Proceedings of the 10th World Congress on Civil, Structural, and Environmental Engineering (CSEE 2025)
Barcelona, Spain - April, 2025
Paper No. ICGRE 208
DOI: 10.11159/icgre25.208

Analysis of an Instrumented Load Test on a Pile in Etihad Rail Project

Anil Cherian
JF SME Testing LLC (James Fisher and Sons plc, United Kingdom), Dubai, United Arab Emirates
dranilct@gmail.com

Abstract - Detailed information on the load transfer and soil characteristics that interact with a pile shaft can be obtained by instrumented static load tests on bored piles. Various design verifications and numerical simulations can use this pile-subsoil interaction load test data. The Bi-directional Static Load Test (BDSLT) is widely used to assess the geotechnical resistance of deep foundations and measures loads, strains, displacement, shaft friction, and end bearing parameters. Due to ground conditions, principally mudstone, pile foundations were designed to carry the high loads along the prestigious project of Etihad Rail, United Arab Emirates. One test pile of 1500 mm diameter and 30.0 m depth, namely, PTP2, was loaded up to 45000 kN with twenty levels of vibrating wire-type strain gauges comprising four units at each level to measure strain at nominated locations, and from that load and unit skin frictions were derived. The quality control tests, such as borehole caliper and cross-hole sonic logging, were performed to check the diameter and shaft integrity. At the ultimate test load, the settlement obtained was 16.15 mm, and that of unit skin friction was 681 kPa. There was no substantial movement at the base of the pile, and hence the ultimate base bearing capacity was not identified. It is noted that the single-pile behavior observed from the preliminary pile testing is stiffer than that predicted. The skin friction values obtained from the load test have been improved from those calculated for the initial design, and a suitable safety factor was used for the optimization of the final pile design.

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

1. Introduction

The axial capacity of deep foundations can be evaluated using a variety of techniques, including static equilibrium, limit plasticity, cavity expansion theory, and direct in-situ load test results. The values of resistance factors used for the design of pile foundations are critically dependent upon the reliability of soil characterization data. In the absence of reliable data, the cost of any foundation can become excessive. Thus, common practice on larger projects, especially those with difficult or expensive foundations, dictates confirmation of soil characteristics and the pile-soil interaction by conducting required number of instrumented full scale static load tests. Such large-scale load tests are performed using instrumented bidirectional static load test (BDSLT) by means of sacrificial hydraulic cells, allows a more reliable and economical foundation design [1-2]. This method is internationally accepted and referred to in the standards [3-4]. In order to confirm the design capacity and construction quality of foundations, a load test was performed on a large-diameter bored pile for the Etihad Rail mega project in the United Arab Emirates.

2. Site Description

The landmark Etihad Rail is a 1200 km infrastructure project, building on its achievements in developing the national railway sector and operating the national rail network with the highest standards of efficiency, quality, and reliability. The high-speed train will pass through key strategic destinations and tourist attractions, ensuring seamless travel for passengers and visitors. The socio-economic and tourism development of the United Arab Emirates would be greatly enhanced by this effective and sustainable rail transportation project.

The geology of the United Arab Emirates, and the Arabian Gulf area, has been substantially influenced by the deposition of marine sediments associated with numerous sea level changes during relatively recent geological time. With the exception of mountainous regions shared with Oman in the north-east, the country is relatively low-lying with near-surface geology dominated by Quaternary to late Pleistocene age, mobile Aeolian dune sands, and sabkha/evaporates deposits. These superficial deposits are underlain by alternating beds of Calcarenite, Mudstone, Sandstone, Siltstone and Conglomerates [5]. The general site soil and rock profile (levels in meter National Abu Dhabi Datum (mNADD)) is provided in the below Table 1.

Table 1: General Geotechnical profile

Layer No.	Soil Strata	Top of Strata Level (mNADD)	Bottom of Strata Level (m)	Unit skin friction (kPa)
Layer 1	Medium dense Sand	2.11	-3.89	45
Layer 2	Mudstone	-3.89	-27.89	450

3. Methodology

The hydraulic cell assembly, related hydraulic supply, and instrumentation was lowered into the pile attached to the steel cage. The bi-directional static load test was carried out after reaching the full strength of the concrete. Exclusive zone was provided for the test set up area. The hydraulic cell was internally pressurized using a common hydraulic creating an upward force on the shaft in upper friction and an equal, but downward force in combined lower shaft friction and/or end bearing. The test pile details are provided in the below Table 2. The instrumentation for the piles includes eight numbers of tell-tales to measure displacements at the pile toe, below and above the jack assembly, and at the pile top. Twenty levels of Geokon vibrating wire strain gauges, each level comprising four strain gauges, were installed to measure the strain; from that, the load transfer and skin friction parameters were calculated. The pile was loaded up to 45000 kN using three 7000 kN bidirectional sacrificial jacks. The jack movement data obtained from the site was analysed using the equivalent top loading method to identify the settlement of the pile [4].

