BEHAVIOR OF DRILLED SHAFTS IN SANDY SOILS OF UNITED ARAB EMIRATES

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Abstract.

The axial end bearing and skin capacities of piles bored in cohesionless soils are often estimated using empirical, semi-empirical and theoretical methods. The aim of this paper is to assess the applicability and evaluate the accuracy of different prediction methods available in the literature, via comparison with data from (39) field pile load tests conducted on shafts drilled in the region of the United Arab Emirates. Meyerhof (1976) empirical method and Vesic (1975) theoretical method yielded reasonable predictions for the base resistances. However, Burland (1973) approach was found to over predict the skin capacities due to the uncertainty in determining the lateral earth pressure coefficient (k) and the soil-pile interaction angle (δ).

1. Introduction

To predict capacity, a pile designer could make two sets of calculations and judgments: first, the design values for parameters must be assessed from test data (if applicable) or to be obtained from empirical or theoretical correlations; secondly the designer must predict capacity as a function of these parameters using various methods available in the literature . For this study the evaluation of the sand parameters was based on the Standard Penetration Test data in conjunction with soil descriptions. Similar procedures were used to obtain the unit weight of the sand, which is needed for evaluation of the effective overburden pressure. Also, information regarding the location of the ground water table was known. Each set of data such as angle of internal friction ϕ, relative density D_r, lateral earth pressure coefficient K and other parameters used in predicting pile capacities are tabulated in spreadsheets at each 1-meter of pile penetration. They are represented as a function of depth, z. Formulae used in predicting pile capacities are then easily applied. Theoretical methods developed by Vesic (1975), Janbu (1976) and Hansen (1970) as well as the empirical approaches described by Meyerhof (1976) and Reese and O'Neil (1989) are considered while predicting the point capacity. Theoretical approach adopted by Burland (1973) in predicting the skin resistance as well as the empirical approaches described by both Vesic (1970) and Meyerhof (1976) is presented. The formulae used can be found in [2]. The assessment of any of these methods is based on comparing the pile point and skin capacities as attained from the pile load test with the capacities predicted by the method under study.

2. Pile Data and Soil Conditions

The piles in this study range in length D from 8 m to 20 m and in diameter B from 500 mm to 1000 mm. The ratio D/B ranges from 10.6 to 33. All piles under consideration were bored in sandy soils. Typical boreholes describing the soil strata are shown in (Figure 1 and Figure 2).

