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Estimation of Load Carrying Capacity of Bored Cast In-Situ Piles

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ABSTRACT

The estimation of pile capacity by using the static method recommended by the Indian Standard code like IS:2911 (2010) requires referring to a lot of factors through graphs and equations. Hence, it is an inefficient and complicated method to calculate the pile capacity using these conventional factors for feasibility checks. Therefore, there is a need to derive a simpler equation to predict the pile capacity for feasibility study purposes. Consequently, this method would help in the prediction of the pile capacity with some allowable variation.

Keywords: Pile, pile foundation, static method, IS 2911, pile capacity

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[4].Determining the load carrying capacity of piles is an interesting subject in geotechnical engineering[3].Several methods and approaches have been developed to overcome the uncertainty in the prediction. In this study, the static analysis approach was employed to evaluate the load carrying capacity of piles. This approach evaluates the pile capacity by taking a number of theoretical and numerical determinants into consideration.

The two main components responsible for the load carrying capacity of a pile are: (a) the end bearing, which is the point or tip shearing resistance at the base of the tip, and (b) shaft friction, which is the frictional resistance offered by the pile shaft as it tends to move down into the ground due to the load of the structure on the pile head. [1]

NEED OF STUDY

The equations suggested by the Indian Standards to compute the load carrying capacity of the bored cast in-situ pile contain many factors that need to be evaluated either using trigonometric functions or by the use of graphs and tables.

Hence, the process of obtaining the bearing capacity by the recommended Indian Standards is quite tedious though it appears to be simple when considered superficially. There is a clear need for a simplified equation for the same, which ideally would not have any trigonometric functions and nor require the use of any graphs or table. This derived equation will be useful for getting quick estimate of the pile capacity during feasibility studies.

SCOPE OF STUDY

In this research, by varying different parameters of soil, such as cohesion and angle of friction, effects in the variation range of the load carrying capacity of the pile was evaluated based on the static formula provided in the Indian Standards, IS:2911 Part-1 Section-2 (2010)[2] for bored cast in-situ piles.

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After the evaluation of the static formula for different values of cohesion, angle of internal friction, diameter of pile and depth of pile; regression analysis was performed on the results to establish a more simplified link between the ultimate bearing capacity and parameters like cohesion, angle of internal friction, diameter of pile and depth of pile.

The research was conducted for the following pile diameters only 1.0m, 1.2m, 1.5m, 1.8m and 2.0m. *(Since these are the most frequently used pile diameters in the majority of the infrastructure projects.)*

The range of the depth of the pile for analysis used was 10m to 45m. *(As observed from data collection, the average depth of soil layer is 10m and a pile usually goes up to a depth of 45m.)*

The effect of the water table has not been taken into consideration. *(Due to research time restriction.)*

For this study's purpose, the range of the cohesion was taken from 0 to 330 kN/m^2 and the range of the angle of internal friction was taken between 0° to 40°. *(Based on the data collected, the following ranges were selected since they encompass the major spectrum of parameters' values for sandy and silty soil.)*

METHODOLOGY

The study was carried out in four stages.

1. First stage included collection of data from various sources. This collection primarily included collecting soil investigation reports. This was followed by data interpretation in accordance with the stated objectives of the study. Descriptive analytics was then performed to set a range for the values of various parameters.

2. Second stage included evaluation of pile capacity for different parameters and obtaining results in terms of ultimate load carrying capacity, shaft resistance and end resistance. After obtaining the results, the data was analyzed for a further understanding of the impact of various parameters on the ultimate load carrying capacity of the pile.

3. Third stage included identification of a trend amongst the data generated. Regression analysis on the trend was then performed, to derive a more simplified equation for computing the pile load carrying capacity. Then using the same parameters, the newly derived equation was checked for the relative proximity of its value with the value of pile load carrying capacity obtained by the IS method.

4. Final stage encompassed discussion and conclusion of the research conducted. Reliability of the methods under certain conditions was reviewed and new methods for pile design were recommended.

