Capacity estimation of Pile by Numerical modelling

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Abstract:- Estimation of Pile capacity has been one of the major challenging issues for geotechnical engineers in Bangladesh. Although various analytical and empirical methods and codes of practices are available to estimate the axial capacity of piles, the estimation has to be supported by pile load test results. However, in practice, being a costly, time-consuming, and risky approach, the number of pile load tests specified by code of practices is often truncated in many projects. Besides, a rigorous understanding of soil mechanics, local geology, and experiences are needed for the efficacious design of piles. This study focuses on estimation of load capacity and soil settlement for piles using the numerical modeling. A finite element based software, PLAXIS-3D, has been used for modelling of piles, to simulate pile load test for piles in this study. Four piles, having various dimensions and located at different parts of the country, are modelled to estimate load capacities. Those piles capacities are also estimated using different static and dynamic methods to validate the estimated pile capacities using PLAXIS model. For simplicity, for the shake of general practitioners, soils and concrete piles are modeled using Mohr-Coulomb, and Linear-elastic material models. The axial load capacity of the piles are estimated by different commonly practiced methods to determine pile capacity in Bangladesh (α or total stress method, β or effective stress method, λ or semi-empirical method, and BNBC 2020, based on SPT N value). Shear strength parameters of soils beneath and surrounding the pile are estimated based on empirical correlations based on SPT N value. Then, pile load tests are carried out for those Four piles to corroborate the load capacity and settlement values estimated by numerical modeling and other methods. The study shows that results from numerical modeling are agreeable with pile load test results and other commonly used methods. Therefore, numerical modeling of piles, which is easy to accommodate, could help the practicing engineers to design piles confidently and cost-effectively because the load-settlement behavior of all piles of the projects can be simulated using the numerical model. It could also decrease the number of pile load tests required for large projects and thus reduce the cost of the foundation.

***Keywords*:-** *Pile capacity, Pile load test, Numerical modelling, Mohr-Coulomb, Linear-elastic.*

I. INTRODUCTION

Pile have been used as man’s oldest method to overcome the difficulties founding on soft soils (Poulos [1]). Piles are typically used to increase the load-bearing capacity of a foundation and to minimize settlement by transferring loads through a soft stratum to a stiffer stratum at a greater depth or by distributing loads through the stratum via friction along the pile shaft or by a combination of these two mechanisms [2]. Bangladesh is a low-lying deltaic country; about 230 rivers crisscrossed the whole country [3]. Safiullah has described that the distribution of soils in different regions of Bangladesh is complex and usually heterogeneous in both vertical and horizontal directions. Soils in different layers of stratum contain a wide range of materials, from poorly graded sand to silt and clay. In general, silt-sized materials are predominant, and most often, sandy soils contain a significant percentage of mica [4]. Predominantly, the top layers of the soil stratum of the country are high in fine particles. Thus, the bearing capacity of the topsoil layers is low, indicating the necessity of pile foundations for construction works in Bangladesh. Different types of Piles have been used in Bangladesh to combat the difficulties of the low bearing capacity of the soil. Researchers in Bangladesh conducted rigorous studies to estimate the load-bearing capacity of different types of piles. Ansary [10], Abedin [11], Sadek [12], Khan [13], Rahman [14], Morshed [15], Halder [16], Khan [17], Rahman [18] are among many prominent researchers who studied the behavior of different types of piles in Bangladesh. They assessed the applicability of different analytical, empirical, and semi-empirical methods to estimate pile capacities of different kinds of piles in the context of Bangladesh. In addition, different static and dynamic methods were used to find empirical equations for pile capacity approximation. With the advancement in computation, pile capacities are estimated using numerical methods based on the finite element method in many countries. However, to determine the pile capacity, the applicability of the numerical method has not yet been studied in the context of Bangladesh. The scope of this study is limited to assess the applicability of the numerical method to estimate the capacity of piles in Bangladesh. For this study purpose, four locations are selected in different locations of the country, and a total of four piles are constructed at the locations, one at each location. The capacity of the piles is studied using commonly used static and dynamic methods in Bangladesh. Also, pile load tests are performed on the constructed piles to find the practical capacity of the piles. Those piles are also modeled using a finite element-based software (PLAXIS 3D) to simulate the pile load tests. Further, the capacity of the piles estimated from pile models is compared with both pile load test results and commonly used methods used to estimate pile capacity. The formatter will need to create these components, incorporating the applicable criteria that follow.

