ISSN XXXX XXXX © 2018 IJESC

Research Article Volume 8 Issue No.7

A Comparative Study of the Ultimate Pile Load Capacity for Cohesive Soil

Smilukalarikkal[1], Sunil Kumar K[2]
M-Tech Structural Engineering[1], Assistant Professor[2]
Department of Civil Engineering
Sahyadri College of engineering and management Mangalore, India

Abstract:
The calculation of ultimate pile load capacity can be carried out using numerous techniques which include the pile load tests, in-situ penetration tests and also the static and dynamic methods. The difficulties in obtaining un-disturbed samples at the depths of deep foundations make the estimation of soil properties a tedious task and thus the analytical procedures are much relied upon for finding out the ultimate capacities for pile designs. However, the load test data can be used for further validating the statically obtained values and conforming the piles to fall below the estimated values of ultimate capacities. The ultimate pile load capacity from various case studies have been found out, for a general case study and real time projects, using various static methods and compared with each other to find out the approaches that gives the most realistic values of capacities for cohesive soils.

KeyWords: Pile Load, Static method, Dynamic method.

1. INTRODUCTION

A pile carries the load acting on it in the form of frictional resistance contributed by the frictional strength of the soil present along the pile shaft coupled with the pile-soil interactions and by the end bearing resistance attained from the bearing capacity of the hard and less compressible stratum onto which the pile is embedded. Depending on the sub surface conditions in the pile embedment, the behavior of pile also shows considerable variation under the action of load and the factors contributing the strength in each of the above conditions also vary respectively. However it can be seen that the effective over burden pressure and the corresponding bearing capacity factors are the most crucial factors for determining pile capacity in case of piles founded on non-cohesive soils and on the other hand, the values of undrained cohesion and adhesion factors are the deciding factors of ultimate pile capacity determination in the case of cohesive soils.

This paper studies the variation of ultimate pile load capacities as obtained from the various static analysis methods for piles in non cohesive soils and the different underlying approaches considered for estimating the ultimate capacities. The results of the study has been arrived at by considering general and real time case studies of bored cast in-situ concrete piles in non- cohesive soils. For non-cohesive soils, the calculation of ultimate pile load capacity takes into account the characteristics of pile behavior such as the concept of critical depth, where in a linear increase of frictional resistance takes place till the critical depth of pile depending on the internal friction angle as 15d for $\phi \leq 30^o$ and 20d for $\phi \geq 40^o$, where d is the diameter of the pile. The methods considered for the study have been further suited to friction and end bearing piles and they have been compared with each other to draw conclusion on the suitability of the approach and the method on the various ground and piling conditions. The methods have been studied and the various parameters contributing to the calculations have been examined to arrive at the results and comparisons. Several comparisons have been made in this regard on the light of which the variation in the values obtained from the various methods when compared with each other and the results prove useful in finding the suitability of the particular methods to the ground conditions and the adoptability and accuracy of the same. This data could further be used to derive correlations between the values obtained from the soil reports, standard penetration test data and other relevant parameters.

2. LITERATURE REVIEW

[1] BogumilWrana

This paper studied the pile load capacity calculation methods based on Eurocode 7 and explained about the various problems encountered in the calculation of foundation capacity. The calculation of long term pile capacity of non-cohesive and cohesive soils were studied by the use of beta method and alpha method was used for the calculation of short term pile capacity. The study explained in detail the methods used in the calculation of capacity and the relevance of the parameters involved. The study revealed that angle of friction at the tip of the pile and below, angle of dilation of the soil, shear modulus, Poisson's ratio are some of the major parameters affecting the end bearing capacity. Also the relevance of considering the critical depth for calculation of skin friction was explained. The study revealed that the frictional resistance does not remain constant after the critical depth in the light of the experimental results but neither increases linearly till the pile tip but rather there is an increase of skin friction till close to the pile tip and there after a drop in the value is seen. The in-situ penetration tests such as the standard penetration test and the cone penetration test was also discussed in the paper.