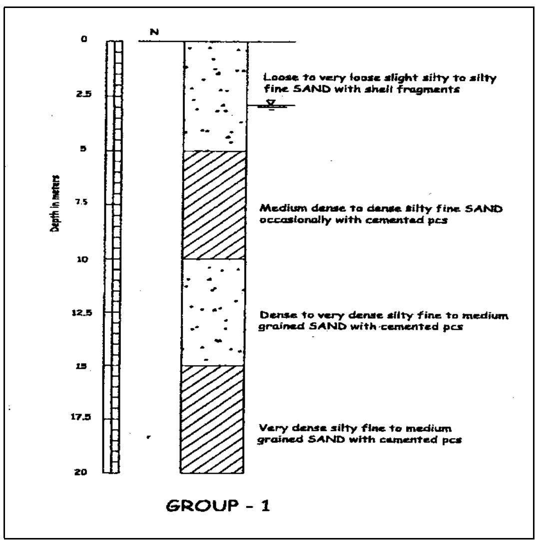

Figure 1: First Typical borehole log

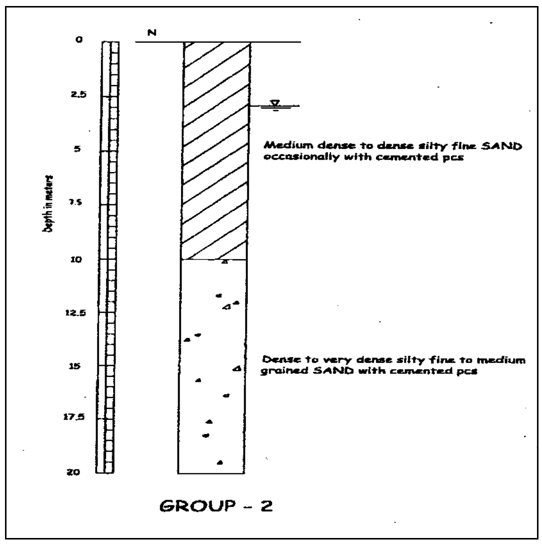

Figure 2: Second Typical borehole log

The ground water table level is allocated at a depth of 2.5 meters below the ground surface. The average corrected SPT blows count, N, encountered in the zone of local failure was reported to be 43 blows per foot. The N values were corrected for the effects of overburden pressure using the recommendation of Peck [3]. The angle of internal friction in the same zone ranges from 33^0 to 50^0 with an average of 41.5^0. Unfortunately, none of the piles in this database was tested up to failure. Under these circumstances several definitions of failure can be adopted. For the analyses reported herein, failure was defined as recommended by Chin [4], but tests were not accepted unless the pile diagnosis met the reported assumptions. Applying Chin approach, both ultimate and skin pile capacities were determined. The tip capacity was then obtained by subtracting the friction capacity from the total capacity of the pile. The skin resistance represents approximately an average of **25.5%** of the ultimate capacity of the pile. The contribution of the tip resistance is about **74.5%** of the total capacity. For the purposes of generalizing the obtained results it was considered desirable to compile regional pile load tests data reported in the literature. Table 1 and Table 2 summarize the experiences and the recommendations available in the gulf region regarding uplift tests and compression tests, respectively, conducted on piles, as reported in [5].

Area	Type of Soil	Type of Pile	Limiting Skin Friction			Reference	Year
			Range	Mean	Recom.		
Saudi Arabia	Carbonate sands	steel pipe driven	17-23	20		Murff	1985
Gulf of Suez	Carbonate sands weakly to moderately cemented	steel pipe driven	10-18	13		Murff	1985
Saudi Arabia	Silty sand	steel pipe driven	12-21	17		Murff	1985
General	Calcareous soil	driven			19	McClelland	1974
General	< 30% carbonate 30-45% carbonate > 45% carbonate	driven Driven			100 32 28	Aggarwal.	1977
Kuwait	Dense, weakly cemented	concrete, bored			100	Ismael and Al-Sanad	1986
General	Uncemented and Weakly cemented well cemented				22 mean 24 mean	As reported by Lacasse.	1989
Saudi Arabia	Dense, granular sand uncemented	H driven H driven H driven H driven			13 17 23 6	Arango, et al	1993
Kuwait	Dense Granular calcareous	Concrete driven			69	Ismael	1989
Gulf of Suez	Dense, fine sand cemented	driven			14	Dutt et al	1984
Saudi Arabia	Silt and Sand	Steel pipe driven			20	Hagenaar et al	1984

Table 1: Literature review on uplift tests and recommended skin friction values in the region (as reported by [5])

Area	Type of Soil	Type of Pile	Tip Resistance, kN/m2	Reference	Year
Saudi Arabia	Sand and silt	Driven, closed Driven opened	5,000-7,000 2,000-3,000	Hagenaar et al.	1985
General	Medium dense silica sand Dense silica sand Very dense silica sand		5,000 10,000 12,000	API API API	1987
General	Uncemented Weakly cemented Well cemented		2,000-8,000 3,500-8,200 6,000-12,000	As reported by Lacasse et al.	1989
General	Moderately compressible Highly compressible Extremely compressible		4,000 2,000 1,000	Coligthly And Nauroy	1990
Australia	Silty sand	driven	>10,000	Angemeer	1973

Table 2: Literature review on compression tests and of recommended tip resistance values (as reported by [5])

3. Analyses of Pile Point Capacities

Analyses were performed for piles in the database using empirical and theoretical recommendations. Measured and predicted point capacities are compared as plotted in Figure 3 through Figure 7. The dispersion of the data is measured by various statistical means such as the standard deviation, the range, the coefficient of variation and the mean values. A Z-test was carried out on the data under study with a level of confidence of 5%. Figure 8 shows the Z-values obtained from each test along with the accepted range that varies between (+1.69) and (-1.69).