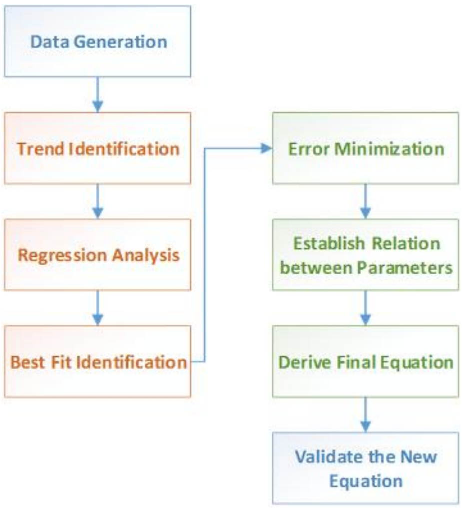

Figure 1: Analysis Methodology

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NOTATIONS

c	Cohesion of soil
¤	Angle of internal friction of soil
¢	Angle of wall friction between pile and soil
D	Diameter of pile
d	Depth of pile
d_c	Critical depth
Q_u	Ultimate bearing capacity of the pile
Q_p	End resistance
Q_s	Shaft resistance
Q_{p_1}	Granular Soil's End-Bearing Resistance
Q_{s_1}	Granular Soil's Shaft Resistance
Q_{p_2}	Cohesive Soil's End-Bearing Resistance
Q_{s_2}	Cohesive Soil's Shaft Resistance
A_p	Cross-sectional area of pile tip
A_s	Surface area of pile shaft
¥	Effective unit weight of the soil
P_D	Effective overburden pressure
K	Coefficient of earth pressure
~	Adhesion factor
£	Error

ANALYSIS

As per the Indian Standard, IS: 2911 Part - 1 Section 2 (2010), the static load carrying capacity equation is provided for the following[5]:

1. Granular Soil
   a. End Resistance (Q_{p_1})
   b. Shaft Resistance (Q_{s_1})
2. Cohesive Soil
   a. End Resistance (Q_{p_2})
   b. Shaft Resistance (Q_{s_2})

Granular Soil's End Resistance

The end bearing capacity (Q_{p_1}) of piles, in kN, in granular soils is given by the following formula:

$$Q_{p_1} = A_p(\tfrac{1}{2} D ¥ N_¥ + P_D N_q)$$

In order to calculate the end resistance, (Q_{p_1}) with the help of above-mentioned equation, numerous calculations are to be undertaken by taking into consideration the factors and graphs recommended in the IS code.

Hence, the above equation takes the form:

$$Q_{p_1} = \frac{® D^2}{4}(\tfrac{1}{2} D ¥ \ [2(\tan^2(45+ ¤/2) e^{® \tan ¤} + 1)\tan ¤] + ¥ d_c/2 \ \tan^2(45+ ¤/2) e^{® \tan ¤}$$

(a) Trend Identification

In order to perform a regression analysis successfully, there was a need to identify a trend in the data first and then proceed with the analysis.

For example, the data for 10m depth was selected and grouped as follows:

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Table 1: End-bearing resistance for Depth = 10m

Angle of Wall Friction (δ) [°]	End-Bearing Resistance (Q_{p1}) [kN]				
	D = 1m	D = 1.2m	D = 1.5m	D = 1.8m	D = 2m
0	123.7	17.81	27.83	40.08	49.48
5	196.7	28.41	44.57	64.45	79.79
10	313.3	45.33	71.34	103.47	128.34
15	503.9	73.03	115.22	167.51	208.11
20	824.9	119.75	189.36	275.91	343.29
25	1386.2	201.55	319.46	466.56	581.38
30	2414.8	351.72	558.91	818.3	1021.34
35	4415.8	644.43	1026.97	1507.71	1885.14
40	8617.7	1260.43	2015.1	2967.53	3717.75

(b) Regression Analysis

Exponential regression was performed on the trend identified in the above table.

A sample of the analysis performed on the data for 1m pile diameter is shown below.

