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Shaft Friction of Bored Pile Socketed in Weathered Limestone in Qatar

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***Abstract*—**Socketing of bored piles in rock is always seen as a matter of debate on construction sites between consultants and contractors. The socketing depth normally depends on the type of rock, depth at which the rock is available below the pile cap and load carrying capacity of the pile. In this paper, the review of field load test data of drilled shaft socketed in weathered limestone conducted using conventional static pile load test and dynamic pile load test was made to evaluate a unit shaft friction for the bored piles socketed in weathered limestone (weak rock). The borehole drilling data were also reviewed in conjunction with the pile test result. In addition, the back-calculated unit shaft friction was reviewed against various empirical methods for bored piles socketed in weak rock. The paper concludes with an estimated ultimate unit shaft friction from the case study in Qatar for preliminary design.

***Keywords*—**Piled foundation, weathered limestone, shaft friction, rock socket, pile load test.

I. Introduction

PILED foundation in weathered limestone is commonly used in Qatar for high-rise building, bridges, and other structures where there is a limitation of space for using shallow foundations. However, there are inadequate studies in Qatar to quantify the shaft friction capacity of bored piles socketed in weathered limestone. As part of the construction program, the dynamic load test and the conventional static vertical load test were carried out on the 900-mm diameter bored pile socketed in weathered limestone with an effective length of 12 m and 6.8 m, respectively. The test results were reviewed and back-calculated for the unit shaft friction. The estimated unit shaft friction values were also reviewed against various empirical methods. A case study of 900 mm diameter bored pile installed into weathered Limestone in Qatar was used in the assessment.

II. Empirical Relationships for Shaft Friction Evaluations

A. Correlations with Unconfined Compressive Strength

For piles in rock, it is common to correlate design parameters with the unconfined compressive strength, q_u, at least for preliminary design purposes. Some of the available correlations are summarized in Table I.

B. Correlations with Rock Quality Designation (RQD)

The pile capacity in rock can also be estimated from RQD values obtained from the rock core samples. Table II shows the typical design or working socket friction values for limestone formation in Malaysia by local engineers.

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III. Laboratory Testing

Unconfined compressive strength tests and point load index tests are usually undertaken as a means of classifying and approximately quantifying the soil strata, and for facilitating estimation of geotechnical design parameters (i.e. ultimate pile shaft friction) via correlation such as those mentioned above.

IV. Pile Load Testing

Some common methods of pile testing are summarized below, including suggestions for the interpretation of the test.

A. Static Vertical Load Test

This test type is the most fundamental and involves the application of vertical load directly to the pile head, usually via a series of increments. Test procedures have been developed and specified by various codes, for example, ASTM D1143. The static load test is generally regarded as a definitive test and the one against which other types of tests are compared. The test may take a variety of forms, depending on how the reaction for the applied pile loading is supplied. This is the type of test that the designer would like to carry out, as it best simulates the way in which a structural load is applied to the pile. Unfortunately, the ideal test cannot usually be achieved in practice, and the reaction system interacts with the test pile, thus creating some problem with the interpretation of the test data.

The usual basic information from such a test is the load settlement relationship, from which the load capacity and pile head stiffness can be interpreted. However, such interpretation should be carried out with caution, as the measured pile settlement may be influenced by interaction between the test pile and the reaction system. Such interaction tends to lead to over-estimates of both capacity and stiffness, and therefore can lead to unconservative results, unless appropriate allowances are made for the effect of the interaction between the pile and the reaction and or settlement measuring system.

B. Dynamic Load Test

The principles of the dynamic load test are very well-established [4]. The test procedure is now accepted as routine, especially for quality control and design confirmation purposes. Despite its widespread use, the dynamic pile load test has a number of potential limitations, including the fact that the load-settlement behavior estimated from the test is not unique, but is a best-fit estimate. Two measurements (strain and acceleration versus time) are taken, and from these, the complete distribution of resistance along the pile, as well as the load-settlement behavior, are interpreted. Also, the load is applied far more rapidly than in most situations in practice, and hence time-dependent settlements are not developed during the test. Fortunately, under the normal design load levels, the amount of time-dependency (from both consolidation and creep) is relatively small as most of the settlement arises from shear deformation at or near the pile soil interface. Hence, the dynamic test may give a reasonable (if over-estimated) assessment of the pile head stiffness at the design load. However, it is expected to be inaccurate as the load level approaches the ultimate value. The test may however provide a convenient means of obtaining the head stiffness of a single pile.