[2] Hamid Alielahi

In this paper, different methods that are used for the interpretation of the results from pile load tests have been studied and cross compared with empirical relations for predicting the load capacities. The results were cited based on a case study of ShahidRajaee Port Complex Project in south of Iran and the empirical relations were based on the American Petroleum Institute (API) and American Association for State Highway and Transportation Officials (AASHTO). The proposals of the API and AASHTO were based on the use of undrained parameters in the case of cohesive soils and relative density and SPT-N value in case of cohesionless soil for the estimation of bearing capacity. The results from the study showed that the predictions based on empirical relations were coherent with the experimental data observed from site and the results showed closer coherence in case of piles that were found on cohesionless soils than in case of cohesive soils.

[3] MotsafaAbdou

This study was to estimate the reliability of using the data obtained from standard penetration tests for the prediction of certain soil properties and also shear strength parameters for the case of silty clay with sand soil. The effects of the standard penetration data on the shear strength of soil was also examined under the scope of this study. The determination of real values of soil properties demanded special techniques where by which undisturbed samples could be obtained along with the consideration of the initial over burden pressure. Problems such as disturbances caused during handling, release of excessive over burden pressure, transportation and poor laboratory conditions for the testing of samples added to the difficulties in obtaining accurate values from site conditions were explained in the paper. The study was evaluated based on experimental results from samples collected and correlating the results obtained experimentally with the corrected SPT N values to evaluate the affects of such parameter on the soil properties. The study was able to conclude that depth of the soil below the ground surface and shear strength of soil strongly affect the SPT number where as the Atterberg limits had no affect on the SPT number. Also the shear strength properties could be predicted quite fairly by correlating results from standard penetration test was another conclusion drawn in this paper.

3. METHODOLOGY

3.1 General

The calculation of load carrying capacity by static method uses the principle that the ultimate load carrying capacity of pile is the sum of load carrying capacity of the shaft of pile in friction in cohessionless soils or adhesion in case of cohesive soils. Therefore the ultimate pile load capacity Q_u is obtained as,

$$Q_u = Q_b + Q_f - W_p$$

Where,

Q_b = base (or tip or point) resistance of pile.

Q_f = shaft resistance due to adhesion of friction between the pile shaft and soil.

W_p = weight of pile.

Here the calculation of quantities $Q_b$and Q_f varies from method to method. However in all these approaches pile capacities are basically estimated by the characteristics of soil. The pile capacity is further depend on many factors such as the material and shape of pile, type of soil condition, penetration or installation techniques and so on. Due to the influence of these factors the pile capacities obtained based on these analytical approaches may vary from the values of pile capacity obtained from the field load tests. Hence the variation of about 20% may be considered as permissible change of values.

3.2 Methods

3.2.1 IS Code Method

The Indian Standard Code gives the load carrying capacity of piles through static analysis in

IS 2911(Part 1/Sec 1)-For driven cast in-situ concrete piles.

IS 2911(Part 1/Sec 2)-For bored cast in-situ concrete piles.

IS 2911(Part 1/Sec 3)-For driven pre cast concrete piles.

IS 2911(Part 1/Sec 4)-For precast concrete piles in prebored holes.

According to Annex B, clause 6.3.1.1 and 6.3.2,

The ultimate pile load capacity (Q_u) in kN is,

$$Q_u=A_p\ N_C\ c_P+ \sum_{i=1}^{n} \alpha_i\ c_i A_{si}$$

The first term gives the end-bearing resistance and second term gives the skin friction resistance.