Regression up to 25°

Table 2: Data for Regression up to 25°

Diameter (D) [m]	Angle of Wall Friction (δ) [°]	End Resistance (Q_{p1}) [kN]
1	0	123.7
1	5	196.7
1	10	313.3
1	15	503.9
1	20	824.9
1	25	1386.2

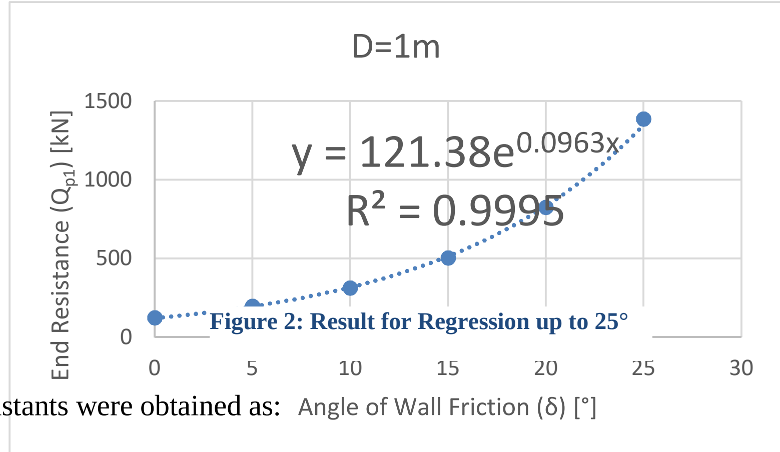


Figure 2: Result for Regression up to 25°

(c) Best Fit Identification

For, 1m diameter pile the regression constants were obtained as:

$$Q_{p_1} = 123.5e^{0.1¤}$$

d = 10m		Original	[kN]	(Q_{p1}) [kN]	Derived (Q_{p1}) [kN]	(Q_{p1}) [kN]						
(D) [m]	(δ) [°]	(Q_{p1}) [kN]	Best Difference	Best Available	Refitted Model 123.5 0.1	Original UBC	Difference [kN]	Difference [%]	Error Corr^{n} [%]	Corrected Model [kN]	C Difference [kN]	C Difference [%]
1	0	123.7	2.32	121.38	123.50	123.7	0.20	0.16	2	125.97	-2.27	-1.84
1	5	196.7	0.25	196.45	203.62	196.7	-6.92	-3.52	-1.86	199.83	-3.13	-1.59
1	10	313.3	-4.66	317.96	335.71	313.3	-22.41	-7.15	-5.04	318.79	-5.49	-1.75
1	15	503.9	-10.72	514.62	553.49	503.9	-49.59	-9.84	-6.94	515.08	-11.18	-2.22
1	20	824.9	-8.01	832.91	912.55	824.9	-87.65	-10.63	-6.96	849.04	-24.14	-2.93
1	25	1386.2	-12.86	1399.06	1504.54	1386.2	-118.34	-8.54	-4.5	1436.83	-50.63	-3.65
1	30	2414.8	-0.32	2415.12	2480.56	2414.8	-65.76	-2.72	1.04	2506.36	-91.56	-3.79
1	35	4415.8	66.34	4349.46	4089.76	4415.8	326.04	7.38	10.26	4509.37	-93.57	-2.12
1	40	8617.7	384.27	8233.43	6742.87	8617.7	1874.83	21.76	23.76	8344.98	272.72	3.16

(d) Establish relation between Parameters

Since the above mentioned equation was obtained for a 10m pile of 1m diameter in soil having 15.75 kN/m^2 density.

The following relation can be established:

$$Q_{p_1} = 123.5\,e^{0.1¤} \times \frac{d}{10} \times \frac{D^2}{1} \times \frac{¥}{15.75}$$

i.e. $Q_{p_1} = 0.785\,e^{0.1¤}\, dD^2¥$

i.e. $Q_{p_1} = \frac{®D^2}{4}(d_c¥\, e^{0.1¤})$

i.e. $Q_{p_1} = A_p(d_c¥\, e^{0.1¤})$

(e) Final Equation

The new simplified equation for Granular Soil's End resistance is:

$Q_{p_1} = .$

where

$$£ = 0.0008¤(¤ + 33)(¤ - 30) + 2$$

(f) Formula Validation

In order to validate the newly derived formula, data was generated against the 12960 cases as per the scope and the difference between the actual resistance and derived resistance was calculated.

Descriptive analytics was performed on this difference to analyse the error range and decide the viability of the new equation.

