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Prediction of Bearing Capacity of Bored Cast- In Situ Pile

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Abstract: *An axially loaded pile tests have been carried out on 0.6m diameter bored cast in-situ piles in clayey silt soil with decomposed organic matter upto minimum depth of 11m.This paper presents an FEM model for simulating these field axial load tests embedded in such soils using PLAXIS 2D. The simulation is carried out for a single pile with an axial load at pile top, so as to evaluate the settlement of the pile. The vertical load versus settlement plots on single pile is obtained from field tests and are compared with the finite element simulation results using PLAXIS 2D, showing reasonable agreement. Different approaches for estimating the bearing capacity of piles from SPT data have been explained and compared. Statistical and probability approaches were engaged to verify the SPT predictive methods with the log-normal distribution in order to predict the degree of scattering of uncertainty.*
Keywords: *Pile Bearing Capacity, Standard Penetration Test, Finite Element Method, Standard Deviation.*

I. Introduction

Pile foundation is one of the most popular forms of deep foundations. Piles are generally adopted for structures in weak soils, characterized by low shear strength and high compressibility, as well as in good soils, in cases where structures are subjected to heavy loads and moments[1].The maximum settlement of the pile and its ultimate load bearing capacity are the governing criterion in the design of axially loaded piles. These are evaluated by carrying out a number of theoretical and numerical approaches. Bearing capacity of piles can be determined by four approaches:

i. By the use of static bearing capacity equations
ii. By the use of SPT and CPT values
iii. By field load tests
iv. By dynamic test

Static analysis methods estimate shaft and base resistances separately and differently. For shaft resistance, in cohesive as well as non-cohesive soils, considerable uncertainty and debate exist over the appropriate choice of the horizontal stress coefficient, Ks. 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. In recent years, the application of in-situ testing techniques has increased for geotechnical design. Standard Penetration Test (SPT) is one of the most common and economical field tests used during ground investigation. 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 (Meyerhof, 1976; Shioi and Fukui, 1982; Decourt, 1995; Robert, 1997).

This paper presents the results of a field test carried out on an axially loaded pile and attempts to study the pile behaviour under an axially loads using a two-dimensional finite element model. The bearing capacity of piles are estimated using direct and indirect methods and highlights the importance of predicting uncertainty which can be estimated from statistical parameters.

II. Bearing Capacity Of Piles Using Penetration Data

Several researchers have proposed several theories to estimate the bearing capacity of pile foundations in sandy soil using mechanics of statics [Janbu(1976), Meyerhof (1976), Vesic (1977), Coyle and Castello (1981)]. Few correlations have also been proposed for estimating the pile bearing capacity using dynamic methods [Murthy (1999)]. In spite of the mechanistic approaches, the most popular method of estimating the bearing capacity of piles still pertain with the use of penetration test data, either Standard Penetration Data (SPT) or Cone Penetration Data (CPT).

The Standard Penetration test (SPT) is a common in-situ testing method used to determine the subsurface soil profile and their geotechnical engineering properties. 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. 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 un-drained shear strength values estimated from measured data based

on different theories. Soil parameters are obtained from SPT results, and the methodology of pile bearing capacity estimation is the same as for the static methods.

For layered clay soil, where the cohesive strength varies along the shaft,

$$Pu= Qu+ Tu= q_u A_b + \Sigma(fsp\Delta L)$$

Where q_u is the unit ultimate end bearing capacity of the soil at the level of the pile tip, A_b is the bearing area, fs is the unit ultimate soil-pile adhesion strength, and p is the pile perimeter at the segment ΔL. The term Σ (fs.p.ΔL) is the total load capacity contributed by the pile shaft in skin-friction calculated as the summation of the side shear forces along the pile's embedment length L. Using different approaches as estimated by Meyerhof (1976) and Vesic (1977),the indirect values are obtained. .Although there are some problems on the explicit interpretation of the results of SPT, this test is the most frequent in-situ test in geotechnical practice because of its simplicity and affordable costs.