II. LITERATURE REVIEW

A. Types of Piles

Based on the literature, piles can be classified based on different categories: pile material, method of pile fabrication, amount of ground disturbance during pile installation, method of pile installation into ground, and method of load transfer. [5]. According to the US Army Corps of Engineers manual for Design of Deep Foundations [6] and Das [7], piles can be categorized as conventional steel, concrete, timber, and composite piles based on the material used. The most common types of steel piles are pipe piles and H-section piles. However, Wide-flange and I-section steel beams can also be used as steel piles. Pipe piles can have their ends open or closed when pushed into the earth, but, in many cases, pile piles are filled with concrete after being into the soil (Das [7]). As described in manual [6], timber piles are used for comparatively light axial and lateral loads, but their applicability is limited to judgments that depend on the pile, soil condition, and driving types. The manual [6] has cautioned about using timber piles and recommended that this type of pile be used where the construction procedures ensure that the piles are not damaged by the driving method used; in addition, the piles are not exposed to water because the lifetime of the timber pile is hampered while submerged in groundwater. Again, due to the difficulties in slicing and the effect of insects, the use of timber piles is generally not encouraged. Das [7] has stated that the concrete piles can be divided into precast concrete piles and cast-in-situ piles. Cast-in-situ piles are constructed by making a hole followed by the fill of concrete, with steel casing or without steel casing. Both types of cast-in-situ piles could have a pedestal. Precast piles are prepared with reinforcement and concrete, cased to the desired length, and cured before driving to the projects. Special care is taken for bending stress management during transportation. Precast piles can be square and octagonal in cross-section. Composite piles are made of a combination of different materials: steel and concrete or timber and concrete, placing one at the top and another at the bottom (Das [7]).

Depending on the installation method, Murthy [8], Tomlinson and Woodward [9] classified the types of piles as precast piles, precast cast-in-situ piles, cast-in-situ piles, and continuous flight auger piles. Cast-in-situ piles are constructed at pile locations, and precast piles are used as prefabricated. Continuous auger piles, commonly known as CFA piles, reinforced or without reinforcement, are constructed at the pile location. Continuous flight augers are used to drill to the calculated depth in one continuous process to construct CFA piles.

B. Selection of Pile Types

The Pile capacity is influenced by many factors, some of the factors are: material used, method of installation, surrounded soil characteristics. Every type and method has individual advantages and disadvantages, depending on the purpose of use. Precast and cast-in-situ type concrete piles are mostly used throughout the world because of the availability of materials, longevity, and ease of construction procedure. However, precast piles have some advantages over cast-in-situ piles. Tomek [19] noted that precast piles are time and cost-saving over the conventional cast-in-situ piles. It also brings substantial safety advantages as the quality of precast piles can be maintained, while in case cast-in-situ piles, maintaining concreting quality is always challenging. Dziadziuszko and Sobala [20] also summarized the significant advantages of precast piles. They noted that precast piles are durable and have resistance to aggressive environments; the construction procedure and monitoring of precast piles are simple and can be applied in most types of soils, including organic and contaminated soils. To compare the ultimate load resistance and settlement between cast-in-situ and precast piles embedded in a soil having sand at top layers underneath by clay, which has a comparable stratification in most of the regions of Bangladesh, Raju and Gandhi [21] studied three pairs of precast pile and bored pile of comparable dimensions. The precast piles had a square cross section of 400 mm x 400 mm and the bored cast-in -situ piles had a diameter of 450 mm. The length of all piles was about 22 m, having 6 m penetration in the bearing stiff clay layer. Pile load test was performed and both the precast piles and cast-in-situ piles were loaded till failure. The results show that ultimate resistant of precast piles has significantly higher resistance capacity and lower settlement value than the cast-in-situ piles. The load test results are shown in Fig. 1.