Where,

A_p = cross sectional area of the pile tip, in m^2;

N_C = bearing capacity factor, may be taken as 9;

c_P= average cohesion at the pile tip, in kN/m^2;

$\sum_{i=1}^{n}$ =Summation for layers 1 to n in which pile is installed and which contribute to positive skin friction;

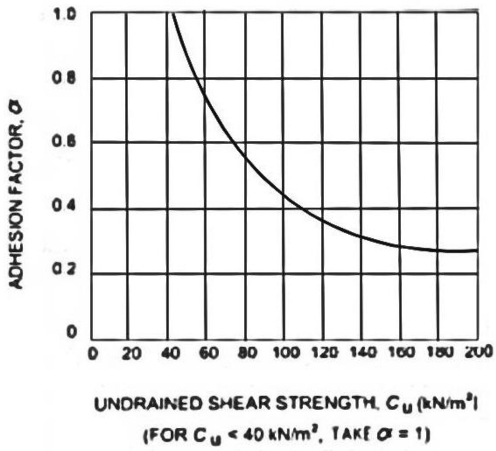

Fig.3.1: Variation of adhesion factor with undrained shear strength

α_i = adhesion factor for the i^{th} layer depending on the consistency of the soil;

c_i= average cohesion for the i^{th} layer, in kN/m^2; and

A_{si}= surface area of the pile shaft in the i^{th} layer, in m^2.

Here, the value of α_i is obtained from Fig 2 of Annex B, IS 2911 and it depends on the undrained shear strength of clay. This method is applicable for both driven and bored piles.

3.2.2. Skin Resistance by α Method:

This method was given by Dennis and Olsen as a simplified approach to problems arising from difference in judgment of soil conditions and wrong interpretations of the geotechnical engineers which often leads to discrepancies in the values of load capacity obtained. They developed a simple curve for finding the relation between the adhesion factor and undrained shear strength of clay. According to this method the ultimate pile load capacity (Q_u) from clay is obtained as,

$$Q_u = c\ N_c A_b + \alpha \bar{c_u} A_s$$

Where,

c= undrained shear strength of clay at the base level;

α =adhesion factor obtained from Dennis and Olson curve;

$\bar{c_u}$ = average undrained shear strength of clay along the shaft;

A_b= cross sectional area of the pile tip, in m^2;

A_s =area of the pile shaft, in m^2;

The Dennis and Olsen curve gives the values of adhesion factor, α for penetrations less than 30 m. The value of α decreases with the increasing depth of penetration beyond 30m as they undergo elastic shortening resulting in small shear strain or slip with greater length. Therefore, it is suggested that for embedment greater than 50m the value of α must be multiplied by a factor of 0.56 and for embedment between 30m and 50m, the reduction factor may be considered to vary linearly from 0.1 to 0.56.

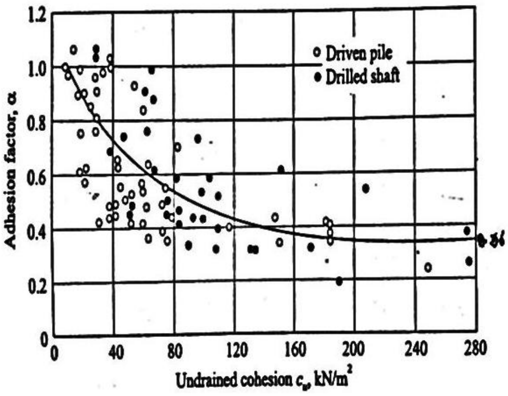

Fig.3.2: Dennis and Olsen's curve for adhesion factor

3.2.3. Effective Stress Method (β Method):

In this method, the unit skin friction f_s is defined as,

$f_s = \overline{K_s}\ \tan\delta\ \overline{q_0'} = \beta\ \overline{q_0'}$

$\beta = \overline{K_s}\ \tan\delta$

$\beta = (1-\sin\phi)\tan\phi$

Where,

$\overline{K_s}$ = lateral earth pressure coefficient.

δ = angle of wall friction.

$\overline{q_0'}$ = average effective overburden pressure.

β = the skin factor.

ϕ = effective angle of internal friction.

3.2.4. Meyerhof's Method:

Meyerhof suggested a simple semi-empirical relationship for determining skin friction in clay soils.

