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Two-tier Bidirectional Static Load Testing for Pile Capacity Evaluation

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Abstract - In recent decades, there has been a significant increase in the construction of high-rise buildings due to the use of high-capacity foundation piles. Multistage (bi-level/two-tier) instrumented bidirectional static load tests (BDSLT) must be used to verify the capacity of these piles. This article describes the successful execution of an instrumented bi-level bored pile test socketed in the layered rocks of a high-rise building on Palm Jumeirah Island, Dubai. In order to ascertain the behaviour of the pile-rock interaction, a 1200mm pile at a depth of 25.60m was instrumented using ten levels of vibrating wire strain gauge technology and load tested up to 67596 kN using 6x9000kN sacrificial hydraulic jacks in two levels. The settlement recorded was 39.50mm, and the unit shaft friction calculated was in the range of 1000 kPa at the ultimate test load. It was found that the side resistances of the rock layers were higher than the values initially selected for the foundation design, indicating that the results of this bi-level load test accurately represented the true state of the subsurface. The design skin friction values were modified, considering the pile test and ground results, to provide the project with an economically feasible outcome.

Keywords: *Multistage load test, Bidirectional, Strain gauges, Skin friction*

1. Introduction

Around the world, a large number of towers and high-rise buildings are being built as a result of population growth and rapid economic expansion. Large-capacity, deep-bored piles and barrettes, whereas shaft and bearing capacity-based methods are still widely used to design the deep foundations [1]. One of the most effective ways to determine a pile's load-carrying capacity is to perform pile load tests, which is a crucial step in the deep foundation design process. Despite this test's accuracy, sometimes the high cost and execution risk of these traditional load tests prevent them from being frequently used in small to medium-sized construction projects. In many science and technological fields, advanced methods utilizing artificial intelligence and machine learning have grown in popularity [2]. However, because they are unable to provide any analytic equations that are recurrently used in foundation engineering, these approaches are not very well-liked among geotechnical foundation engineers [3]. The Bidirectional Static Load Test (BDSLT), a self-reaction method, eliminates the requirement for the reaction load needed for the traditional pile loading test in order to solve these issues. It responds by pushing the separable toe downward against the resistance of the pile shaft. This testing method was widely used in the last two decades for cost-effective value engineering of foundation piles and barrettes in the Middle East Region [4-5]. This method is internationally accepted and referred to in the standards [6-9]. This article discusses the application of multistage BDSLT on an instrumented pile foundation in rocks to identify the geotechnical parameters and thereby provide an economically feasible design for the proposed residential building AVA at Palm Jumeirah on Plot No. PJTRNKL01, Dubai, UAE.

2. Geotechnical parameters of the study area

The subsurface geology of the study area consists of sand fill, Calcarenite, sandstone, conglomerate, limestone and Calcisiltite. Based on the geotechnical investigation data, the general design unit shaft friction (kPa - Kilo Pascal) with depth 9 (DMD- meter Dubai Municipality Datum) was derived (Table 1).

Table 1: General Geotechnical profile

Depth (m DMD)	Type of Soil/Rock	Ultimate unit shaft friction (kPa)
+4.00 to -9.00	Fill layers comprising of sand	-
-9.00 to -10.00	Sand	100
-10.00 to -14.00	Calcarenite	433
-14.00 to -16.00	Calcarenite / Sandstone	335
-16.00 to -23.00	Sandstone/Conglomerate	468
-23.00 to -25.00	Limestone	707
-25.00 to -30.00	Very weak Calcisiltite	354
-30.00 to -31.00	Calcisiltite	468