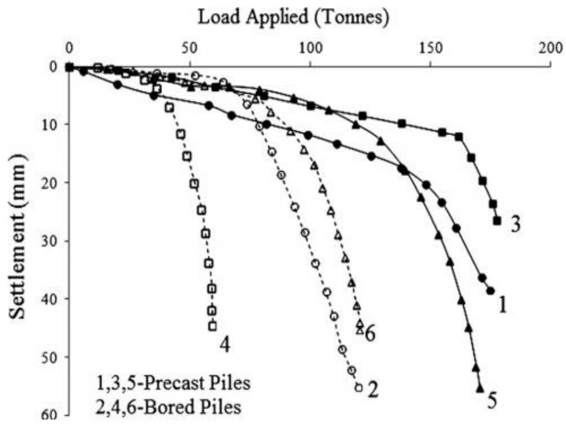

Fig. 1: Comparison of axial load capacity and settlement of precast and cast-in-situ piles [21]

Soil stratification throughout Bangladesh shows the presence of soft and low-bearing capacity soils at top layers. Pile foundation provides the best possible solution to transfer the load to the deeper, harder layers of soil. In Bangladesh, for the foundation for low-cost housing on soft ground, timber piles were used traditionally. This was suitable for modest load and piling depth. However, with the country's development, high-rise building construction has increased, so has the load on the foundation, and cast-in-situ

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and precast piles have been used for load transfer (Ansary [10]). As the quality of precast piles can be maintained better than cast-in-situ piles, the cost is less, an increase of building construction on soft and filled soil, the use of precast piles is increasing in Bangladesh. To estimate the pile capacity of precast piles in different zones of Bangladesh, during the 1990s number of projects were carried out by the Public Works Department (PWD) of Bangladesh under the supervision of the Bangladesh University of Engineering and Technology (BUET). This study focuses on preparing a data set of the capacity of precast piles used in different regions of Bangladesh. Alongside this, the suitability of the numerical method to determine the capacity of precast piles in Bangladesh is also assessed in this study.

III. METHODS OF PILE CAPACITY ESTIMATION

Piles are used to transfer load to soil at greater depth having greater bearing capacity through relatively soft soil. The axial load on pile is transfer in the form of skin friction and end bearing. The ultimate load capacity Q_u of a pile is given by the equation [2, 7],

$$Q_u = Q_s + Q_p \tag{1}$$

Where, Q_p is load carried at the pile point, and Q_s is load carried by skin friction developed at the side of the pile.

End bearing $$Q_p = A_p q_p. \tag{2}$$

Where, A_p = end bearing area of the pile = Cross-sectional area of pile tip (bottom), and q_p = end bearing resistance on unit tip area of pile.

Skin friction $$Q_s = A_s f_s \tag{3}$$

Where, f_s is skin frictional resistance on unit surface area of pile that depends on soil properties and loading conditions (drained or un-drained).

And, A_s = skin friction area (perimeter area) of the pile = Perimeter × Length

For layered soil, $$Q_s = \sum p\Delta Lf \tag{4}$$

Where, p is the perimeter of the pile, f is the unit friction resistance at any depth of the pile, and ΔL is incremental pile length over which p and f is constant.

The load transfer mechanism of Pile is not straightforward. When a load is applied on the Pile, some part of the load is resisted by side friction developed along the Pile's shaft, and the rest of the load is resisted by the soil below the tip of the Pile. However, the maximum frictional resistance of Pile and the maximum tip resistance don't occur at the same condition. Das [7] described that the maximum frictional resistance develops at the relative displacement of the Pile shaft, and the soil becomes 5 to 10mm, not dependent on pile size and length. On the other side, the maximum tip resistance develops at a displacement of 10 to 25% of pile diameter or width, where the lower limit is applicable for Pile. That is, relative to the point resistance, the frictional resistance of the Pile (or the unit skin friction along the pile shaft) develops at a significantly smaller pile displacement. Fig. 2 shows the typical load transfer mechanism of Pile.