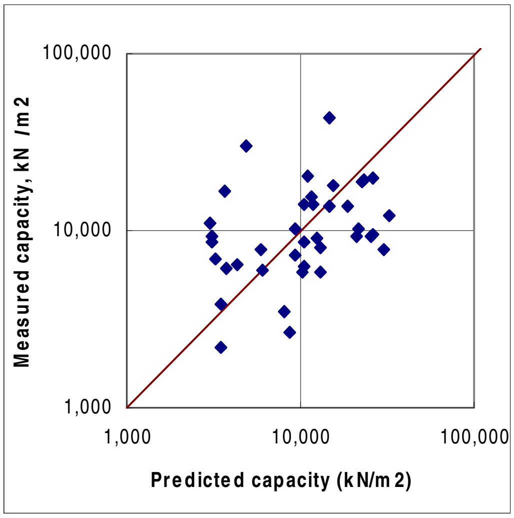

Figure 3: Comparison of measured capacities to capacities predicted using Hansen Approach

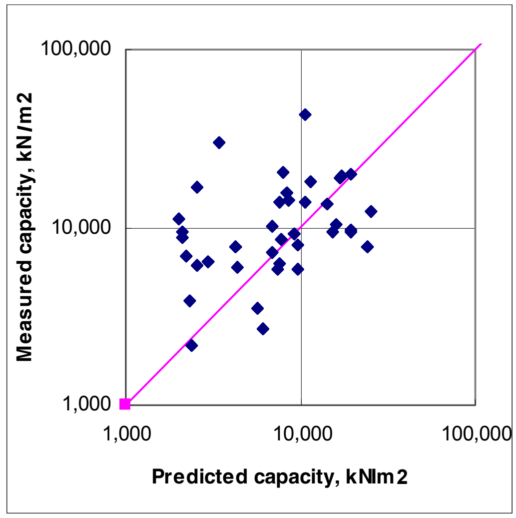

Figure 5:Comparison of measured capacities to capacities predicted using Janbu Approach (ψ = 90).

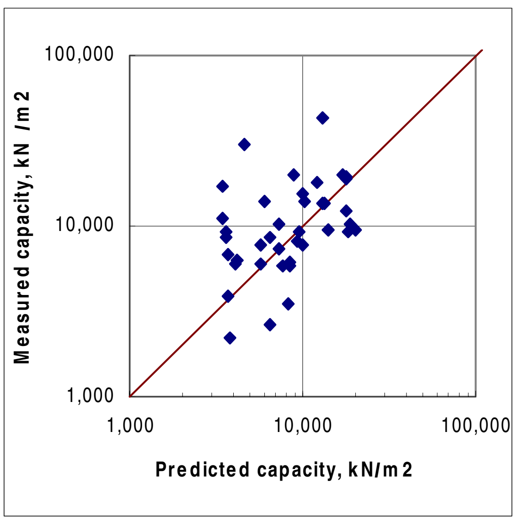

Figure 4: Comparison of measured capacities to capacities predicted using Vesic Approach

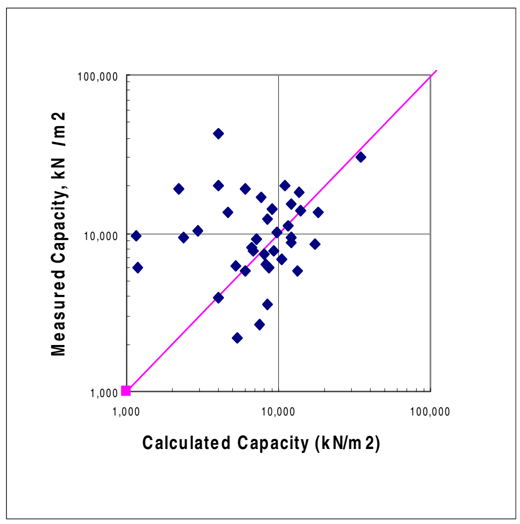

Figure 6: Comparison of measured capacities to capacities predicted using Meyerhof Approach.

