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Prediction of the Axial Bearing Capacity of Piles by SPT-based and Numerical Design Methods

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ABSTRACT: The prediction of the axial capacity of piles has been a challenge since the beginning of the geotechnical engineering profession. In recent years determining bearing capacity of piles from in-situ testing data as a complement of static and dynamic analysis has been used by geotechnical engineers. The Standard Penetration Test (SPT) is still the most commonly used in-situ test and pile capacity determination by SPT is one of the earliest applications of this test. On the other hand, the acceptance of numerical analyses in geotechnical problems is growing and finite element calculations are more and more used in the design of foundations. In this paper, different approaches for estimating the bearing capacity of piles from SPT data have been explained and compared with numerical method. Then, comparisons between numerical and empirical results are presented and discussed.

Keywords: Pile, Axial capacity, Standard Penetration Test, Finite Element Method

1. INTRODUCTION

The prediction of the axial capacity of piles is recognized as being the area of greatest uncertainty in foundation design. Several methods and approaches have been developed to overcome the uncertainty in the prediction. The methods include some simplifying assumptions or empirical approaches regarding soil stratigraphy, soil-pile structure interaction and distribution of soil resistance along the pile. Therefore, they do not provide truly quantitative values directly useful in foundation design [1]. Bearing capacity of piles can be determined by five approaches: static analysis, dynamic analysis, dynamic testing, pile load test and in-situ testing.

Design guidelines based on static analysis often recommend using the critical depth concept. However, the critical depth is an idealization that has neither theoretical nor reliable experimental support, and contradicts physical laws. Dynamic analysis methods are based on wave mechanics for the hammer-pile-soil system. The uncertainty in the hammer impact effect, as well as changes in soil strength from the conditions at the time of pile driving, and also at the time of loading, causes uncertainties in bearing capacity determination. Dynamic testing methods can only be used by an experienced person and the capacity estimation is not available until the pile is driven [2].Pile load test is the best method for pile bearing capacity determination but such tests are expensive, time-consuming and the costs are often difficult to justify for ordinary or small projects. In recent years, the application of in-situ testing techniques has increased for geotechnical design. This is due to the rapid development of in-situ testing instruments, an improved understanding of the behavior of soils.

2. METHODS OF PILE BEARING CAPACITY

The Standard Penetration Test, SPT, is still the most commonly used in-situ test. Also SPT is the most common testing methodology adopted in the field to gain idea about the stratigraphic profile at a site. Due to its simplicity of execution (apart from the difficulty in repeatability), a field engineer finds the method to be one of the most amiable and reliable one.

The introduction in the United States in 1902 of driving a 25-mm diameter open-end pipe into the soil during the wash-boring process marked the beginning of dynamic testing and sampling of soils. Between the late 1920s and early 1930s, the test was standardized using a 51-mm O.D. split-barrel sampler, driven into the soil with a 63.5-kg weight having a free fall of 760 mm. The blows required to drive the split-barrel sampler a distance of 300 mm, after an initial penetration of 150 mm, is referred to as the SPT N-value. This procedure has been accepted internationally with only slight modifications. The number of blows for each of the three 150-mm penetrations must be recorded. Apart from its main applications in soil characterization, SPT N-value has also been extensively used for designing structural foundations and other earth structures, particularly, for the bearing capacity of piles.

Pile capacity determination by SPT is one of the earliest applications of this test that includes two main approaches, direct and indirect methods. Direct methods apply N values with some modification factors. Indirect SPT methods employ a friction angle and undrained shear strength values estimated from measured data based on different theories. Amongst the two, the direct methods are more accepted amongst the field engineers for the ease of computations. In the present study, the following common SPT-based direct methods have been employed to predict the pile bearing capacity (Table I).

Table 1 SPT direct methods for prediction of pile bearing capacity in the present study