Table 2: Test pile details

Test Pile details	PTP2
Pile diameter (mm)	1500
Pile length(m)	30.00
Pile cutoff level (mNADD)	+2.11
Pile toe level (mNADD)	-27.89
Jack level (mNADD)	-18.39
Test load (kN)	45000
Strain gauge levels (mNADD)	1.61, 0.61, -0.89, -2.39, -3.89, -5.39, -6.89, -8.39, -9.89, -11.39, -12.89, -14.39, -15.89, -17.39, -19.39, -21.89, -23.39, -24.89, -26.39, -27.39,

The non-destructive tests, such as caliper logging and cross-hole sonic logging, were used to control the test pile's quality. The caliper logging technique was employed for assessing pile length and diameter, pinpointing any collapses and over-usage of concrete. Cross-hole sonic logging used ultrasonic pulse velocity to determine the quality of the pile concrete. The uniformity and integrity of the concrete shaft can be assessed by measuring the pulse velocity at different elevations across the pile profile to identify the anomalies such as soil inclusion, quality, and major voids.

4. Results and Discussion

4.1. Caliper logging

Borehole caliper logging performed for the test pile is presented in Fig. 1. The result shows that the test achieved the required minimum diameter of 1500 mm. There was no collapse, and a borehole with a rather consistent size and shape was found along its depth. Additionally, no apparent change in lithology with depth was found, suggesting the presence of a rock layer.