TABLE I
CORRELATIONS WITH UNCONFINED COMPRESSIVE STRENGTH FOR PILES IN ROCK

Approach	Equation	Rock Formation [a]	Remarks
Horvath and Kenny (1979) [12]	$f_s = \alpha q_u^{0.5}$	Unknow	$\alpha = 0.2\ to\ 0.25$
Rowe and Armitage (1987) [11]	$f_s = 0.45 q_u^{0.5}$	Shale	For roughness classes R1, R2, R3
Reese and O'Neil (1988) [13]	$f_s = \alpha q_u^{0.5}$	Clay-shale	For q_u>2.01 MPa
Kullhawy and Phoon (1993) [1]	$f_s = P_a \psi (q_u \| 2P_a)^{0.5}$	Limestone	$\psi_{lower} = 0.17\ t0\ 2$

TABLE II
SUMMARY OF ROCK SOCKET FRICTION DESIGN VALUES FOR LIMESTONE FORMATION IN MALAYSIA

Working Rock Socket Friction (kPa)	RQD	Approach
300	<30%	Tan (2009) [3]
400	30%	
500	40%	
600	55%	
700	70%	
800	>85%	
300	<25%	Neoh (1998) [2]
600	25-70	
1000	>70	

V. ULTIMATE AXIAL CAPACITY INTERPRETATION

For conventional static load testing, it is common for the test to be stopped prior to complete plunging failure being achieved. A vast number of suggestions have been made on how the ultimate axial load capacity can be estimated from such tests, some of which have been reviewed and assessed by Hwang et al. [5]. They can be classified in to the following categories:

1. "Conspicuous turning point of load-settlement curve". This is often a subjective assessment.
2. Settlement S of the pile head, including:
   - S=10% of dimeter typically [6]
   - Tangent Flexibility of pile head, for example, [7]
3. Residual settlement (Sp) of pile head. Examples include Davisson [8], who suggest that the ultimate capacity is the load at which the pile head settlement = 0.15 + 0.1d (inches), where d = pile diameter, in inches, and DIN4026 (Germany) in which the residual settlement upon unloading from the ultimate load is 2.5% of the diameter.
4. Creep rate of head settlement, where the ultimate capacity is taken as the load at which a sudden increase in the slope of the settlement-time curve occurs
5. Coordinate transformation of the load-settlement curve, with procedure of Chin [9] being typical. This involves plotting the ratio of settlement to load as a function of settlement, and defining the ultimate capacity from the slope of the straight-line portion of this plot.
6. Employing a specified shape of load-settlement curve, such as that employed by Hirany and Kulhawy [10]

Hwang et al. [5] concluded that the approach attributed to Terzaghi [6] was preferable to many of the other approaches.

VI. CASE STUDY IN QATAR

A. Ground Investigation and Site Characterization

Ground investigation and pile load tests data collected as part of the construction of a highway project in Qatar were used in the assessment.

A borehole drilling up to 20 m was carried out near the pile load test locations as presented in Fig. 1. Core recoveries were typically 89-100% and rock quality designation (RQD) values were between 0 and 50%. It was also found that the stratigraphy was relatively uniform. No encountered groundwater was recorded during the investigation.

B. Laboratory Test Results

Conventional laboratory testing was undertaken, consisting of unconfined compressive strength tests and point load index tests. The limestone within the pile length (up to 12m) were generally very low to low strength with UCS values ranging between 4.9 and 13.1 MPa with the $Is_{(50)}$ values ranging between 0.17 and 5.36 MPa.

C. Static Vertical Load Test Result

The conventional static pile load test was carried out in accordance with ASTM D1143 on the tested 900-mm diameter bored pile socketed in weathered limestone. The tested pile was maintained unloaded for 24h prior to the initial loading. The tested pile was loaded in three cycles. The load increment was taken up to 4000 kN, 6000 kN and 10000 kN, respectively. The effective pile length is 6.8 m, and the core photo within the pile length is presented in Figs. 2 and 3.