Method	Unit Base (Q_b) and Unit Shaft (Q_s) resistance	Remarks
Meyerhof (1976)	$m N_b \le \left(\frac{L}{D}\right)$ Q_b (MPa) = k N_b Q_s (kPa) = $n_s N_S$	N_b:average of N between 10D above and 5D below pile base N_s: average value of N around pile embedment depth. bored piles: n_s=1, k=0.012, m=0.12 driven piles: n_s=2, k=0.04, m=0.4
Bazaraa & Kurkur (1986)	Q_b (MPa) = $n_b N_b$ Q_s (kPa) = $n_s N_S$	N_b:average of N between 1D above and 3.75D below pile base, $N_b \le 50$ n_b= 0.06 - 0.2 n_s= 2 – 4 N_s: average value of N around pile embedment depth
Decourt (1995)	Q_b (MPa)= k_b N_b Q_s (kPa) = α (2.8 N_S+10)	driven piles and bored piles in clay: α =1 bored piles in granular soils: α=0.5-0.6 driven piles in sand: k_b=0.325 bored piles in sand: k_b=0.325 driven piles in clay: k_b=0.1 bored piles in clay: k_b=0.08 N_b: average of N around pile base N_s: average value of N around pile embedment depth.
Shariatmadari et al.(2008)	Q_b (MPa)= 0.385 N_{gb} Q_s (kPa) = 3.65 N_{gs}	N_{gb}: the geometrical average of N values between 8D above and 4D below pile base N_{gs}: geometrical average of N values along the pile

3. DETERMINATION OF PILE BEARING CAPACITY BY SPT (CASE STUDY)

By performing a 15m borehole in a region in Babol (Fig 1), north of IRAN, the soil stratigraphy has been recognized(Fig 2). The groundwater table is 1.5 m below the ground surface. The average unit weight of the soil is 1.93gr/cm^3 and its average modulus of elasticity is 90 kg/cm^2. Fig 3 depicts the variation of SPT-N values with depth of this site.

Fig.1 The region considered in this study

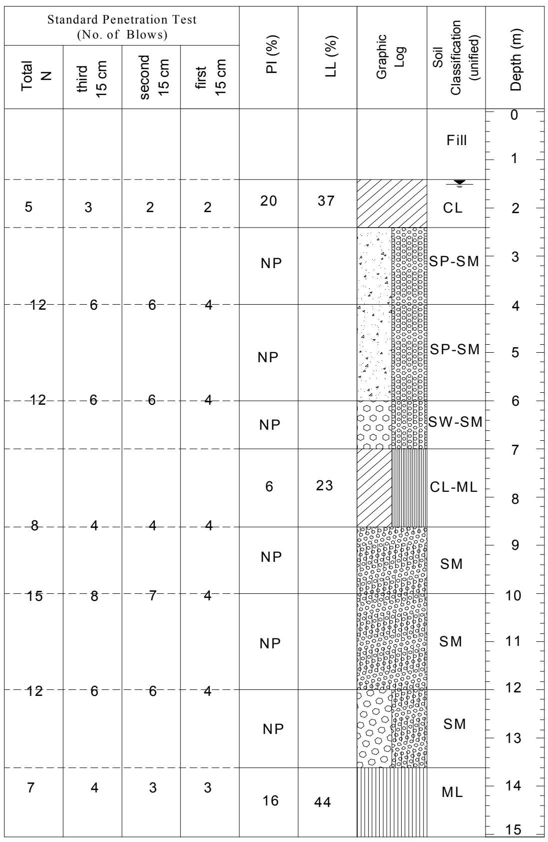


Fig.2 Exploratory boring log

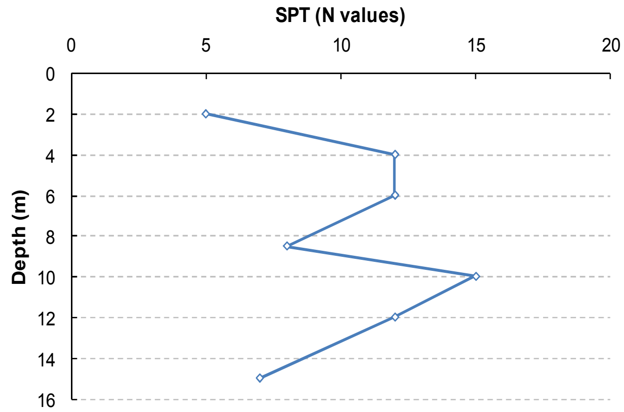


Fig.3 Variation of SPT-N values with depth

Based on the SPT data above, a hypothetical problem is considered wherein the bearing capacity of a bored pile (L=7m, D=1m) is determined by the methods mentioned above.(Table II).