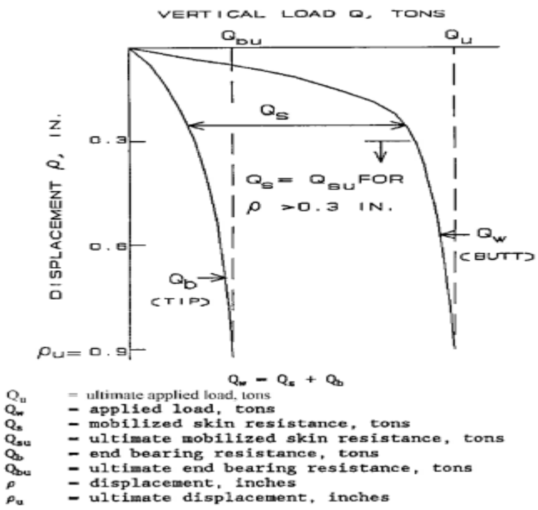

Fig. 2: Axial-load deflection relationship of Pile [6]

Meyerhof [22] suggested that point bearing capacity of a Pile embedded in Sand increases gradually; however, after a critical embedment depth the value remains constant. He proposed equation for estimating point bearing capacity of piles as below:

$$Q_p = A_p q' N_q^* \leq A_p q_l \tag{5}$$

Where, A_p is area of pile tip, N_q^* is the bearing capacity factor; q' is effective vertical stress at the level of the pile tip, q_l is limiting point resistance. The limiting point resistance, $q_l = 0.5\, P_a\, N_q^* \tan \emptyset'$. Fig. 3 shows the variation of N_q^* with soil friction angle $\emptyset'$.

Where, P_a = atmospheric pressure= $100\ kN/m^2$, and $\emptyset'$ is effective soil friction angle of the bearing stratum.

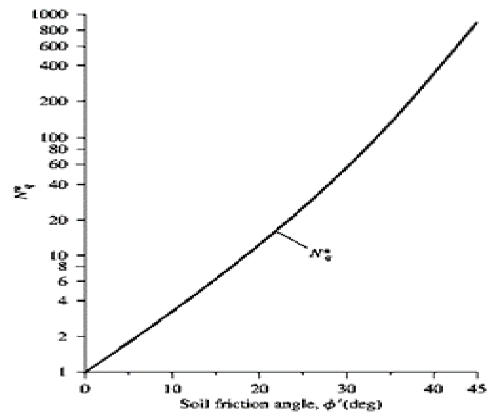

Fig. 3: Variation of N_q^* with soil friction angle $\emptyset'$[22]

In 1981Coyle and Castello [23] studied 24 extensive field load tests and proposed equation for estimating end bearing of driven piles in sand. According to them,

$$Q_p = A_p\, q' N_q^* \qquad (6)$$

Fig. 4 shows the graphical method proposed by them to determine bearing capacity factor, N_q^*

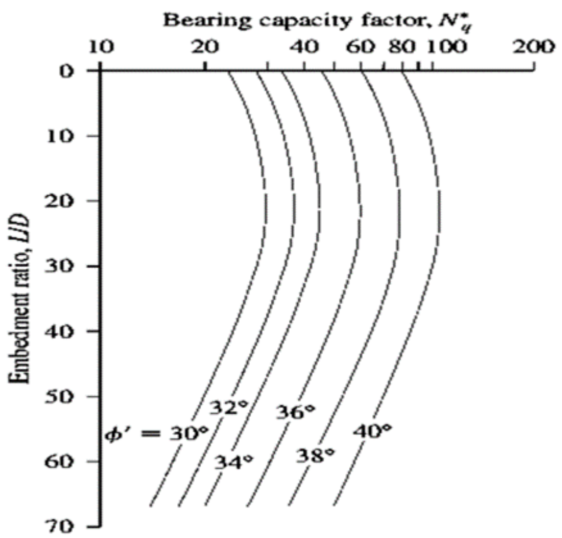

Fig. 4: Variation of $N_q^*$with L/D

Tomilson [28] considered the analogy of bearing capacity estimation of shallow footings and proposed a method for determining end bearing of Pile in Sand.

