was decided to perform further predictions of ultimate pile capacity from the SLT results using two common methods.

A method of analyzing the results of the load test to get a sign of the ultimate bearing capacity of soil strata/pile is adopted according to the approaches defined by Van der Veen [7] and Chin Fung Kee [8]. The settlement Δ at each loading stage is divided by the load P at that stage and plotted against Δ/P. The inverse slope of the lines gives the ultimate bearing capacity of the soil strata. Van der Veen suggests another extrapolation method whereby the hyperbolic fit is replaced by an inverse logarithmic curve. The curves lead to a vertical asymptote, which shows the ultimate capacity of the pile. However, the ultimate pile capacity is limited by a settlement equal to 10% of the pile diameter if soil failure is not reached before that. The hyperbolic and logarithmic curves were compared with the settlement values and are depicted in Fig.5.

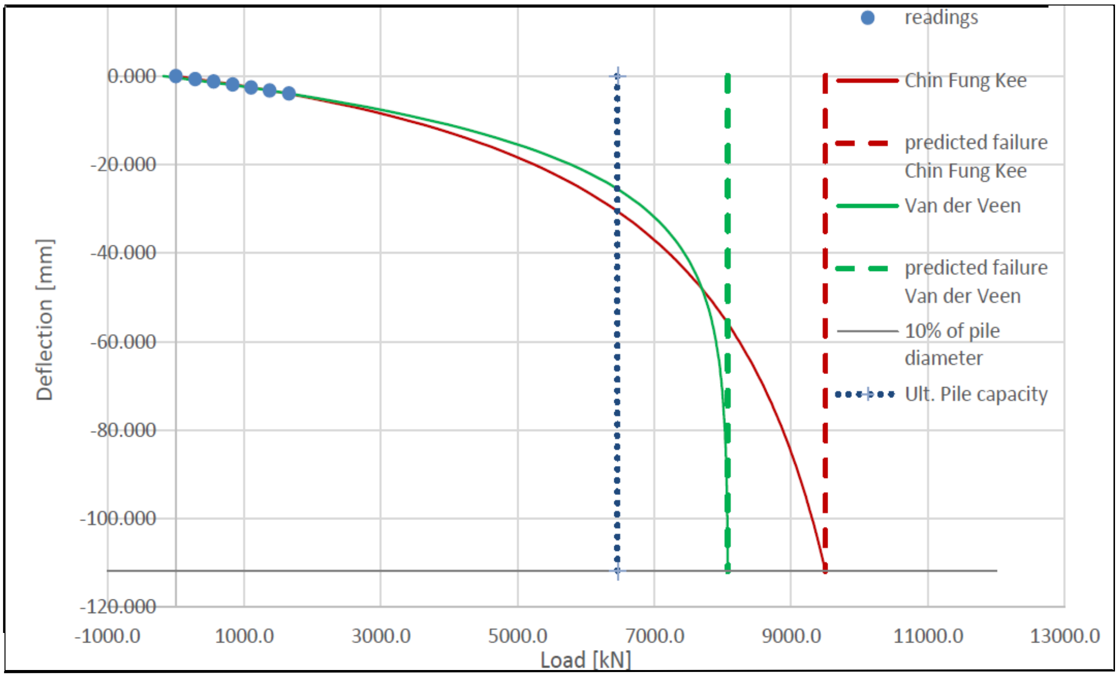

Fig.5. Estimated static pile capacity

The pile capacity of SLT is significantly higher than the applied working and test load. The applied load indicates a linear soil behavior of the pile. The Chin method has a higher limit of ultimate pile capacity of 9500 kN, which is reached by pile settlement rather than geotechnical failure. Van der Veen's method estimates the ultimate pile capacity at 8073 kN. Based on the Chin method, the load at which the pile will reach a deflection equal to 10% of the pile diameter is 8073 kN, assuming that there is no further increment in soil resistance. This is the load obtained at an asymptotic pile deflection. Generally, the ultimate load is considered to be 80% of the load at asymptotic pile deflection and was estimated as 6458 kN. Conversely, the capacity estimated from the dynamic test using CAPWAP analysis was 6460kN. From the comparison, it was found that both test methods are reasonably accurate and a suitable estimate of the load-settlement curve can be obtained. Based on the study, it is suggested that dynamic load testing can be used as an alternative, cost-effective testing method to assess the pile capacity, especially in offshore steel tubular piles.

5 Conclusion

The present investigation of static and dynamic tests yields valuable information and illustrates which dynamic testing results can be used. It is generally believed that there are significant differences between static and dynamic tests. Comparisons between the results of static load tests performed on steel tubular piles and those of dynamic pile testing have shown the ability of HSDPT as an alternative offshore pile testing tool to produce precise estimates of the capacity. However, because this study was based on a small number of tests, further investigation is needed before routine application to reduce uncertainty in the estimation of the axial capacity of the piles.

Acknowledgement

The author is grateful to James Fisher Strainstall for their continued support and encouragement.

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