For driven piles:

$f_s = 1.5\ c_u \tan\phi$

For bored piles:

$f_s = c_u \tan\phi$

Note:

*Taking $\phi=20^\circ$ for stiff to very stiff clays,

*$f_s=0.55\ c_u$ (for driven piles)

* $f_s=0.36\ c_u$ (for bored piles)

4. CASE STUDY

4.1 GENERAL CASE STUDY – 1

Table 4.1: Details of Case Study - 1

Types of pile	Bored cast in-situ
Diameter of pile	600mm
Length of pile	20m
Unit weight of soil	18kN/m^3

4.1.1 Results

Table 4.2: Results of Case Study-1

Method	Case Study – 1		
	Base Resistance (Q_b) (kN)	Shaft Resistance (Q_f) (kN)	Ultimate Pile Capacity (Q_u) (kN)
IS Code Method	76.32	1130.97	1207.30
α-Method	76.32	912.13	988.45
β-Method	76.32	1621.42	1697.75
Meyerhof's Method	76.32	411.53	487.86

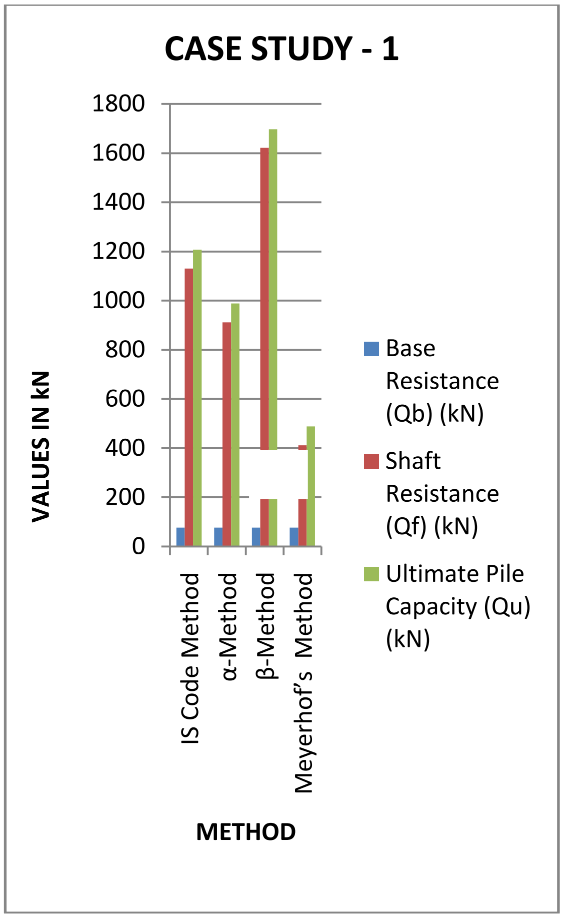

Fig.4.1: Results of Case Study-1

4.2 CASE STUDY 2

Table 4.3: Details of Case Study - 2

Type of structure	Residential building
Project Name	Proposed high rise residential building
Location	Kolkata
Types of pile	Bored cast in-situ
Diameter of pile	1000mm
Length of pile	45m
Unit weight of soil	18kN/m^3

Table 4.4: Details of Case Study - 2

Layer	Types of soil	Depth	SPT N value
Layer 1	clay	10	7
Layer 2	clay	8	17
Layer 3	clay	2	44
Layer 4	clay	5	30
Layer 5	clay	3	22
Layer 6	clay	8	31
Layer 7	clay	2	55
Layer 8	clay	3	40
Layer 8	clay	4	60

Note:

SPT N value at termination depth = 100

Angle of internal friction = 20°

4.2.1 Results

Table 4.5: Results of Case Study-2

Method	Case Study – 2		
	Base Resistance (Q_b) (kN)	Shaft Resistance (Q_f) (kN)	Ultimate Pile Capacity (Q_u) (kN)
IS Code Method	971.92	7081.32	8053.24
α-Method	971.92	6333	7304.92
β-Method	971.92	8210.15	9181.97
Meyerhof's Method	971.92	11793.08	12862