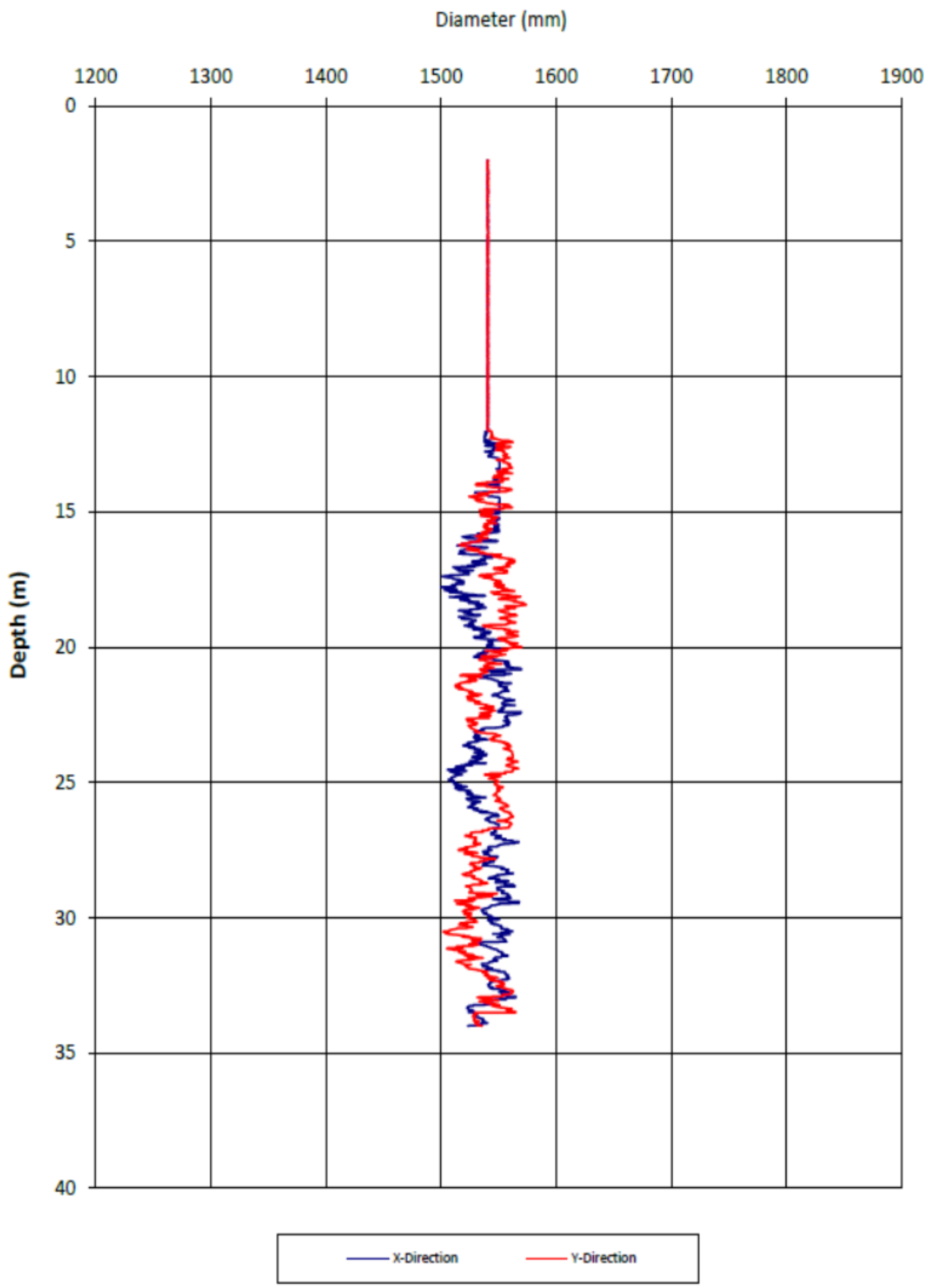

Fig. 1: Caliper logging of the test pile

4.2. Cross-hole sonic logging

Fig. 2 shows the outcome of the field test conducted on the test pile. As anticipated, the presence of the BDSLT jack assembly is the cause of the little delay in travel time at about 10 meters from pile toe level. Anomalies such as soil inclusion, poor-quality concrete, and any major voids were not identified. The concrete used to construct the test pile was of acceptable quality and grade, and the pile was uniform.

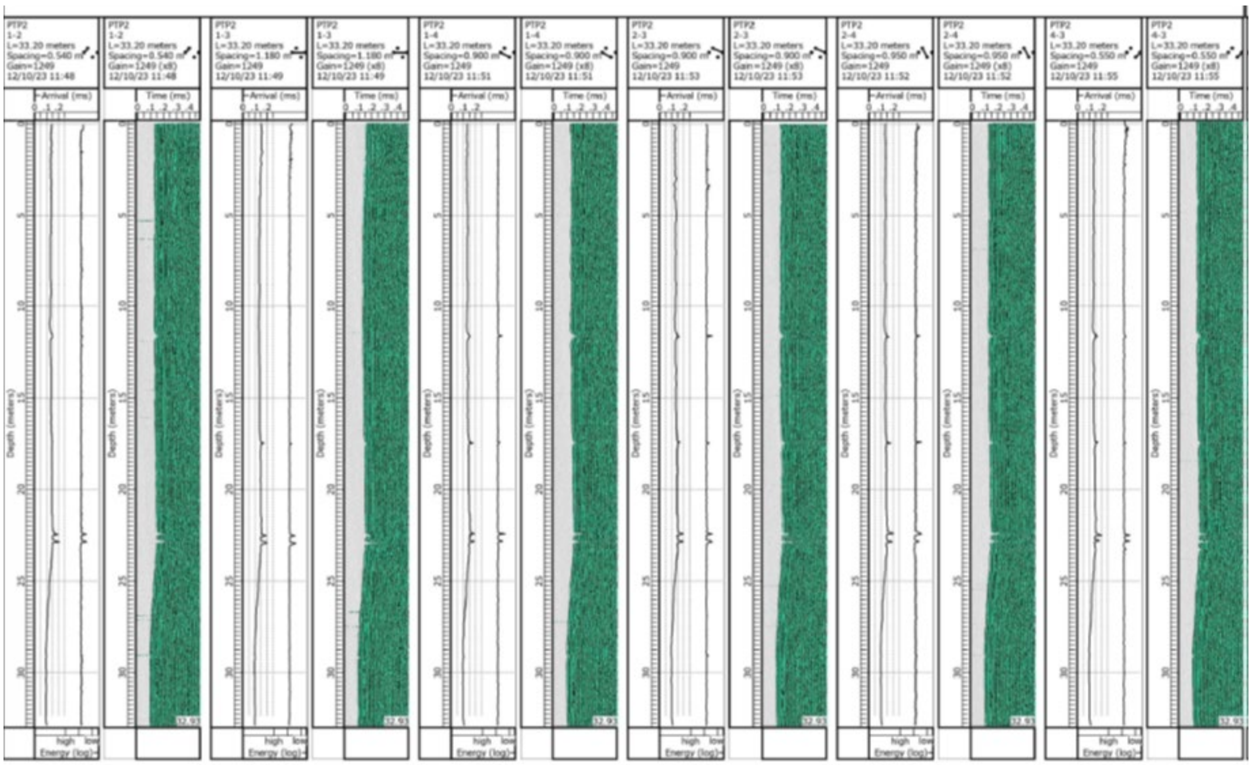

Fig. 2: Cross-hole sonic logging of the test pile

4.3. BDSLT

The unit shaft resistance is obtained from the strain gauge data by computing the difference in load between the two consecutive strain gauge levels divided by the pile surface area. The skin friction obtained during the test was presented in Table 3.