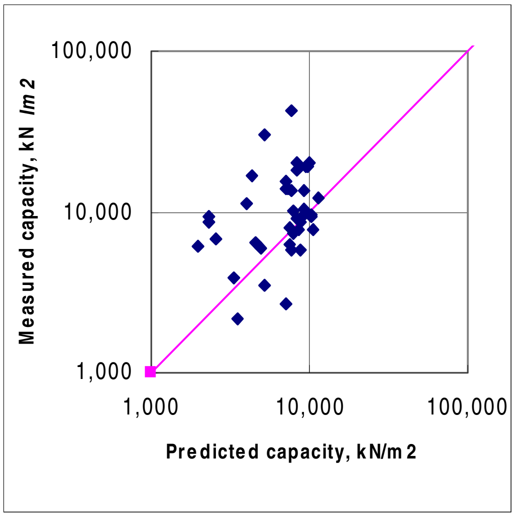

Figure 7:Comparison of measured capacities to capacities predicted using Reese Approach.

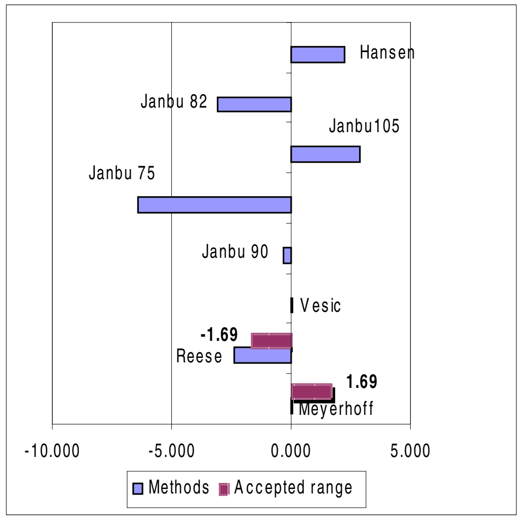

Figure 8: Results of the Z-test.

A simple statistical analysis on the ratio of calculated-to-measured point capacity was performed and tabulated in Table 3.

	Meyerhof	Vesic	Janbu				Reese	Hansen
			90	75	105	82		
Mean	1.00	1.01	0.97	0.60	1.56	0.75	0.81	1.32
Min	0.09	0.15	0.11	0.08	0.20	0.09	0.17	0.16
Max	2.80	2.45	3.07	1.58	5.95	2.15	2.69	3.87
Median	0.95	0.94	0.88	0.53	1.40	0.68	0.77	1.18
Standard Deviation	0.68	0.58	0.68	0.39	1.21	0.50	0.50	0.89
Coef. Of Variation=	68.09	57.84	70.20	64.81	77.64	67.12	61.83	67.76
Z-test for α = 0.05	0.04	0.07	-0.29	-6.38	2.90	-3.09	-2.35	2.22
Variance	0.47	0.34	0.46	0.15	1.47	0.25	0.25	0.80
Range	2.71	2.30	2.95	1.50	5.75	2.06	2.52	3.71
Mean Log Qc/Qm	-0.13	-0.08	0.60	-0.32	0.06	-0.23	-0.17	0.01
Standard Deviation Log Qc/Qm	0.38	0.28	0.39	0.33	0.36	0.33	0.28	0.34

Table 3: Statistical Comparison of methods used in predicting the pile point capacity

Based on the above, the Meyerhof approach, based on SPT values, can be considered as the best empirical approach to predict the tip resistance of drilled piles in the region. As an output of the Z-test carried out on the sample, a high confidence can be considered while judging this approach. The ratio of calculated-to-measured axial point capacity (Q_c/Q_m) obtained shows a mean value of 1.00 with a Z-test value 0.04. The mean log (Q_c/Q_m) was -0.13 (antilog is 0.74), and the standard deviation was 0.38 for the logarithmic ratio. The median (Q_c/Q_m) of 0.95 indicates that the method slightly under predict the actual capacities.