Fig. 4 shows the load displacement curve and mobilized unit shaft friction for a bored pile socketed into weathered limestone. The maximum pile top settlement 4.18 mm was observed at the test load of 10000 kN at the third cycle. It is also evidenced that the ultimate shaft friction has not been fully mobilized yet.

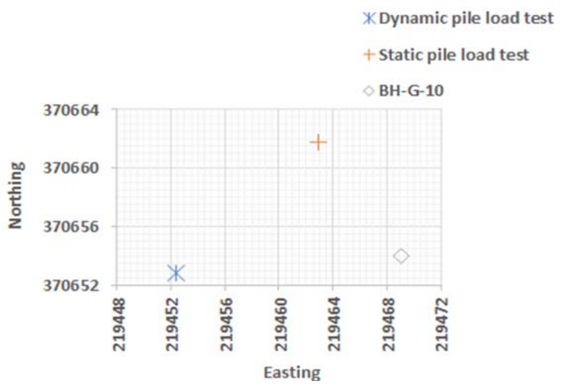

Fig. 1 Borehole and load test location plan

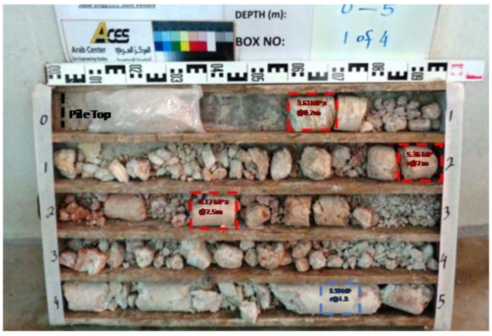

Fig. 2 Core photo between 0 and 5m depth

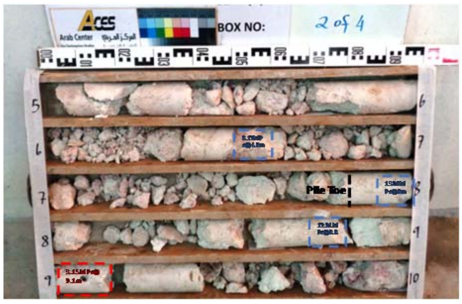

Fig. 3 Core photo between 5 and 10m depth

D.Dynamic Load Test Result

The dynamic load test was conducted in accordance with ASTM D4945 on the working 900 mm diameter bored pile socketed in weathered limestone. The 8-ton hammer was used for the test and the drop height was set at 0.4 m. The effective pile length is 12 m, and the core photo within the pile length is presented in Figs. 2, 3 and 5.

Fig. 6 shows the load displacement curve and mobilized unit shaft friction for a bored pile socketed into weathered limestone. The activated shaft friction of 6907 kN was evaluated based on the CAPWAP analysis. The maximum pile top settlement was recorded at 2.8 mm at the activated pile capacity of 7720 kN. It is also noted that the ultimate shaft friction has not been utilized as the dynamic load was carried out on the working pile. The test load of 4260 kN (1.5 time of design load) was set to verify the design assumption.

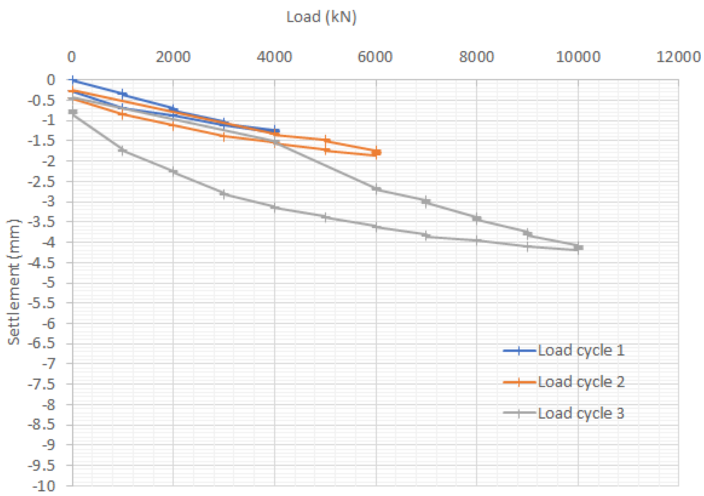

Fig. 4 Load displacement curve for a bored pile socketed into weathered limestone (6.8 m)