$$Q_b = A_b\, f_b = A_b\, (\sigma'_v)_b\, (N_q)_b \qquad (7)$$

Where, N_q is a bearing capacity factor that depends on angle of internal friction $\emptyset'$of the soil at the base of the Pile . Subscript "b" designates the parameters at the base soil. He proposed a graphical method to determine bearing capacity factor, N_q , which depends on (L/d) ratio of Pile.

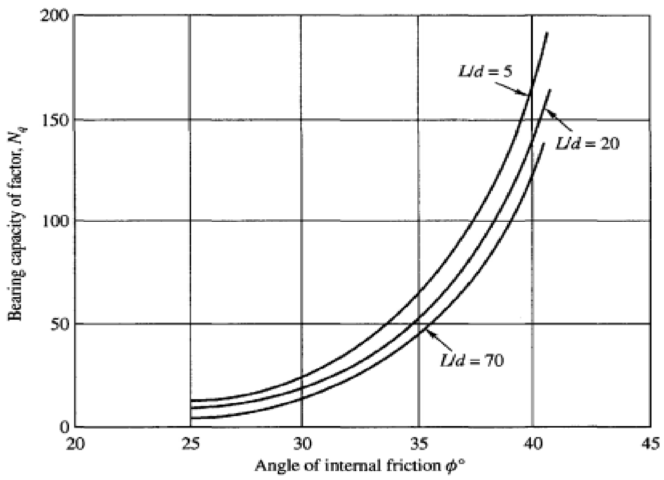

Fig. 5: Bearing capacity factor, N_q for deep foundation [28]

For piles rest on saturated clay, Meyerhof proposed undrained end bearing capacity of pile as,

$$Q_p = 9\, c_u\, A_p \qquad (8)$$

Where, c_u is undrained cohesion of clay below the tip of the Pile. Veisic [24] suggested,

$$Q_p = A_p\, q_p = A_p\, c_u N_c^* \qquad (9)$$

Where, $N_c^* = \frac{4}{3}(\ln I_r + 1) + \frac{\pi}{2} + 1$

O' Neill and Reese [25] suggested the value of I_r as below,

$\frac{c_u}{P_a}$	I_r
0.25	50
0.48	150
$\geq$ 0.96	250-300

Table 1 variation of I_r with c_u of clay

Note: p_a = atmospheric pressure = 100 kN/m^2

Frictional resistance, $Q_s = \sum p\Delta Lf$, Coyle and Castello [23] proposed that,

$$Q_s = K\, \overline{\sigma'_0} \tan(0.8\, \emptyset')\, pL \qquad (10)$$

Where, K can be estimated based on Fig. 5.

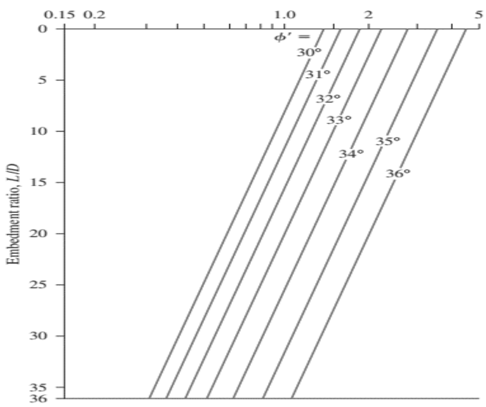

Fig. 6: Variation of K with L/D [23]

Burland [26] developed β method to obtain skin friction from effective stress on the shaft of pile. The friction along the pile shaft is found using Coulomb's friction law, where the friction stress is given by $f_s = \mu\sigma'_x = \emptyset'_x$. The lateral effective stress, $\emptyset'_x$is proportional to vertical effective stress, $\emptyset'_z$ by a co-efficient, K. As such, $f_s = k\sigma'_z \tan \emptyset' = \beta\sigma'_z$

$$\text{Where, } \beta = k \tan\emptyset' = (1-\sin\emptyset')\sqrt{OCR} \qquad (11)$$

