Optimization of Piles in Weak Carbonate Rocks – A Case Study of Reclaimed Land, Dubai - UAE

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Abstract: This study evaluates rock-socketed pile behavior in weak rock using two bi-directional static load tests in Dubai. Results show that conventional UCS–skin friction correlations can overestimate capacity, while test-based value engineering reduced pile lengths by over 22%. This optimization significantly improves cost, time, and overall foundation performance.

Keywords: ***Weak rock; Bi-directional static load test (BDSLT); Pile optimization, Skin friction fs.***

Introduction

Deep foundations in weak rock formations are typically designed with sockets in the rock mass. The design of such foundations is based on the loading magnitude, geometry, elastic properties and the side frictional resistance of the socket length. In the designs, it is a common trend to overestimate the pile capacities, which leads to needless and inefficient use of materials such as concrete and reinforcement. Most of the published correlations of fs (skin friction) to UCS (Unconfined compressive strength) are developed based on the load tests on low-capacity piles in specific geological conditions, and the UCS values which are not necessarily representative of the test depths, resulting in large variations in the calculated foundation design depths. To overcome the problem, value engineering methods using Preliminary Test Pile (PTP) can be adopted to optimize the pile lengths (Figure 1), while meeting effectively the acceptable load carrying capacities.

For this study, two nos. of BDSLT results are utilized. These tests were performed on 1000 mm diameter drilled shafts for the proposed Project in Dubai. The details of the tested piles are in Table 1.

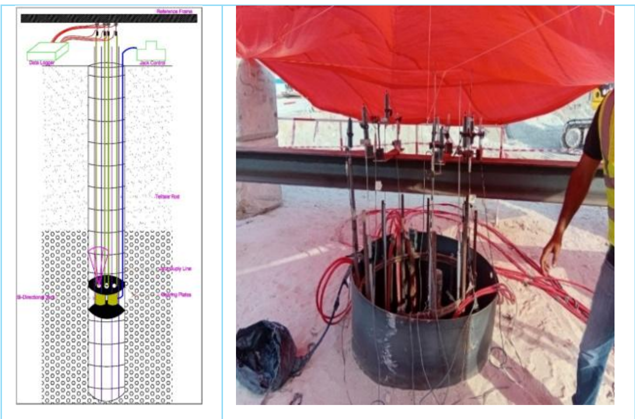

Figure 1, Typical set up of PTP.

Table 1, Details of Tested Pile.

Pile No.	Pile Día (mm)	Cut Off Level	Toe Level	Pile Length below Cut off	Working Load (kN)	Specified Test Load (kN)	Remarks
		(m DMD)		(m)			
PTP-01	1000	-1.965	-19.00	17.035	4000	12000	**Compression**
PTP-02	1000	-2.165	-23.00	20.835	5400	16200	**Compression**

Vibrating wire strain sensors were installed at different zones at each level as detailed in Table 2.

Table 2, Installation levels for each PTP test.

PTP Test	Test Pile Dimension (m)	Cut-off Level (m DMD)	Toe Level (m DMD)	Strain Gauge No	Installation Levels (m DMD)
PTP-01	1000mm	-1.965	-19.00	Zone 1	**-2.465m DMD to -5.520m DMD**
				Zone 2	**-5.520m DMD to -8.050m DMD**
				Zone 3	**-8.050m DMD to -11.630m DMD**
				Zone 4	**-11.630m DMD to -15.430m DMD**
				Zone 5	**-15.430m DMD to -16.960m DMD**
				Zone 6	**-16.960m DMD to -18.500m DMD**
PTP-02	1000mm	-2.165	-23.00	Zone 1	**-2.665m DMD to -6.030m DMD**
				Zone 2	**-6.030m DMD to -9.890m DMD**
				Zone 3	**-9.890m DMD to -13.760m DMD**
				Zone 4	**-13.760m DMD to -17.560m DMD**
				Zone 5	**-17.560m DMD to -20.030m DMD**
				Zone 6	**-20.030m DMD to -22.500m DMD**

Methodology

As per the Dubai Building Code (DBC) 2021 requirement, for obtaining the allowable working capacity of a pile based on site investigation data, a global safety factor of not less than 2.5 must be considered; however, when verification by static load testing is performed, partial safety factors as per Eurocode 7 may be applied (Dubai Municipality, 2021). Method for value engineering is shown in Figure 2.

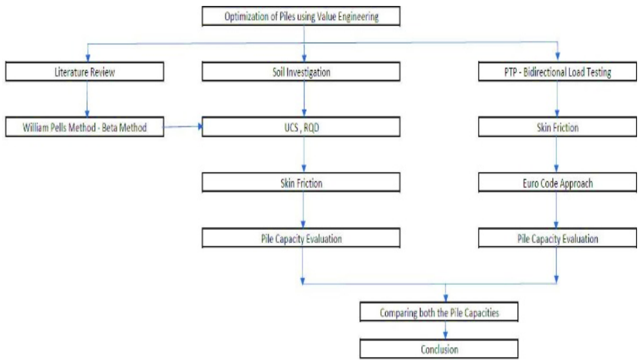

Figure 2, Methodology adopted for value engineering.