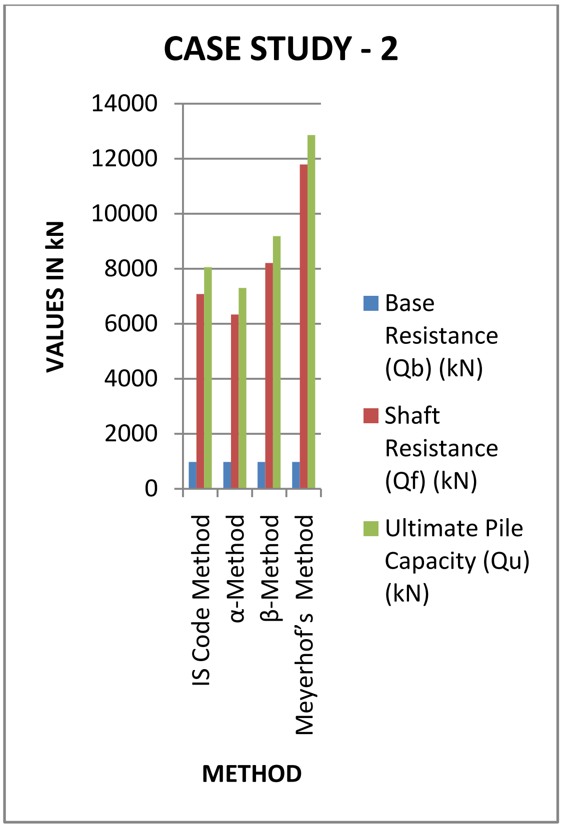

Fig.4.2: Results of Case Study-2

4.3 CASE STUDY – 3

Table 4.6: Details of Case Study - 3

Type of structure	Residential building
Project Name	ORB tower
Location	Noida
Types of pile	Bored cast in-situ
Diameter of pile	100mm
Length of pile	33m
Unit weight of soil	18kN/m^3

Table 4.7: Sub surface conditions for case study - 3

Layer	Types of soil	Depth	SPT N value
Layer 1	clay	12	15
Layer 2	clay	4	25
Layer 3	clay	17	70

Note:
SPT N value at termination depth = 150
Angle of internal friction = 20°

4.3.1 Results

Table 4.8: Results of Case Study-3

Method	Case Study – 3		
	Base Resistance (Q_b) (kN)	Shaft Resistance (Q_f) (kN)	Ultimate Pile Capacity (Q_u) (kN)
IS Code Method	971.92	5053.74	6025.66
α-Method	971.92	5681.30	6653.22
β-Method	971.92	4415.14	5387.12
Meyerhof's Method	971.92	8647.66	9619.58