Vesic's approach can be considered as the best theoretical method that can be used to predict the tip resistance of drilled piles in the region. The ratio of calculated-to-measured axial point capacity (Q_c/Q_m) shows a mean value of 1.01 with a Z-test value 0.07. The mean log (Q_c/Q_m) was -0.08 (antilog is 0.83), and the standard deviation was 0.28 for the logarithmic ratio. Actually both methods could be judged as "accurate methods of predicting the tip resistance". Following Vesic approach, Janbu method could be considered as the second best theoretical method in describing the tip resistance of the piles in the region. The ratio of calculated-to-measured axial point capacity (Q_c/Q_m) shows a mean value of 0.97 with a Z-test value –0.29. The other investigated approaches are considered practically inapplicable for the region, since they greatly under predict (e.g. Reese) or over predict (e.g. Hansen) the tip capacities of the piles. The effect of the SPT blow counts on the predicted point capacity is shown in Figure 9 where measured point capacity (as predicted by Chin [1]) is compared to the calculated point capacities by the methods under study. Similarly, the effect of the angle of internal friction (ϕ) on the predicted point capacity is presented in Figure 10.

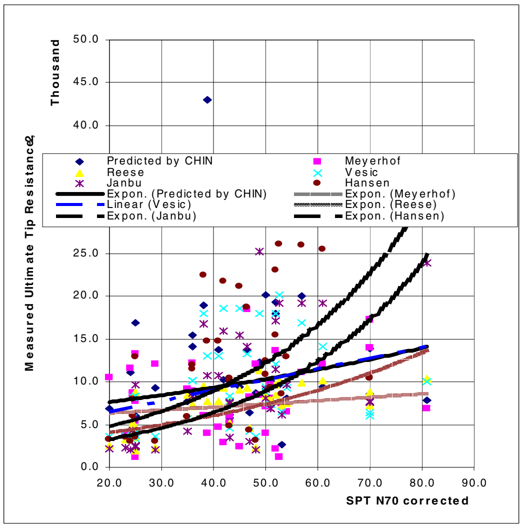

Figure 9: Effect of the corrected N_{70} on the predicted base resistances of the piles

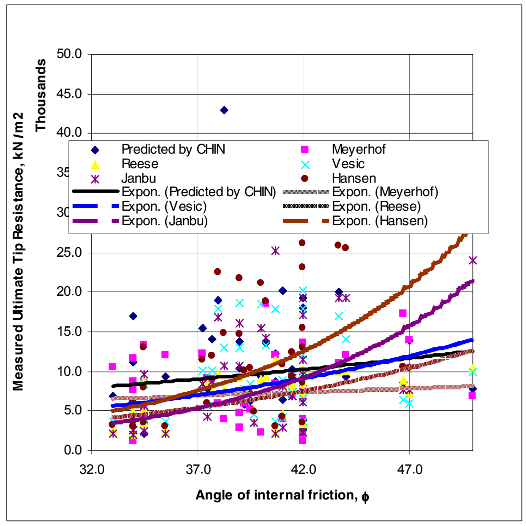

Figure 10: Effect of the angle of internal friction (ϕ) on the predicted base resistances of the piles

The plots shown in Figure 11 and Figure 12 describe the effect of the pile penetration on the measured pile point capacities using Meyerhof and Vesic approaches. From the plots, a larger scatter is encountered while applying Vesic approach. This is also supported by the values of the least squares R^2 analysis obtained for the data. Moreover, and in spite of the large scatter obtained, the use of Vesic method leads to under-prediction of capacities for short piles and over-prediction of capacities for long piles. Using Meyerhof approach, the trend of the points in the graph is towards over prediction of capacities of short piles and under prediction of long piles. It is worth mentioning that applying Reese approach, the point capacity is not greatly affected by the pile penetration. This is due to the nature of the empirical formula used by Reese where the only factor considered is the SPT number.

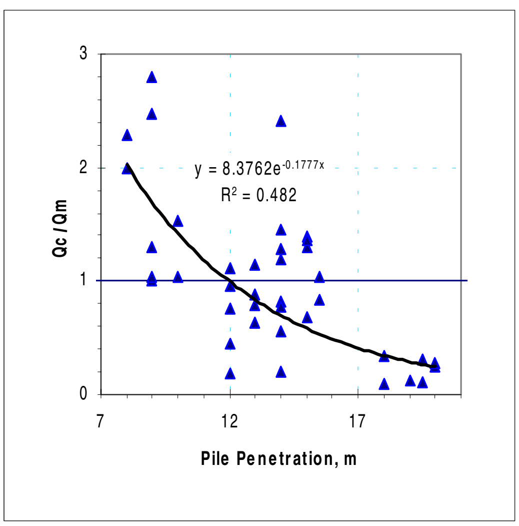

Figure 11: Effect of Pile Penetration on the Capacities Computed by Meyerhof Approach.

