Comparison Between Dynamic and Static Pile Load Testing

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ABSTRACT

Based on experience and extrapolation, it is found that the best way to predict pile behavior is to perform a pile loading test. In this study a comparison between the static and dynamic load tests results was made to evaluate the ability of the High Strain Dynamic Pile Testing (HSDPT) using SIMBAT method to estimate the static capacity of bored concrete piles. Four case studies conducted in Red Sea state were taken. The two test results are consistent to a good extent.

The dynamic load pile test, which is a simple quality control test offering a considerable savings of time and cost and requires less space, can be used for predicting pile capacity and pile integrity under proper care and it should be calibrated by at least one static test.

The (settlement/pile diameter) ratios, which are less than 1% for all piles, reflected conservative pile design. The pile design for projects should be optimized by determining the actual ultimate pile capacity, which may need to conduct pile test to failure or near to failure.

KEYWORDS: Dynamic Pile Load Test, Compressive wave, SIMBAT Method, Static Pile Load Test, Pile Capacity, Comparison.

INTRODUCTION

The static and the dynamic pile testing methods are the two main types of pile tests that are periodically used to assess the pile load capacity. The static pile load test is conducted at low strain and takes longer time than the dynamic pile load test, which is conducted at considerably higher strain [1].
The main objective of this study is to compare the static and dynamic load tests results and to evaluate the ability of the High Strain Dynamic Pile Test (HSDPT) using SIMBAT method to estimate the static capacity of bored piles. This will be achieved by taking four case studies, conducted in Red Sea State in eastern Sudan.

**DYNAMIC LOAD TEST**

Dynamic pile load test procedure is standardized by ASTM D4945-00 Standard Test Method for high strain dynamic testing of piles. It consists of estimating soil resistance and its distribution from force and velocity measurements obtained near the top of a foundation impacted by a hammer or drop weight. The impact produces a compressive wave that travels down the shaft of the foundation.

A pair of strain transducers receives the signals necessary to compute force, while measurements from a pair of accelerometers are integrated to yield velocity. These sensors are connected to an instrument (such as a pile driving analyzer), that records, processes and displays data and results [2], [3], [4].

The capacity of the hammer should be large enough to achieve sufficient pile settlement so that the resistance of the tested pile can be fully mobilized. The load should be applied axially on the pile. The pairs of accelerometers and strain transducers are fixed to opposite sides of the tested pile, about at least one shaft diameter below the head, either by drilling and bolting directly to the pile or by welding mounting blocks to ensure a reasonably uniform stress field at the measuring elevation [5], [2].

The modern change, which is considered as one of the significant beneficial changes that have been made to the system since the last Irish survey in 2000 is the introduction of theodolite to measure the pile displacement during the impact [6], [7].

This dynamic pile load testing technique that has been used most often in Ireland and UK is called SIMBAT [6].

There are two known methods, based on wave propagation theory, for the analysis and interpretation of the dynamic pile load test. The CASE method, IMPEDANCE method and TNO method are considered as direct methods. CAPWAP, TNO wave and SIMBAT are considered as indirect methods [1].

**SIMBAT DYNAMIC LOAD TEST METHOD**

The SIMBAT is used mainly for bored piles [5] & [2]. It is well accepted in France, Eire and the UK and to a lesser extent in Italy and Spain [8]. Essential preparations should be made before the test is carried out in the field. A pile cap, as an extension to the shaft head (with the same diameter as the shaft), should be constructed. The length of the cap should be at least 1.5 to 2.5 shaft diameter. The cap must be cylindrical, smooth, well-reinforced and of good quality concrete. The side of the cap is instrumented with two strain gauges, two accelerometers and electronic theodolite target. The electronic theodolite is placed 3 to 5m from the pile head. A schematic sketch of SIMBAT equipment and instrumentation is presented in Figure (2), whereas a photograph of a complete set of the equipment is shown in Figure (3). A series of hammer blows are made with the hammer drop height progressively increased and decreased [8].
The main difference between this system and other dynamic load test systems is the using of an electronic scanning theodolite that records penetration for each blow and records real-time elastic displacement [9].

As mentioned in [5] & [9], the interpretation of the dynamic pile load test data according to the SIMBAT procedure includes measuring of velocity from the integral of the acceleration and then correcting velocity using the theodolite as an adjustment signal. The measured force at the pile top is separated into components upward and downward. The dynamic (or total) reaction, $R_{dy}$ is calculated for each hammer blow and plotted versus cumulative penetration for the whole set of blows. The dynamic load is converted to static load and the predicted static load-settlement curve can be plotted. The static plot is verified by modeling.

![Figure 1: Schematic of SIMBAT Instrumentation](image1.png)

![Figure 2: Complete SIMBAT kit including data collection unit, accelerometers, digital theodolite cable reels and waterproof carry case](image2.png)
CASE STUDIES IN EASTERN SUDAN

Mark R. Svinkin (2011) analyzed a distinctive case history presented by Briaud et al. (2000) toward correlation between the results of dynamic and static tests. This case showed the results of application of CAPWAP, TNOWAVE and SIMBAT methods for dynamic testing of the same three bored piles constructed in different soil types. He concluded that SIMBAT and TNOWAVE methods gave good results in clay and substantially overestimated and underestimated pile capacity in sand, whereas CAPWAP method yielded good results in sand and significantly overestimated pile capacity in clay [10].