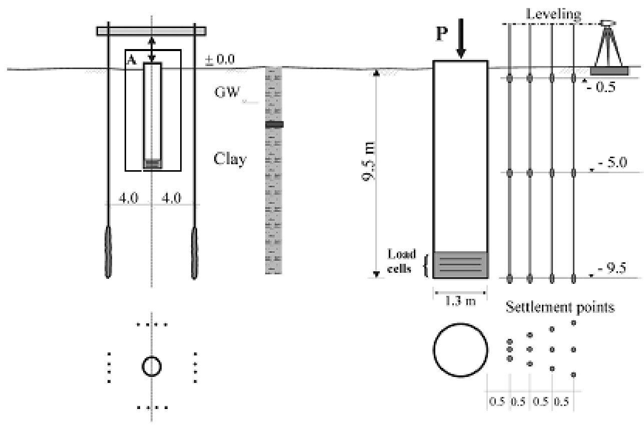
Table 2 The bearing capacity of the bored pile by common SPT-based methods (L=7m, D=1m)

Method	Meyerhof	Bazaraa & Kurkur	Decourt	Shariat madari
value(kN)	916	1102	1700	3655

4. VALIDATION

In order to validate the program, a pile load test in Germany has been analyzed. The load test investigated the load-settlement behavior of a single pile. The upper 4.5m subsoil consist of silt (loam) followed by tertiary sediments down to great depths. These tertiary sediments were stiff plastic clay similar to the so-cal1ed Frankfurt clay, with a varying degree of overconsolidation. The groundwater table was about 3.5m below the ground surface. The considered pile had a diameter of 1.3 m and a length of 9.5m. It was located completely in the overconsolidated clay. The loading system consisted of two hydraulic jacks working against a reaction beam. This reaction beam was supported by 16 anchors. These anchors were installed vertically at a depth between 15 and 20 m below the ground surface at a distant of about 4 m from the tested pile, in order to minimize the effect of the mutual interaction between the tested pile and the reaction system. Then, loading test was carried out. The loads were applied in increments and maintained constant until the settlement rate was negligible.

The mentioned pile load test has been carried out by El-Mosallamy in Frankfort clay, was used to verify the present numerical method. Fig 4 shows the layout of the pile load test and measurement points by El-Mossallamy. Fig 5 demonstrates a comparison between the result obtained by El-Mosallamy and that obtained in the present study .The comparison depicts a good agreement between the results.



a- Layout of the load test b- Details A

Fig.4 Layout of the pile load test and measurement points by El-Mossallamy

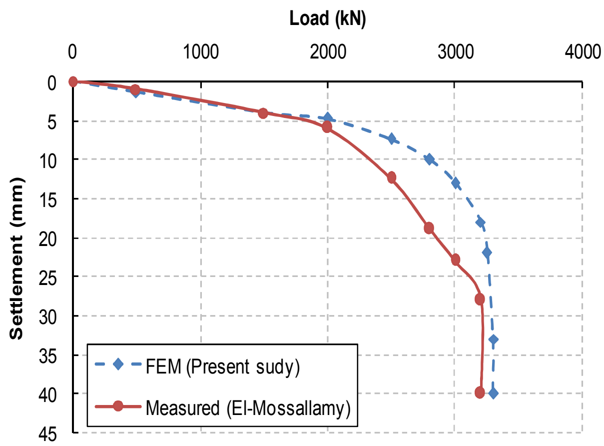


Fig.5a Load – settlement curve (a comparison)

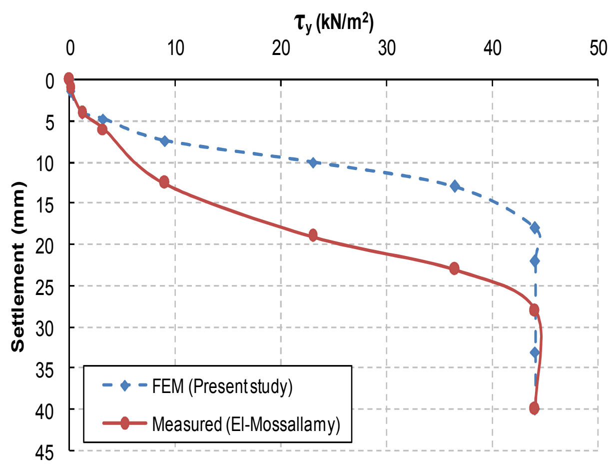


Fig.5b Stress – displacement curve (a comparison)

5. DETERMINATION OF PILE BEARING CAPACITY BY PLAXIS 3D FOUNDATION

In this part, the bearing capacity of the pile mentioned above is determined by the program "plaxis 3d foundation". "Plaxis 3d foundation" is a finite element method-based three-dimensional program specially developed for the analysis of foundation structures, including off-shore foundations. This program combines simple graphical input procedures, which allow the user to automatically generate complex finite element models, with advanced output facilities and robust calculation procedures. In order to analyze the behavior of the single pile, at first a model is made. A working area 50m x 50m has been used. The pile is modelled as a solid pile using volume elements in the center of the mesh. Interfaces are modelled along the pile. The generated mesh of the system (for pile: L=7m, D=1m) by this program is as follows (Fig 6).