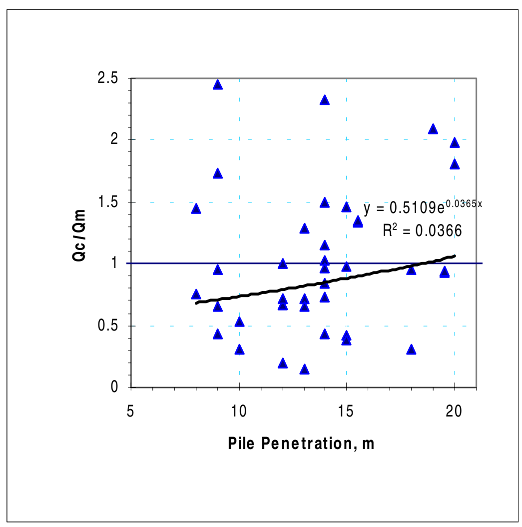

Figure 12: Effect of Pile Penetration on the Capacities Computed by Vesic Approach.

4. Analyses of Pile Skin Capacities

Analyses were performed for piles in the database using empirical recommendations of Meyerhof (1976) and Vesic (1970) as well as Burland Approach (1973) [2]. Measured and predicted skin capacities are then compared to each other. Results show that predictions using empirical methods are by far different from the actual measured values.

Meyerhof method is considered unsafe in most cases since it over predicts the skin capacity of the piles with an average of 13 times. Vesic method gives a relatively less mean value for the calculated-to measured ratio of skin resistance if compared to that obtained by using Meyerhof approach. However it is as well considered as unsafe way to predict the skin resistance of the piles since it highly over predicts the capacity up to 7 times (as an average). This could be explained that most of these methods are mainly based on the analysis of experimental data and field measurements that if applicable in some regions, are not necessarily applicable in the region under study.

On the other side, the β–method developed by Burland (1973) shows comparable values to the actually measured skin resistances. This method intensely counts on the soil-pile interaction parameters such as the angle of soil-pile friction angle (δ) and the coefficient of earth pressure (k). Lists of typical values of both parameters for pile foundations are reported in [6]. As can be easily demonstrated from the equation used, the skin resistance along the pile tends to increase with the increase of both parameters. It was found out from the analysis that a combination between the value of ($k = 0.5\ k_o$) and the value of ($\delta = 2/3\ \phi$) gives a calculated-to-measured mean ratio (Q_c/Q_m) three times greater than the unity.

Figure 13 shows a comparison between the measured and the predicted capacities using the above values of (k) and (δ). The large scatter indicates that the method can be unsafe in some cases and uneconomical in others. Obviously, increasing the values of the parameters (k) and (δ), the mean ratio tends to increase significantly.

Graphs showing other combinations between (k) and (δ) are ignored since they all over predict the capacity of the skin resistance with an amount much greater than the case under discussion. As these parameters can only be estimated, further research is recommended to accurately determine these values in order to best describe the soil in our region. Till then the skin resistance capacity cannot be accurately predicted: they can only be estimated to within the broad ranges offered by the analysis in this study and the literature. In general, Burland method while being applied tends to over predict the skin capacity of the piles. This tendency increases in case of long piles as shown in Figure 14 where the effect of pile penetration on the predicted capacities is presented. A relation between the skin friction coefficient β and the depth ratio D/B of the piles is plotted on a logarithmic scale and shown in Figure 15.