III. Determination Of Pile Bearing Capacity By Spt (Case Study)

By performing a 50m borehole at the site of National Institute of Technology, Langol, a region in Lamphelpat, Imphal, Manipur. The soil stratigraphy and SPT values along with depth is shown in Figure1. The groundwater table is 0.45m below the ground surface.

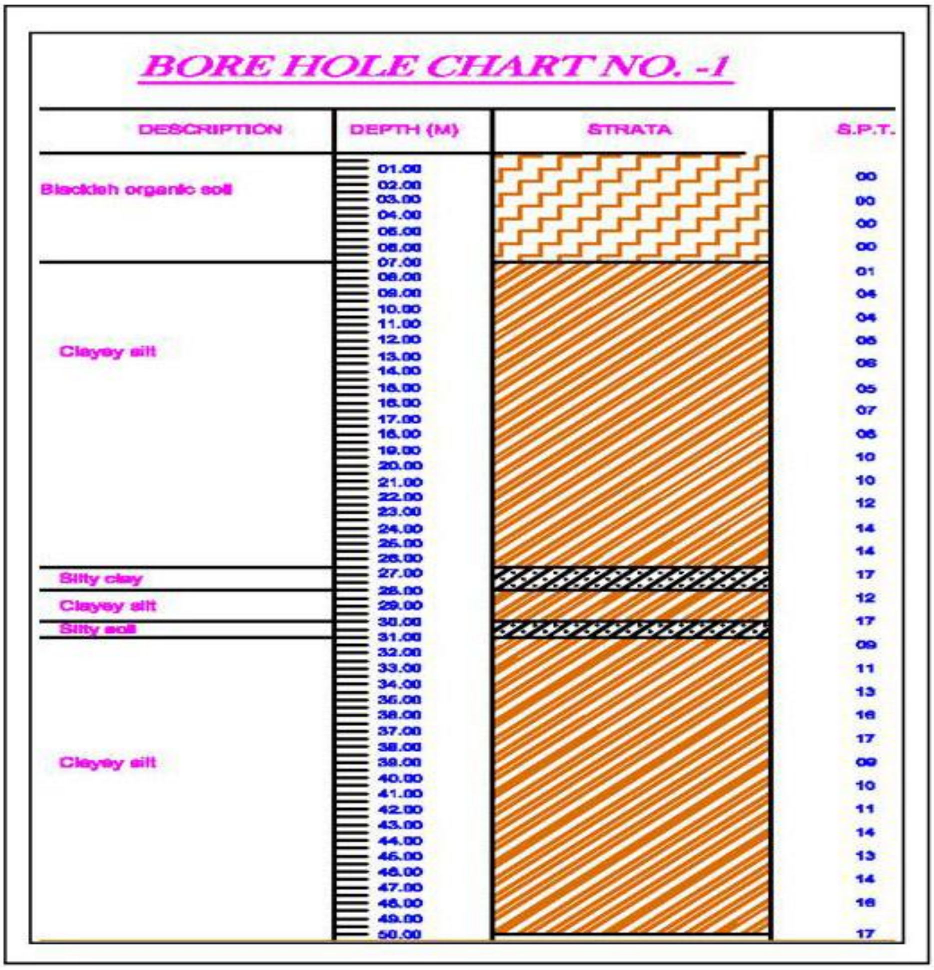

Fig.1. Borehole Considered

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

Method	Unit base(Qb)and Unit shaft resistance(Qr)	Remarks
1. Aoki and De'Alencar (1975)	Qb(MPa)=(k/1.75)Nb Qs(kPa)=(ak/3.5)Ns	**Nb:** Average of three values of SPT blows around pile base **Ns:** Average value of N around pile embedment depth For sand: a=14, k=1 For clay: a=60, k=0.2
2. Bazara and Kurkur (1986)	Qb(MPa)=nbNb Qs(kPa)=nsNs	**Nb:** Average of N between 1D above and 3.75D below pile base, Nb<=50 **Ns:** Average value of N around pile embedment depth nb=0.06-0.2 ns=2-4
Decourt (1995)	Qb(MPa)=kbNb Qs(kPa)=α(2.8Ns+10)	Driven and bored piles in clay :α=1 Bored piles in granular soils :α=0.5-0.6 Driven piles in sand: Kb=0.325 Bored piles in clay: Kb=0.08 Driven piles in clay: Kb=0.1 Bored piles in sand: Kb=0.325

Based on the SPT data above, the bearing capacity of a bored pile (L=26m, D=0.6m), is determined by the methods mentioned as given in Table1 below

IV. Validations

In order to validate the program, a pile load test has been analyzed. The bored cast-in situ pile considered in this study is of diameter (D) 0.6m, length 26m.The site soil considered in this study is shown above in the fig.