3. Methodology

One multistage bi-directional static load test was carried out for a pile of 1200mm with a maximum length of 25.60m below the cutoff level. The pile was tested to a maximum load of 67596 kN to verify its geotechnical capacity. The test was performed in two stages using a hydraulic jack assembly comprising six 900 tonne capacity bi-directional jacks (Fig.1). In the first test stage, we will use the bottom hydraulic cell (Cell 2), during which the base of the pile will be loaded using the side shear above it as a reaction. This stage of testing is carried out until Cell 2 reaches its cell bottom movement of about 25mm, then the test will be advanced to Stage 2 (Cell 1). During this loading, negligible movement is expected in the shaft above Cell 2, and hence only the bottom load or movement is used for analysis. In the second test stage, using the upper hydraulic cell (Cell 1), the side shear below Cell 1 and above Cell 2 will be loaded using the side shear above Cell 1 as a reaction. During this loading, negligible movement is expected towards the lower shaft friction and end bearing. If the test using Cell 1 reaches test capacity, then the test is considered to be complete. The total load achieved from both stages is 67596 kN (27036 kN + 40560 kN). Ten levels of Geokon model 4200 vibrating wire-type strain gauges were also installed on the test pile to measure strains along the shaft. Table 2 gives the details of the pile, hydraulic jack position, and strain gauge levels. The pile top and jack movements were measured automatically using displacement transducers. The upward and downward jack movement data were used for computing the load and settlement behavior of the test pile [4]. The shaft resistance parameter obtained from the load test results was compared with the initial site geotechnical parameters.

Table 2: Instrumentation details of test pile

Test Pile ID	PTP1
Diameter (m)	1.20
Length(m)	25.60
Cutoff level (m)	-5.40
Toe level (m)	-31.00
Cell locations (m)	-17.00 (Cell 1) and -24.00 (Cell 2)
Working load (kN)	15617
Achieved Test load (kN)	67596
Vibrating wire strain gauge levels (m)	-5.90, -9.10, -12.30, -15.50, -18.50, -20.50, -22.50, -25.50, -28.00, -30.50

Fig.1: Cage installation of two –tier BDSLT

4. Results and Discussion

The bidirectional test results are considered the sum of upward and downward load-displacement curves. In the case where upward deflection is less, extrapolation is required using a hyperbolic curve fitting method. It is anticipated that the skin resistance of the test pile above the cell will control the upward load displacement behavior, while the skin friction and/or toe resistances below the cell would control the downward behavior. Generally, the upward and downward displacement curves combine the upward and downward loads for the same displacement. An elastic shortening of the foundation section above the cell is also required for the determination of the total settlement and the equivalent top-down load test. The downward displacement of the bottom plate already includes the base settlement and the elastic shortening of the foundation below the cell. Therefore, no additional adjustment is required to account for the elastic shortening of the foundation below the cell assembly. The resultant equivalent load-settlement diagram was created from the software by using additional parameters like the shape factor, pile concrete strength, weight of the pile above the cell position, etc. Because of the compression load between the foundation head and the jack assembly, elastic compression is already present in the equivalent top load curve that was obtained. Consequently, to determine the net elastic compression, the elastic compression from the BDSLT should be deducted from the top-down load test. The displacement derived from the test data and the net elastic compression are added to determine the total settlement. Based on the experience of author in various high rise building projects, the result obtained from BDSLT are comparable to the traditional static test loads. Even for foundations with the same geometry, compressibility often increases with the stiffness of the surrounding medium. This suggests that the elastic shortening must be taken into account in the interpretation of the load test findings when BDSLTs are conducted on relatively long drilled shafts installed in stiff material, such as dense soil and hard rocks. The bidirectional load- displacement data obtained from the test of PTP1 is analyzed to obtain the Equivalent Top-Loading Curve (ETL). The ETL curve is an estimation of the foundation head load-displacement behavior which would result from a top-loading static compression test. The settlement values (Table 3) obtained during the test at working load was 6.05mm and the ultimate load was 39.50mm respectively. The increase of settlement values in the ultimate load is perhaps due to the soil types, varying density, and imply that the load-carrying capacity is dominated by shaft resistance [1].

Table 3: Settlement values obtained from BDSLT

Total Settlement (mm)		
Load Percentage	Load (kN)	Settlement (mm)
100	15617.0	6.05
150	23425.5	9.00
200	31234.0	12.10
250	39043.0	15.30
432	67596.0	39.50

Estimating the potential differential settling under different loading conditions and after the completion of the superstructure is challenging. Consequently, the settlement value was not taken into consideration during the design of this foundation; instead, the side resistance of the pile was the only capacity parameter that explained the overall design [4]. The initial geotechnical characteristics were compared with the unit shaft resistance derived from the strain gauge data, which was calculated by dividing the difference in load between the two successive strain gauge levels by surface area. Fig. 2 displays the unit skin friction with depth findings from the load test and ground test at the ultimate load. The load test yielded a maximum unit shaft friction of 1096 kPa.