In this paper, four case studies in Portsudan city in Red Sea state, eastern Sudan, in which SIMBAT method was used, will be considered. All tests were carried out on bored concrete piles. One site in Portsudan new strategic depot Project, namely Liquefied Petroleum Gas (LPG) site. Three projects are residential tower buildings representing a part of the residential tower buildings complex of Red Sea state.

GENERAL SUBSURFACE FORMATION OF THE AREA

The area considered in this research represents the second city and the main Sea port in Sudan. This is Portsudan city, which is located in western coast of the Red Sea in eastern Sudan [11]. The formation at this area is predominantly coralline deposits consisting of completely to slightly weathered coral reef limestone that contains marine shells and fossils. This formation is characterized with great variability in horizontal and vertical directions.

PERFORMANCE OF TESTS

The dynamic load test was performed using hammers weighing 1% of the test load of the tested pile with a series of impact starting from 10.0 to 45.0cm. The test was carried out according to SIMBAT method, see Figure (3). For the static test, kentledge reaction system was used, refer to Figure (4)
RESULTS AND DISCUSSION

A summary of the SIMBAT dynamic load test results for all selected projects is shown in Table 1.

**Table 1: Summary of SIMBAT dynamic load test results**

<table>
<thead>
<tr>
<th>Project Name</th>
<th>Pile Diameter, D (mm)</th>
<th>Pile Length, L (m)</th>
<th>Design Load (kN)</th>
<th>Settlement (δ) at Design load (mm)</th>
<th>Settlement (δ) at 1.5xdesign load (mm)</th>
<th>δ/D Ratio (%) For design load</th>
<th>δ/D Ratio (%) For max. test load</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tower 1</td>
<td>1000</td>
<td>24</td>
<td>2450</td>
<td>1.40</td>
<td>3.00</td>
<td>0.14</td>
<td>0.30</td>
</tr>
<tr>
<td>Tower 7</td>
<td>1000</td>
<td>24</td>
<td>1700</td>
<td>0.40</td>
<td>0.70</td>
<td>0.04</td>
<td>0.07</td>
</tr>
<tr>
<td>Tower 8</td>
<td>1000</td>
<td>30</td>
<td>1800</td>
<td>2.00</td>
<td>2.90</td>
<td>0.20</td>
<td>0.29</td>
</tr>
<tr>
<td>Liquefied Petroleum Gas (LPG)</td>
<td>1500</td>
<td>10.5</td>
<td>5000</td>
<td>1.10</td>
<td>1.80</td>
<td>0.11</td>
<td>0.18</td>
</tr>
</tbody>
</table>

The table hereunder shows the static load test results:

**Table 2: Summary of conventional static load test results**

<table>
<thead>
<tr>
<th>Site</th>
<th>Test Pile Diameter (mm)</th>
<th>Length (m)</th>
<th>First Loading Cycle</th>
<th>Second Loading Cycle</th>
<th>Total Elastic Rebound (mm)</th>
<th>Permanent settlement, δ (mm)</th>
<th>δ/D Ratio (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tower 1</td>
<td>1000</td>
<td>24.0</td>
<td>2450</td>
<td>3675</td>
<td>0.8</td>
<td>0.2625</td>
<td>0.11</td>
</tr>
</tbody>
</table>
Figure (5), Figure (6) and Figure (7) reflect the comparison between the dynamic and static load test curves for the three residential towers projects, whereas Figure (8) shows the Load – settlement curves predicted from the SIMBAT dynamic load test results for the LPG tank project.

The initial part of the load-settlement curves illustrated in Figure (6-b)
Figure 6-a: Main Load-Settlement Curves

Figure 6-b: The initial part of the load-settlement curves

Figure 6: Load-Settlement Curves for Tower No. 7 Project

Figure 7: Load-Settlement Curves for Tower No. 8 Project
The results of the dynamic and static tests indicated very conservative pile design as the (settlement/Pile Diameter) ratios range from 0.07 to 0.85% even though the loading in dynamic tests exceeded 2 to 3 times the pile design load. These very small values compared with the general criterion for pile design, which indicates 10% for pile failure. In our opinion, it is wise that to determine the actual pile ultimate capacity for a project by testing at least one pile to failure. This will enable an economical pile design and offer a considerable saving of cost for the project.

The comparisons of load-settlement behaviors for dynamic and static load tests, shown in Figure (5), Figure (6) and Figure (7), indicate that the predicted settlement (from dynamic) and the measured settlement (from static) are generally consistent to a reasonable extent as reflected by the results of towers 7 and 8. But generally the settlements predicted by dynamic load test are slightly higher than the settlement measured by the static load test. This is very clear especially in the results of the pile of tower 1 project.

CONCLUSIONS

The High Strain Dynamic Pile Load Test (HSDPLT) has been introduced recently in Sudan by ESD. This paper has been focused on this type of pile loading test. Four case studies of dynamic and static pile loading tests conducted in the eastern of Sudan have been presented. The load-settlement behaviors for dynamic and static load tests were compared for the three case studies of the residential tower buildings complex project. This shows a reasonable agreement between the two test results. But generally the dynamic load test slightly overestimates the
settlement. It can be concluded that the dynamic load pile test can be used for predicting pile capacity and pile integrity under proper care and it should be calibrated by at least one static test.

All results of static and dynamic load tests indicate very conservative pile design as the (settlement/pile diameter) ratios are less than 1% for all piles. Therefore, it is strongly recommended to optimize the pile design for projects by determining the actual ultimate pile capacity, which may need to conduct pile test to failure or near to failure. The dynamic pile test is very useful for such tests as it is a simple quality control test offering a considerable savings of time and cost and requires less space [12], [13] & [14].

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