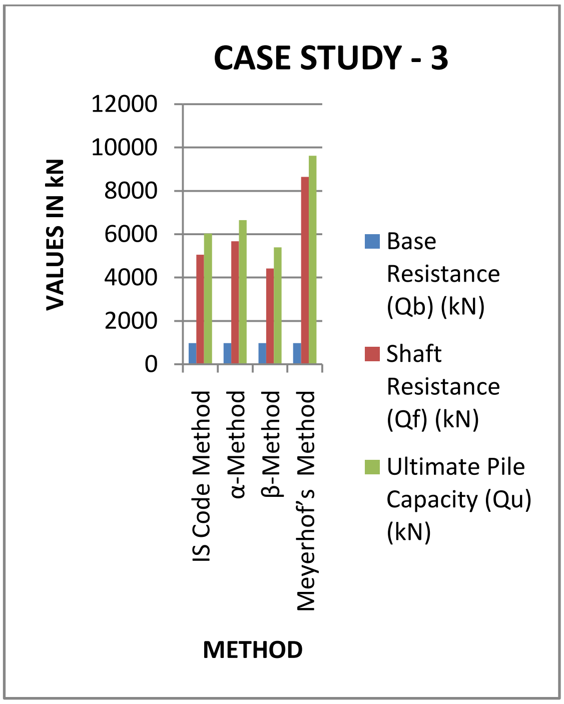

Fig.4.3: Results of Case Study-3

5. COMMENTS

5.1 IS CODE METHOD:

In case of cohesive soils the major contributing factor to the pile capacity is the frictional resistance provided by the soil present in the pile-soil interface. Here, the value of ultimate load capacity is obtained as the sum of the end bearing resistance and frictional resistance and both can be estimated separately using the formula. The major factor in determining the resistance is the value of undrained cohesion and the adhesion factor as suggested by the code in this method. The determination of adhesion factor separately for each of the change in strata increases the accuracy of values as predicted by this method.
The case studies reveal that the values of ultimate capacities as obtained from this method is much in conformity to all the other methods compared in the study and gives a fairly judicious prediction of ultimate load capacity values.

5.2 SKIN RESISTANCE BY α METHOD:

This method varies from the IS method in the value of adhesion factor. Here the value of adhesion factor is obtained from the Dennis and Olsen curve and uses a multiplication factor depending on the range of pile lengths.

From the case studies, it can be seen that the adhesion factor as suggested by this method is obtained from the value of undrained cohesion at the pile tip and hence is more a generalized value compared to the IS code method. However the value of the ultimate load capacity obtained is seen to be close to the values obtained from the IS method.

5.3 EFFECTIVE STRESS METHOD (β METHOD):

This method depends on parameters such as lateral pressure coefficient, skin factor and the friction angles between the soil and pile-soil system for the estimation of ultimate load capacity. The average effective over burden pressure is also a contributing factor to the ultimate frictional resistance by this method.

The case studies reveal a varying pattern in the range of values obtained in this method by sometimes providing the highest of estimated values and sometimes the lowest of ultimate capacities in comparison to the other methods. Due to this fluctuating patterns this method is the least preferred among the rest of the methods.

5.4 MEYERHOF'S METHOD:

This is a highly simplified empirical relationship for estimating the pile capacity with the unit skin friction dependent only on the values of cohesion and the internal friction angle.

However, the case studies reveal a varying pattern in the values obtained by giving both the high end and low end values in different cases and hence isn't preferred as much as the IS method and α method.

Table 5.1: Order of preference of methods for cohesive soils

PREFERENCE NO.	METHOD
1	IS Code Method
2	Skin Resistance by α Method
3	Meyerhof's Method
4	Effective Stress Method (β Method)

6. REFERENCES

[1] BogumilWrana, "Pile Load Capacity – Calculation MethodsStudiaGeotechnicaMechanica, Vol. 37, No. 4, 2015, DOI: 10.1515/sgem-2015-0048

[2] Fatema Sultana[1], NusratKhanum Zinia[2], Farjana Akter[3]& Md. MotiurRahman Khan[4], "Testing and design of a piled foundation Project", Journal of the Southeast Asian Geotechnical Society (2009) 40(3) 129-137.

[3] B. Manjula Devi1[1], Chore H.S[2], V.A.Sawant[3], "Analysis Of Laterally Loaded Pile Groups", IOSR Journal of Civil Engineering (IOSR-JMCE), ISSN: 2278-0661, ISBN: 2278-8727, PP: 60-64.

[4] Thadapaneni Kanakeswararao[1], B.Ganesh[2] "Analysis of Pile Foundation Subjected to Lateral and Vertical Loads", International Journal of Engineering Trends and Technology (IJETT) – Volume-46 Number-2 - April 2017 ISSN: 2231-5381.

[5] IS 2911: PART 1 : Sec 1 : 1979 Driven cast in – situ concrete piles.

[6] IS 2911: PART 1 : Sec 2 : 1979 Bored cast in – situ concrete piles.

[7] IS 2911: PART 4 : 1985 Load test on piles.

[8] IS 14593 - 1998: Bored cast in – situ piles founded on rocks – Guidelines.

[9] BS 8004: Code of practice for foundations.

[10] EN 1997: General rules and ground investigation and testing.

[11] JGJ 94/94: The Chinese limit state design code for building pile foundation.