Reaction load test (by compression) was done as per IS : 2911 (PART – IV) 1985 in which reaction load was applied on the pile top (after preparation f pile top) by means of a hydraulic jack against rolled steel joist capable of providing reaction and settlement was recorded by two or four dial gauges of mm sensitivity, each position at equal distance around the pile and held by datum bars resting on immovable support at minimum distance of 1.5D meter times from the edge of the pile. The rolled steel joist was loaded by putting suitable size of wooden joists transversely and wooden planks on it and sand bags filling about 30 to 35 kg weight around 2700 nos. of bags on the platform. The reaction for the jack was obtained from a kentledge placed on a platform supported clear of the test pile. The center of gravity of kentledge was tried to be kept on the axial of pile and the load applied by hydraulic jack was made co – axial with this pile.

The field results have been compared with the PLAXIS 2D.In PLAXIS 2D, 15 noded triangular element has been chosen which results in a two-dimensional finite element model with two translational degrees of freedom per node. The 15-noded triangle provides a fourth order interpolation for displacements and the numerical integration involves twelve Gauss points. The pile is made up of reinforced cement concrete and the behaviour is assumed to be linear-elastic. The Mohr-Coulomb model can be considered as a first order approximation of real soil behaviour. This elastic perfectly plastic model requires 5 basic input parameters, namely Young's Modulus, E, Poisson's ratio, μ, cohesion, c, friction angle, ϕ and dilantacy angle, ᴪ. This is a basic, well-known soil model. Figure below shows the generation of a mesh and deformations when loads of 55T is applied.