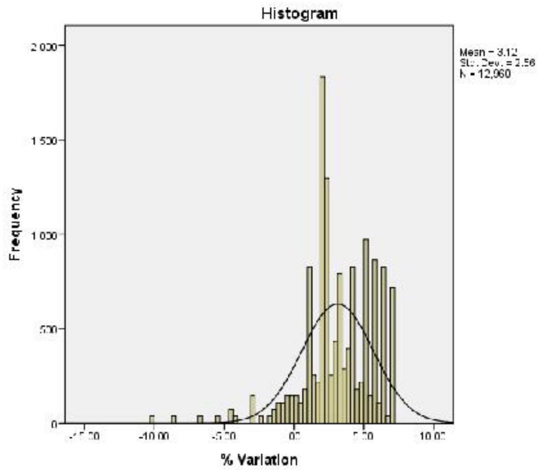
From the analytics performed the following results were obtained.

Table 32: Statistical Analysis for Variation for Q_{p1}

Statistics

% Variation

Sample	Valid	12960
	Missing	0
Mean		3.1225
Median		3.0720
Std. Deviation		2.56039
Skewness		-1.084
Std. Error of Skewness		.022
Range		17.10
Minimum		-10.07
Maximum		7.03



Similar analysis was performed for Granular Soil's Shaft Resistance and Cohesive Soil's Shaft Resistance.

RESULTS

	Original Equation	Derived Equation	-ve Deviation	+ve Deviation
Granular End Bearing	$Q_p = \pi D^2 (\frac{1}{2} D\, \gamma [2(\tan^2(45 + \frac{\phi}{2}) e^{\pi \tan\phi} + 1)\tan\phi] + \gamma d \tan^2(45 + \frac{\phi}{2}) e^{\pi \tan\phi})$	$Q_{p_1} = \frac{\pi D^2}{4}(d_c \gamma\, e^{0.1\phi})(1 + \varepsilon\%)$	-10	7
Cohesive End Bearing	$Q_p = \pi D^2 N_p c_u$	$Q_{p_2} = 9\pi D^2 c_p$	0	0
Granular Skin Friction	$Q_s = (1 - \sin\delta)\gamma d/2 \tan\delta \pi D d$	$Q_{s_1} = A_s P_D \frac{\delta(70 - \delta)}{8000}$	0	4.5
Cohesive Skin Friction	$Q_s = \alpha c_u A_s$	$Q_s = 0.3 c_u A_s$ $c_u \leq 40$ kN/m^2 $Q_s = (0.36 c_u^{0.96}) c_u A_s$ 40 kN/m$^2 < c_u < 150$ kN/m^2 $Q_s = c_u A_s$ $c_u \geq 150$ kN/m^2	-5.7	1

CONCLUSION

As seen from the results there is no need to refer to myriad of factors that need to be evaluated either using trigonometric functions or by the use of graphs and tables unlike the equations recommended by the Indian Standards.

Also, the pile capacity obtained using new simplified equations only has a variation range between -10% (underestimation) to 7% (overestimation) when compared to the pile capacity obtained using IS recommended equations. Hence, they are applicable and can successfully predict the load carrying capacity of a pile, in an easy and quick manner.

This study had been carried out for a particular scope of values of different parameters. However, there is a scope to evaluate the newly derived equations for more exhaustive ranges of parameters for better validation purposes.

REFERENCES

[1] D. Mohan, Pile Foundations. Oxford & IBH Publishing Co. Pvt. Ltd., 1990.

[2] IS:2911 Part-1 Section-2 : Design and Construction of Pile Foundations (Bored Cast In-Situ Concrete Piles). Bureau of Indian Standards, 2010.

[3] I. Shooshpasha and et al., “Prediction of the Axial Bearing Capacity of Piles by SPT-based and Numerical Design Methods,” Int. J. GEOMATE, vol. 4, no. 2, pp. 560–564, 2013.

[4] P. Thounaojam, Sanatombi Sultana, “Prediction of Bearing Capacity of Bored Cast- In Situ Pile,” IOSR J. Mech. Civ. Eng., pp. 01–06, 2015.

[5] P. C. Varghese, Foundation Engineering. Prentice-Hall of India Pvt Ltd, 2005.