Accordingly, to estimate the in-situ skin friction in weak rocks, 2 high-capacity bidirectional load tests were performed. The value engineering exercise was carried out, using Eurocode approach, through back analysis of the data to optimize the design lengths of the piles. The theoretical pile capacity was estimated based on William and Pell's method (1981) was found to be 4000 kN and 5400 kN for a length of 12/15.5 m rock socketed. It was anticipated that a minimum reduction of +20% in pile length was considered.

Geology

The reclaimed land site in Dubai was explored with 9 boreholes drilled up to depth of 40 m. The exploration reveals a subsurface profile with 12 to 14 m thick sand, underlain by 20 m of sandstone followed by 3 m thick conglomerate bed, and further underlain by siltstone up to 40 m depth.

Analysis With Eurocode Approach Based On PTP

Eurocode 7 (BSI, 2004) describes three procedures for obtaining the characteristic compressive resistance $R_{c;k}$ of a pile. The $R_{c;k}$ is to be determined directly (i.e. not estimated) from the measured pile resistance $R_{c;m}$ values (ultimate limit state resistances) by applying correlation factors ξ_1 and ξ_2 (related to number of piles tested), to the mean and minimum measured resistances according to below equation and values of ξ_1 and ξ_2 (Table 3).

$$R_{c;k} = Min\left\{\frac{(R_{c;m})_{mean}}{\xi_1};\frac{(R_{c;m})_{min}}{\xi_2}\right\}$$

Table 3, Values of ξ_1 and ξ_2.

ξ for n =	1	2	3	4	≥ 5
ξ_1	1.55	1.47	1.42	1.38	1.35
ξ_2	1.55	1.35	1.23	1.15	1.08

Considering Design Approaches

DA1.C1: A1+M1+R1; A1=1.35, M1=1 and R1=1; DA1.C2: A2 + M1+R4(Governing); A2=1, M1=1 and R4=1.4.

Design Approach-1, combination 2 is mostly governing; hence, was considered for this case study. Based on the above estimated skin frictions, the allowable skin frictions were recommended. The below figure 3 shows the estimated skin frictions from PTP as well as through the theoretical estimates. The results of PTP shown in Figure 4 indicate that piles under maximum tested load behave as friction piles with limited settlement.

Conclusion and Recommendation

The above value engineering method/ exercise as shown in Figure 2 helped in optimizing the pile lengths by over 22%. Hence, it is recommended to carry out the estimations of rock socket frictions in intermediate geomaterials based on the pile load tests and optimize the design length of deep foundations. The value engineering exercise brought in substantial impact on the cost, time schedule, safety and performance of the structure.

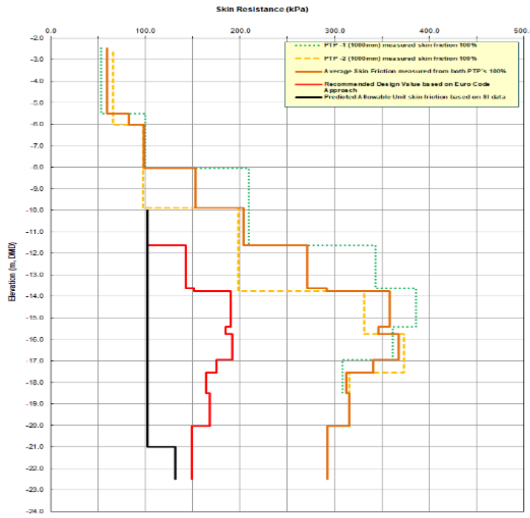

Figure 3, Graphical presentation of skin friction values from PTP.

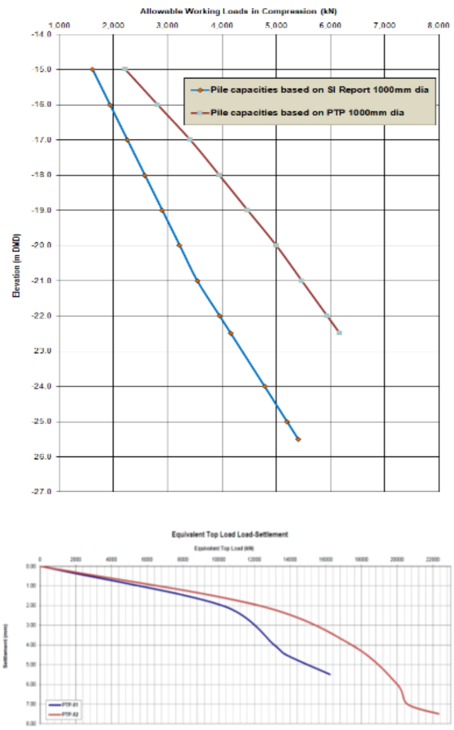

Figure 4, Pile capacities estimation based on SI report and PTP along with Pile capacities vs settlement.

References

British Standards Institution. (2004). BS EN 1997-1: Eurocode 7—Geotechnical design: Part 1, General rules. BSI.

Dubai Municipality. (2021). Dubai Building Code (DBC) Part F: Structure. Table F.17: Piles foundation minimum design criteria.

Williams, A. F., and Pells, P. J. N. (1981). Side resistance of rock sockets in sandstone, mudstone and shale. Canadian Geotechnical Journal, 18 (1), 109–116. https://doi.org/10.1139/t81-061