E. Evaluation of Results

For the view point of the ultimate shaft friction evaluation, some of findings from the laboratory test results and pile load test results were as follows:

1. An average unconfined compressive strength value of weathered limestone within the top 6.8 m along the test pile is 8.55 MPa.
2. An estimated unit shaft friction of 520 kPa was back-calculated based on the static vertical pile load test. However, it is noted that the ultimate unit shaft friction does not seem to be mobilized yet due to the set test load.
3. An estimated unit shaft friction of 204 kPa was back-calculated based on the dynamic load test. However, it is noted that the full capacity of the pile has not been activated due to the set test load, and the test was carried out on the working pile.

4. Fig. 7 shows the results of evaluation of ultimate shaft friction based on the static vertical load test result along with commonly used empirical methods.

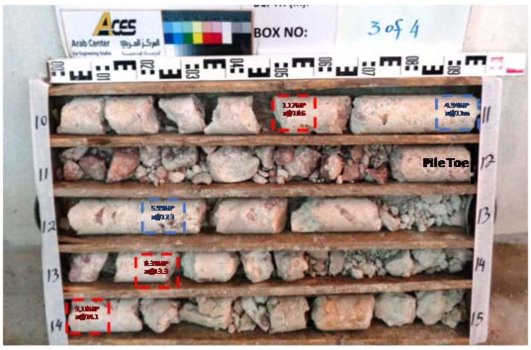

Fig. 5 Core Photo between 10 and 15m depth

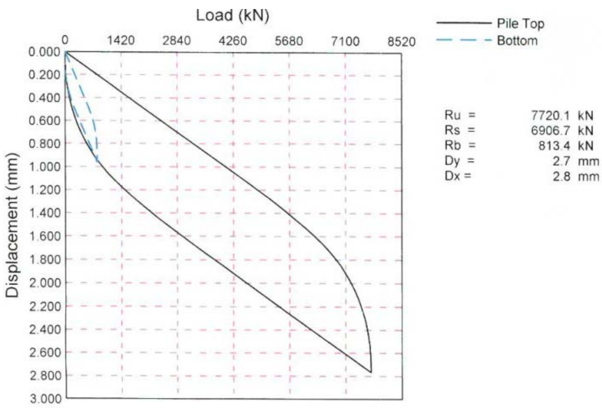

Fig. 6 Load displacement curve for a 900-mm bored pile socketed into weathered limestone with an effective length of 12 m

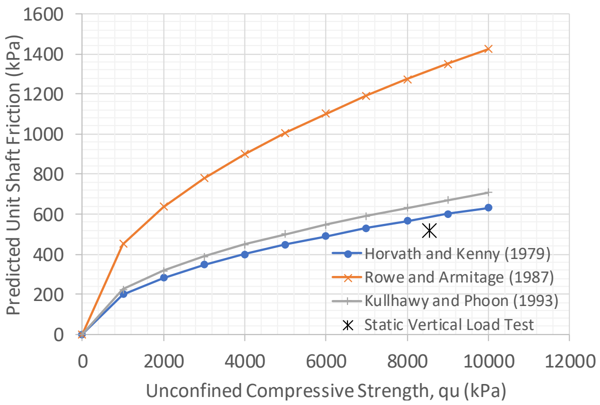

Fig. 7 Unit shaft friction of rock versus unconfined compressive strength

VII. Summary and Conclusions

The estimated unit shaft friction based on static vertical load test seems to agree with the unit shaft friction evaluating using the empirical correlations proposed by [1], [11], [12]. However, it is noted that the pile load test has not reached to the ultimate pile capacity, the ultimate unit shaft friction is therefore likely to be higher that the estimated value. Similarly, the estimated unit shaft friction from the dynamic load test is likely to be under-estimated.

The UCS values for weathered limestone in Qatar are generally lower than 5 MPa (weak rock), based on the author's experiences in Qatar. The ultimate shaft friction of 300 kPa to 500kPa shall therefore be reasonably used for the preliminary design for the bored pile socketed into weathered limestone. Alternatively, empirical correlations can be used in conjunction with site specific geotechnical investigation to evaluate the ultimate shaft friction. However, the adopted UCS value shall be made with caution as it can over-predict the ultimate unit shaft friction.

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