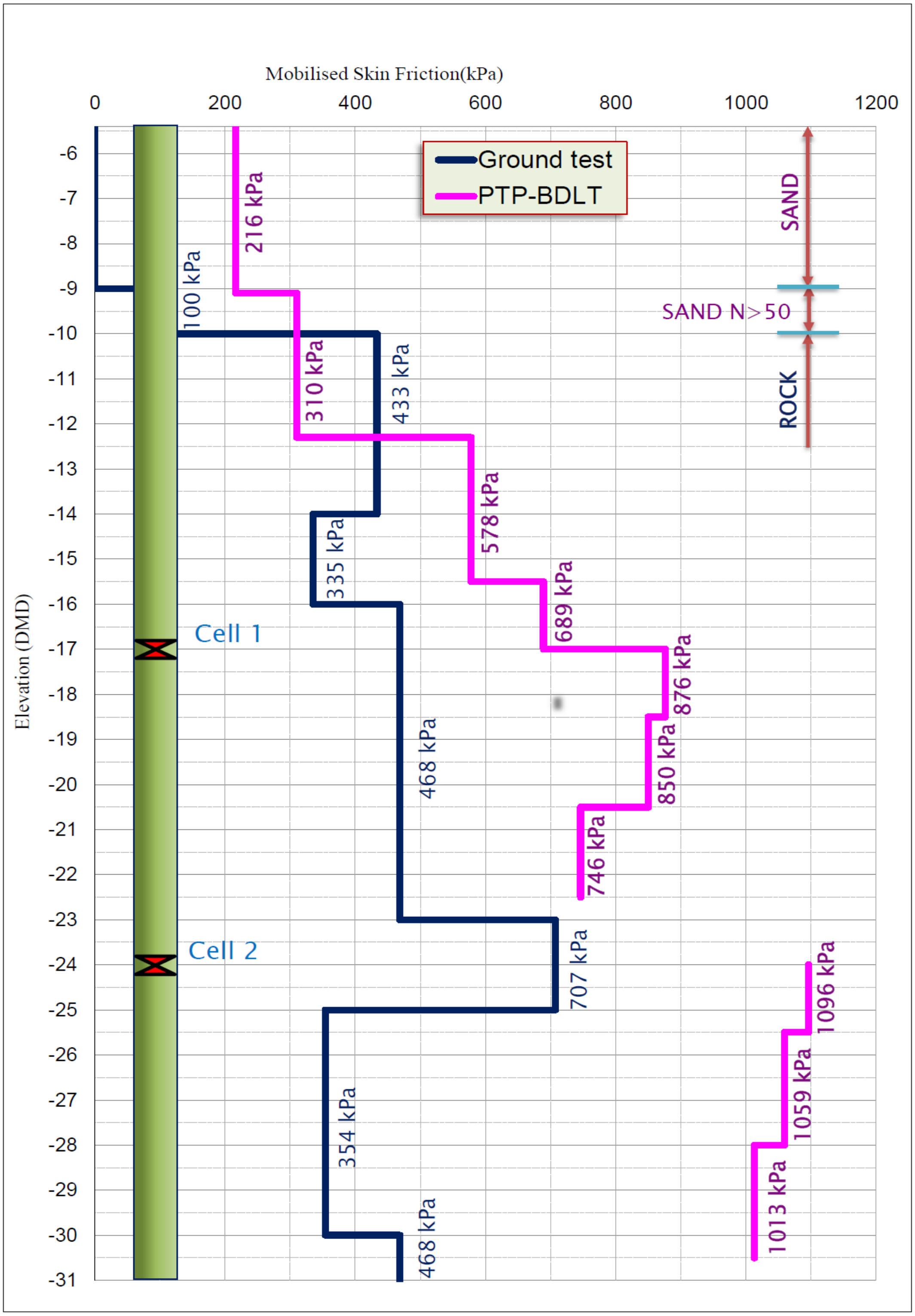

Fig.2: Unit skin friction from BDSLT and Ground data

It is noticed that design skin friction increased from values given prior to pile testing throughout the evaluation of the majority of the load test results, necessitating the use of the updated suggested values of allowed shaft friction. There may be optimizations necessary since the side resistances found from the load tests are higher than the original design values used. There is no indication that a geotechnical failure is about to occur because the unit skin friction values are increasing linearly. We can conclude that the side resistances observed are significantly higher than the design values applied and that the load tests can accurately represent the properties of soil layers. As a result, new design values were determined using the theoretical load test results, and these values included a 10% or more reduction in pile lengths applied while executing piles in the majority of the projects on the site [1, 4]. Hence, every reduction in socket length lowers foundation expenses by saving money on labor, materials, drilling, building time, and load testing. The mobilized skin friction values from PTP were compared to the design values from the soil report based on the plot above. The recommended skin friction values are shown in Table 4 below and are used for the execution of production piles at the site.