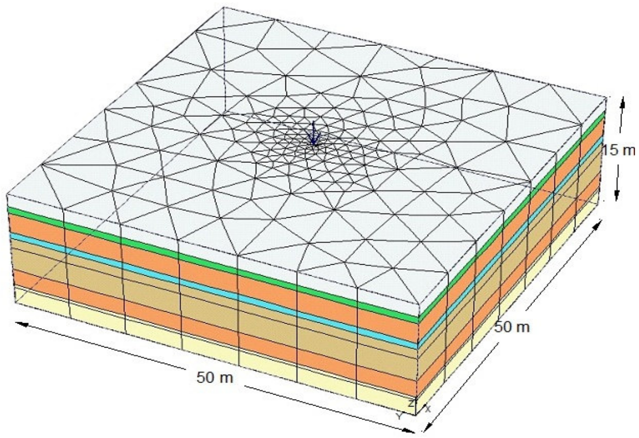


Fig.6 The typical mesh used in the study

The stress-settlement behavior of the pile, analyzed by the program is presented in Fig 7.

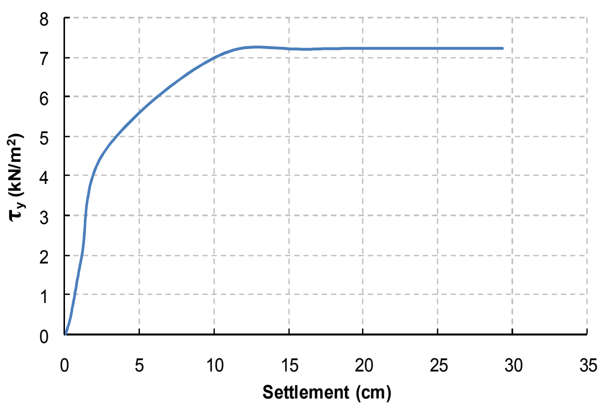


Fig.7 Stess-settlement behavior of the considered pile

The bearing capacity of the considered pile, obtained by this program, is 1200 kN. Fig 8 shows a comparison between different methods and the present study.

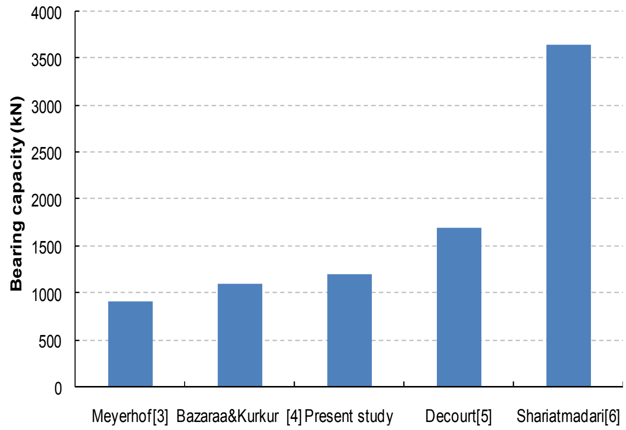


Fig.8 Comparison between the results obtained by different methods and the present study FEM

6. CONCLUSION

Determining the bearing capacity of piles is an interesting subject in geotechnical engineering. The complex nature of the embedment ground of piles and lack of suitable analytical models for predicting the pile bearing capacity are the main reasons for the geotechnical engineer's tendency to peruse further research on this subject. Direct bearing capacity predicting methods for piles are developed based on in-situ testing data, specially SPT, having applications that have shown an increase in recent years.

In this study, by analyzing the pile by FEM and comparing it with common methods, tried to find a reasonable prediction for its bearing capacity. The results indicate that, in this site, the bearing capacity predicted by Bazaraa & Kurkur method is very close to the one obtained by the finite element method (FEM). Also Meyerhof method underestimates and Shariatmadari method overestimates the bearing capacity of the single pile. Therefore, 1200 kN can be a good prediction for the bearing capacity of the bored pile considered (L=7m, D=1m) in this study.

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