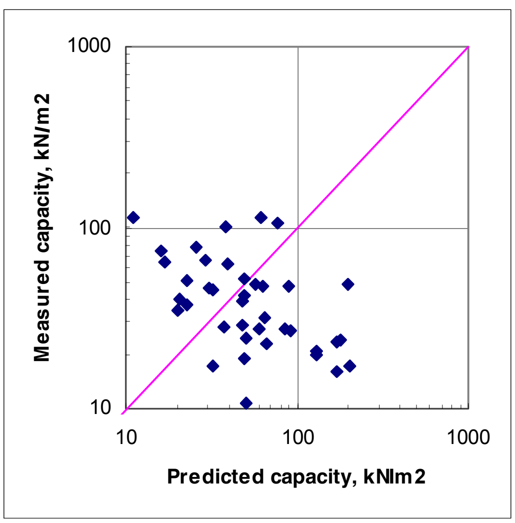

Figure 13: Comparison of Measured Capacities to Capacities Predicted By Burland (k=0.5ko, δ=2/3ϕ)

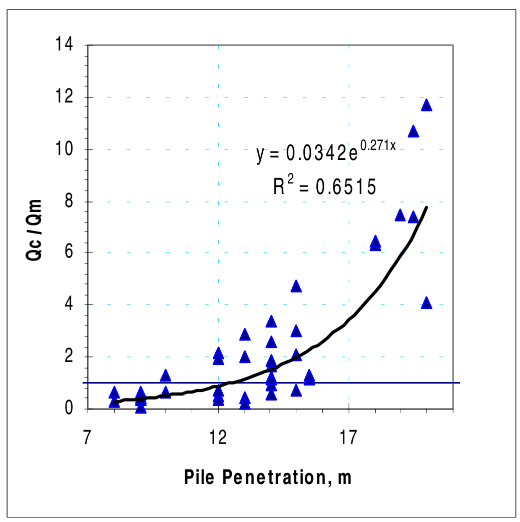

Figure 14: Effect of Pile Penetration on the Skin Capacities Computed by Burland ($k=0.5\ k_o$, $\delta = 2/3\ \phi$)

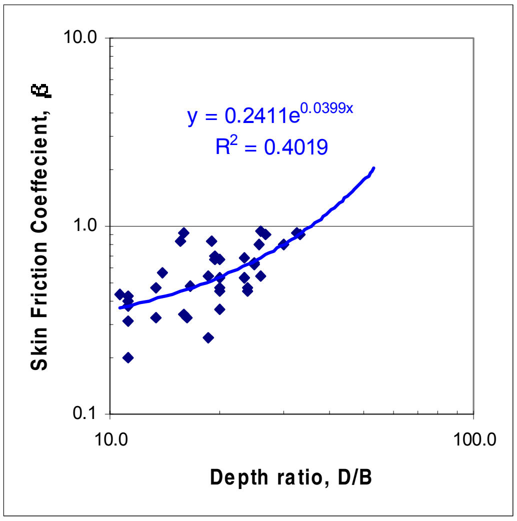

Figure 15: Relation Between Depth Ratio D/B and Skin friction Coefficient β as predicted by Burland.

5. Conclusion.

The following conclusions are drawn from the results in this study:

- The contribution of the skin resistance in developing the ultimate capacity of the drilled piles in the region under consideration does not exceed an average of 25%. Tip resistance develops most of the pile capacity.
- Good and reasonable predictions for the tip resistance of the piles are achieved using Meyerhof (1976) empirical approach. This conclusion is in full agreement with what has been reported in [7] and using Vesic (1975) theoretical approach.
- Predictions using Vesic (1975), Janbu (ψ = 90) and Hansen approaches lead to under-prediction of point capacities of short piles and over-prediction of long piles while the use of Meyerhof approach goes towards over prediction of capacities of short piles and under-prediction of long piles.
- The use of the empirical methods suggested by Vesic (1970) and Meyerhof (1976) in predicting the pile skin resistance is not recommended since it highly over estimate the actual value. These methods are considered unsafe in most cases.
- Burland (1973) method for predicting the pile skin resistance tends to over predict the capacity of the piles. This tendency increases in case of long piles.
- It is possible that good predictions of skin resistance could be attained by assuming that the coefficient of lateral earth pressure (k) is some fraction of the value of the at-rest earth pressure (k_o) as well as the assumption that the value of (δ) is a fraction of the angle of internal friction (ϕ).

6. References

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