Here, $\emptyset'$is the effective angle of internal friction of soil and OCR is the over-consolidation ratio. For normally consolidated clay, β varies from 0.25 to 0.29. The value of β decreases for a very long pile, as such a correction factor is used (Kaniraj [27]), correction factor for β=log $(\frac{180}{L}) \geq 0.5$

The ultimate axial capacity of piles in cohesive soil may be calculated from static formula, given by Equations 1, 2 and 3, using a total stress method for undrained loading conditions, or an effective stress method for drained loading conditions. Appropriate values of adhesion factor (α) and coefficient of horizontal soil stress (k_s) for cohesive soils that are consistent with soil condition and pile installation procedure may be used. The α-method that is based on total stress analysis and is normally used to estimate the short term load capacity of piles embedded in fine grained soils. In this method, a coefficient α is used to relate the un-drained shear strength $C_u$or $S_u$to the adhesive stress (f_s) along the pile shaft. To calculate the skin friction of pile in cohesive soil, Tomlinson [43] proposed that

$$Q_s = \alpha C_u A_s \tag{12}$$

American Petroleum Institute [44] provides the following values to find the skin friction in clay soils.

Adhesion factor	Conditions
$\alpha = 1$	For clays with C_u ≤25 KN/m^2
$\alpha = 0.5$	For clays with C_u ≥70 KN/m^2
$\alpha = (1 - \frac{C_u - 25}{70})$	For clays with 25 KN/m^2≤ C_u ≤70 KN/m^2

Table 2: adhesion factor for piles in clay [44]

The end bearing of pile embedded in clay is estimated as below (Meyerhof [22]):

$$Q_b = (C_u)_b (N_c)_b A_b \tag{13}$$

N_c is a bearing capacity factor and for deep foundation the value is usually 9. C_u is the undrained shear strength of soil at the base of the pile. The suffix b's are indicatives of base of pile. The general equation for N_c is, however, as follows (Skempton [29]).

$$N_c = 6[1+0.2\,(\frac{L}{D_b})] \tag{14}$$

D_b represents the diameter of the pile at base and L is the total length of pile. The skin friction value, $f_b = (C_u)_b (N_c)_b$ should not exceed 4.0 Mpa (Engeling and Reese [30]).

Standard Penetration Test N-value is a measure of consistency of clay soil and indirectly the measure of cohesion. The skin friction of pile can thus be estimated from N-value. The following relation may be used for preliminary design of ultimate capacity of concrete piles in clay soil. According to Meyerhof [22],

For skin friction, $f_s = 1.8\,\bar{N}_{60} \leq$ 70 kPa (15)

For end bearing, $f_b = 45\,N_{60} \leq$ 4000 kPa (16)

Where, $\bar{N}_{60}$ is the average N-value over the pile shaft length and N_{60} is the N-value in the vicinity of pile tip.

Standard Penetration Test N-value is a measure of relative density hence angles of internal friction of cohesion less soil. The skin friction of pile can thus be estimated from N-value. The following relation may be used for ultimate capacity of concrete piles in cohesion less soil and non-plastic silt. For skin friction the relationship is as below (Meyerhof [22]).

For sand, $f_s = 2\bar{N}_{60} \leq 60$ kPa (17)

For non-plastic silt, (18)

$f_s = 1.7\bar{N}_{60} \leq 60$ kPa

For end bearing, the relationship is as below (Mayerhof, [22]).

For sand, $f_b = 40N_{60}(\frac{L}{D}) \leq 400\ N_{60}$ and $\leq 11000 kPa$ (14)

For non-plastic silt, $f_b = 30N_{60}(\frac{L}{D}) \leq 300\ N_{60}$ and $\leq 11000 kPa$ (15)

Where, N_{60} is the N-value in the vicinity of pile tip.