Table 3: Unit shaft friction after BDSLT

Unit Skin Friction (kN/m^2)						
Level	7500 kN	15000 kN	22500 kN	30000 kN	37500 kN	45000 kN
	50%	100%	150%	200%	250%	300%
1 to 2	2	9	10	16	21	27
2 to 3	4	13	14	24	35	48
3 to 4	6	15	21	30	42	51
4 to 5	7	17	25	37	52	61
5 to 6	9	22	36	49	61	78
6 to 7	13	27	39	53	71	107
7 to 8	15	34	43	71	123	199
8 to 9	13	48	94	132	177	241
9 to 10	18	50	101	154	192	262
10 to 11	22	68	158	219	288	323
11 to 12	66	103	174	239	303	350
12 to 13	81	151	198	259	321	385

13 to 14	120	225	277	369	415	425
14 to Jack	220	357	490	546	591	658
15 to Jack	257	379	528	577	628	681
15 to 16	103	222	376	504	575	630
16 to 17	75	173	254	371	452	524
17 to 18	58	113	150	234	339	481
18 to 19	31	84	99	132	268	360
19 to 20	25	55	74	110	135	248

The maximum mobilized skin friction obtained in the mudstone layer was 681 kPa. The unit skin friction values are increasing linearly and do not show evidence of developing geotechnical failure. This indicates that the piles can still be loaded to mobilize ultimate skin friction resistance along the complete shaft length. It can be concluded that the load tests can appropriately represent the characteristics of soil strata, and the side resistances determined are much larger than the design values adopted. The mudstone in the study area was capable of supporting high skin friction loads and can reduce the pile length and thereby save costs [2]. The initial test piles were mainly performed prior to the installation of the production piles to check the pile capacity, skin friction, efficacy of the piling, and provide assurance of the satisfactory performance of the foundations.

The bidirectional displacement data obtained from the load test was analysed to obtain the total settlement. The settlement value obtained during the test at working load was 5.20mm and that of ultimate load was 16.15mm (Table 4).

Table 4: Settlement values

Load (kN)	Settlement (mm)
15000	5.20
22500	8.00
30000	10.50
37500	13.10
45000	16.15

The settlement values are lower and fall within the allowable range of 10 mm or 1% of the pile diameter under working load conditions. Typically, for piles relying solely on skin friction, the capacity criterion tends to dictate the overall design. The load test did not achieve any end bearing resistance since the skin friction measured was more than sufficient to handle loads exceeding the pile's design load. Therefore, the settlement values observed after the load test were not factored into the redesign of the piles, with only shaft resistance parameters being considered. It should be noted that a number of factors, including the typical stress on the socket, the size and shape of the borehole, the quality of the pile concrete, construction debris beneath the base, the type of rock, the groundwater, etc., influence how much load is carried on the side and base of a vertically loaded pile.

5. Conclusion

Preliminary instrumented load tests using the BDSLT method provide detailed and quantitative information on pile-soil interaction, improving the calculation and design methodology for pile foundations. This test was also a method for verifying and calibrating axially loaded pile models and the load into the ground transfer process. The test results provided a significant increase in the design shaft friction parameters, which is considered to provide substantial cost and time savings for the project. Quality control tests provide a broad spectrum of useful and valuable information about the test pile and give confidence in the instrumented load test results. A systematic study of various parameters in the pile construction, instrumentation, testing, and design will result in a more economical foundation design.

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] Anil Cherian, "Assessment of pile capacity using Bidirectional Static Load Test (BDSLT), " *Indian Geotechnical J.* vol.5**,** pp.369-375, 2020.

[3] ASTM D8169, "Standard test methods for deep foundations under Bi-Directional Static Axial Compressive Load," *ASTM International, USA*, 2018.

[4] ICE, "Manual of Geotechnical Engineering, " 1458-1460, 2012.

[5] Macklin and Gaba, "Engineering in the Barzaman formation, coastal Dubai, UAE," *Proceedings of the Institution of Civil Engineers*, vol 162, pp. 18-24, 2009.