Tabe 4: Recommended skin friction values after PTP

Depth (mDMD)	Unit skin friction (kPa)
-9.00 to -12.50	250
-12.50 to -17.00	425
-17.00 to -31.00	570

It is to be noted that there are many parameters that affect the distribution of loads carried on the side and base of a vertically loaded pile, such as the normal stress on the socket, the strength and quality of the concrete in the shaft and base of the pile, the amount of loosened material and construction debris below the base, the drilling shape and equipment, the pile diameter, the pile length, the rock type, and the groundwater. The resistance actually reduced with increasing movement, indicating a strain-softening behavior of the clay. The polymer slurry materials appeared to promote an excellent bond between the concrete and soil. There was a distinct tendency for shafts constructed using these materials to exhibit strain-softening behavior, although the mechanism for this effect is unclear [10]. The boring in soft clay and silty material causes lateral yield of the ground around the borehole due to the removal of stress at the shaft walls. After pile installation, the stress will gradually build up, and some degree of softening takes place around the shaft prior to and during concreting. Thus, to assure a reliable foundation system under long-term conditions, the quality of shaft construction must be enhanced in order to reduce overall foundation risk.

5. Conclusion

The contemporary strain gauge instrumented multistage static load testing in bored piles can give geotechnical designers a variety of useful information depending on the ground geotechnical conditions. This article describes in detail the technical feasibility and effective performance of the pile foundation in the multi-layered stratum subjected to full-scale instrumented BDSLT. This study has demonstrated that the strain gauge-instrumented BDSLT method can be used to accurately determine the design resistance parameters anywhere in the world. The accurate outcomes of this instrumented multistage BDSLT provided the basis for similar esteemed future high-rise building projects and highlighted the importance of employing preliminary pile load tests for design purposes.

References

[1] Anil Cherian, "On-site and numerical analysis of bidirectional static load testing (BDSLT) on bored pile," Materials *Today: Proceedings*, vol. 85, pp. 51-54, 2023.

[2] H.Moayedi, M.Mosallanezhad, A.S.A.Rashid, W.A.W.Jusoh, and M.A. Muazu,. (2020a), "A systematic review and meta-analysis of artificial neural network application in geotechnical engineering: theory and applications," Neural *Computing & Applications*, vol.32(2), pp.495-518, 2020.

[3] S.Hanandeh, S.F.Alabdullah, S.Aldahwi, A. Obaidat, and H. Alqaseer, "Development of a constitutive model for evaluation of bearing capacity from CPT and theoretical analysis using ANN techniques," *International Journal of GEOMATE*, vol. 19(74), pp.229-235, 2020.
[4]Anil Cherian, "Assessment of pile capacity using Bidirectional Static Load Test (BDSLT), " *Indian Geotechnical J*. vol.5**,** pp.369-375, 2020.
[5] Anil Cherian, "Geotechnical evaluation of multilayered Simsima Limestone using Bidirectional Static load test," *J. Geological Society of India*, vol.97, pp.670-674, 2021.
[6] ASTM D8169, "Standard test methods for deep foundations under Bi-Directional Static Axial Compressive Load," *ASTM International, USA*, 2018.
[7] ICE , "Manual of Geotechnical Engineering, " 1458-1460, 2012.
[8] Federation of Piling Specialists, "Handbook on pile load testing. Federation of Piling Specialists", 2006.
[9] IRC 78, "Standard specifications and code of practice for road bridges, Foundations and Substructure, India," 2014.
[10] C.Lam, C, V.Troughton, S.Jefferis, andT. Suckling, "Effect of support fluids on pile performance - A field trial in east London," *Ground Engineering*, vol. 43(10), pp. 28–31, 2010.