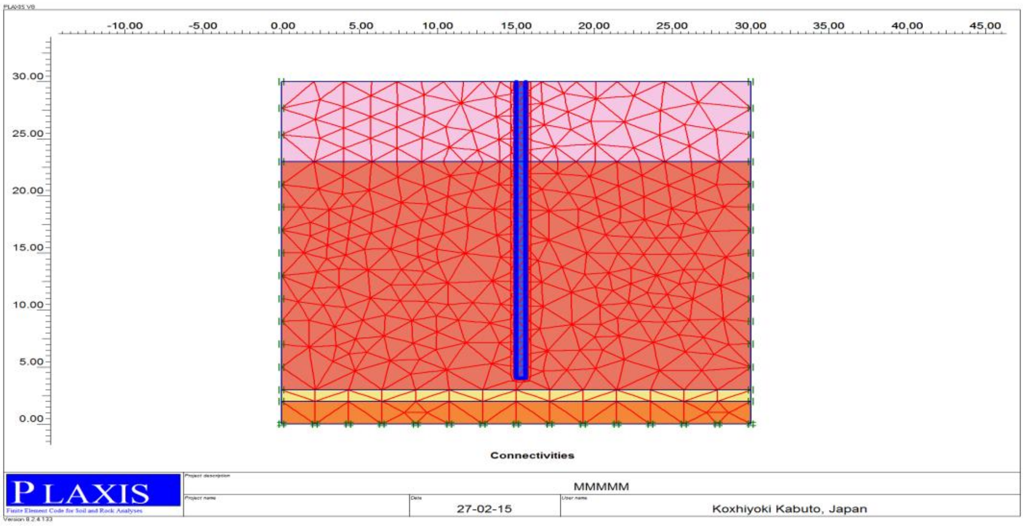

Fig.2. Mesh Generation

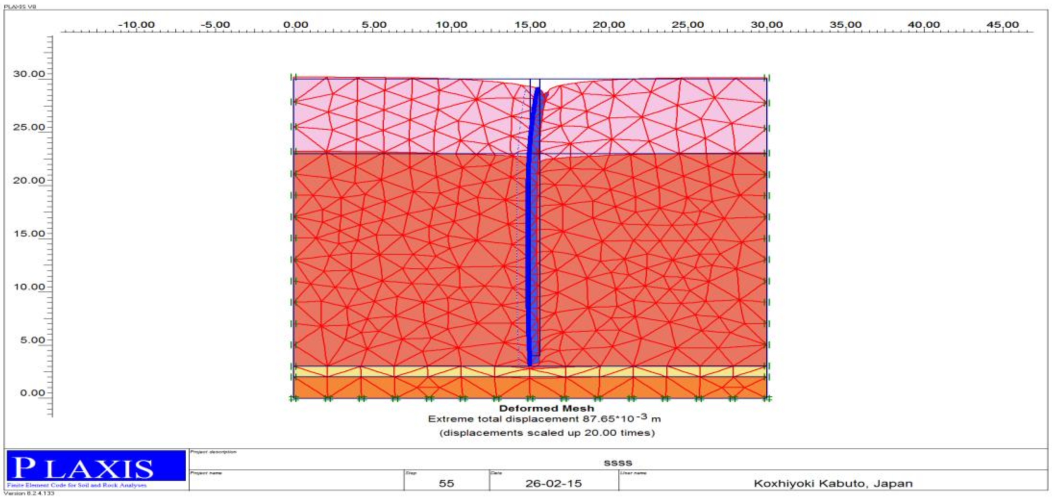

Fig.3. Total Deformation Mesh

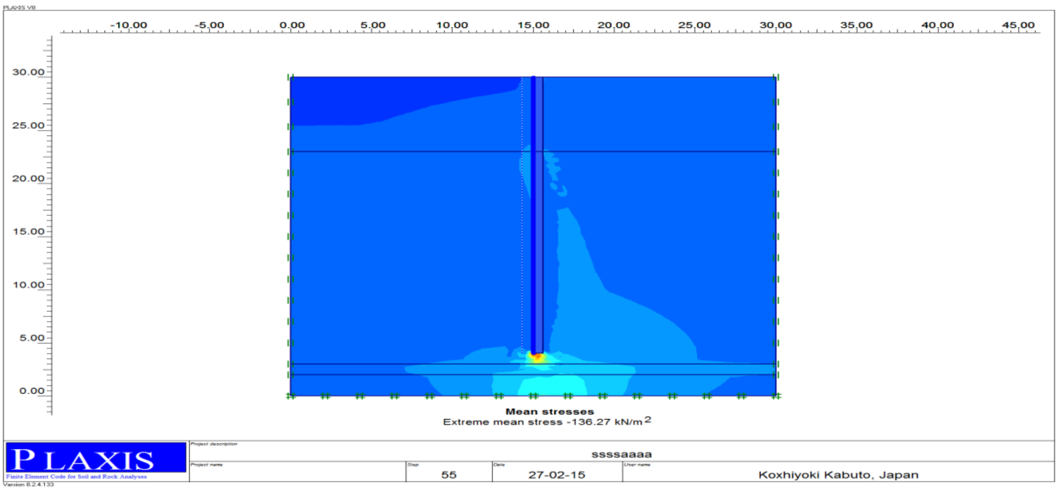

Fig.4. Total Stresses

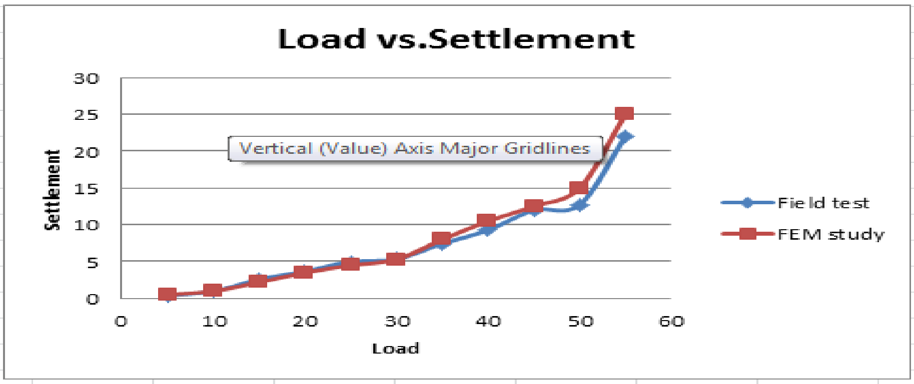

Fig.5. Comparison of Load vs. settlement graph

From Figure above, it is shown that the curve obtained using PLAXIS 2D simulations is close to field test results. This implies that numerical simulation is applicable with the field test by predicting a good results.

The pile bearing capacity can either be estimated by Direct and Indirect methods employing an in-situ tests. The results as estimated are given in table below considering both methods.

Table 2. Bearing Capacity of bored piles (L=26m,D=0.6m)

Borehole	**Bearing capacity methods(k N)**				
	Indirect methods		**Direct methods**		
	Meyerhof(1976)	**Vesic(1977)**	**Aoki and De'Alencar(1975)**	**Bazara and Kurkur(1986)**	**Decourt(1995)**
Borehole1	1521.31	1593.77	1513.43	1844	672.40

Based on this analysis, Bazara and Kurkur prediction is highly overestimating. This is due to ignoring the plug effect in pipe piles that are categorized as low displacement piles in this method .Among the five SPT methods, the prediction by Decourt is conservative.

Statistical and probability approaches were engaged to verify the SPT predictive methods. The log normal distribution can be employed to evaluate the performance of the pile capacity prediction method [5].Probability density function with log normal distribution have been considered to compare different approaches of pile bearing capacity. This distribution was used to evaluate the different methods based on their prediction accuracy and precision. These results indicate that Meyerhof method has a better precision than others in predicting the pile bearing capacity which can be estimated from standard deviation.

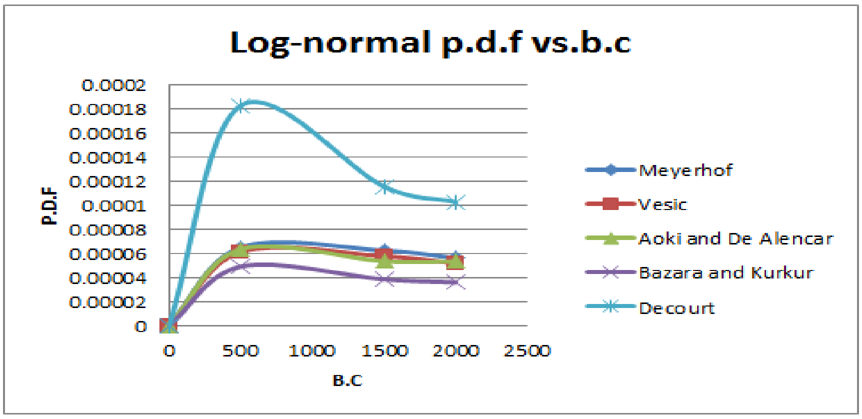

Fig.6. Log-Normal Distribution P.D.F vs Bearing capacity

For a statistical set of data, standard deviation is a measure of the degree of the degree of scattering. The more the standard deviation, the higher is the degree of scattering which indirectly points out to the degree of uncertainty. So, from among the five SPT methods, Bazara and Kurkur[3] has the high degree of scattering as compared to others.

V. 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. Among different common methods, pile load testing can represent reasonable results, but such tests are expensive, time-consuming, and the costs are often difficult to justify for ordinary or small projects. Direct bearing capacity predicting methods for piles are developed based on in-situ testing data, especially SPT and CPT, having applications that have shown an increase in recent years. SPT test is the most frequent in-situ test in geotechnical practice because of its simplicity, easy performance, short time, and low cost.

A comparison of both direct and indirect methods have been employed along with the field test comparison with numerical analyses. The results of the comparison demonstrate that Bazara and Kurkur[3] method has a high degree of scattering as compared to others.

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