IV. ESTIMATION OF PILE CAPACITY

A. Pile Load Test

Static load tests relied upon an accurate measure of a pile's ultimate resistance. Ultimate resistance is the maximum resistance mobilized by the positive shaft resistance and toe bearing in the soil. Static load testing involves loading the pile statically by placing increments of load and recording settlements as the load is applied following ASTM D1143 [34] . As the pile resistance may set up (resistance increased with time) or relax (resistance decrease with time), static load tests are often performed after some wait period so that equilibrium conditions are re-established .Two principal types of test may be used for compression loading on piles - the constant rate of penetration (CRP) test and the maintained load (ML) test.

Maintained load (ML) test was used in this study. In the ML test the load is increased in stages to 1.5 times or twice the working load with time settlement curve recorded at each stage of loading and unloading. The general procedure is to apply static loads in increments of 25% of the anticipated design load. The ML test may also be taken to failure by progressively increasing the load in stages. In the ML test, the load test arrangements as specified in ASTM D1143 was followed. According to ASTM D1143 [34] each load increment is maintained until the rate of settlement is not greater than 0.25 mm/hr or 2 hours is elapsed, whichever occurs first. After that the next load increment is applied. This procedure was followed for all increments of load. After the completion of loading if the test pile has not failed the total test load is removed any time after twelve hours if the butt settlement over one hour period is not greater than 0.25 mm otherwise the total test load is kept on the pile for 24 hours. After the required holding time, the test load is removed in decrement of 25% of the total test load with 1 hour between decrement. If failure occurs, jacking the pile is continued until the settlement equals 15% of the pile diameter or diagonal dimension.

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B. Load test evaluation methods for axial compressive load

Number of arbitrary or empirical methods are used to serve as criteria for determining the allowable and ultimate load carrying capacity from pile load test. Some are based on maximum permissible gross or net settlement as measured at the pile but while the others are based on the performance of the pile during the progress of testing Chellis [32], Whitaker [35], Poulos and Davis [1] , Fuller [36] . It is recommended to evaluate the load carrying capacity of piles and drilled shaft using any of the following methods along with the arbitrary methods:

(a) Davission Offset Limit
(b) British Standard Institution Criterion
(c) Indian Standard Criteria
(d) Butler-Hoy Criterion
(e) Brinch-Hansen 90% Criterion

The recommended criteria to be used for evaluating the ultimate and allowable load carrying capacity of piles and drilled shaft are summarized below.

- A very useful method of computing the ultimate failure load has been reported by Davisson [37]. This method is based on offset method that defines the failure load. The elastic shortening of the pile, considered as point bearing, free standing column, is computed and plotted on the load-settlement curve, with the elastic shortening line passing through the origin. The slope of the elastic shortening line is 20o. An offset line is drawn parallel to the elastic line. The offset is usually 0.15 inch plus a quake factor, which is a function of pile tip diameter. For normal size piles, this factor is usually taken as 0.1D inch, where D is the diameter of pile in foot. The intersection of offset line with gross load-settlement curve determines the arbitrary ultimate failure load. Davisson method is too restrictive for drilled piles, unless the resistance is primarily friction. This method is recommended for precast piles.
- Terzaghi [38] reported that the ultimate load capacity of a pile may be considered as that load which causes a settlement equal to 10% of the pile diameter. However, this criterion is limited to a case where no definite failure point or trend is indicated by the load-settlement curves. This criterion has been incorporated in BS 8004 "Code of Practice for Foundations" which recommends that the ultimate load capacity of pile should be that which causes the pile to settle a depth of 10% of pile width or diameter.
- The allowable load capacity of pile should be 50% of the final load, which causes the pile to settle a depth of 10% of pile width or diameter (BSI [39])
- Ultimate load capacity of pile is smaller of the following two IS: 2911[40] Part-4:
  - ➢ Load corresponding to a settlement equal to 10% of the pile diameter in the case of normal uniform diameter pile or 7.5% of base diameter in case of under reamed or large diameter cast in-situ pile.
  - ➢ Load corresponding to a settlement of 12 mm.
- Allowable load capacity of pile is smaller of the following IS: 2911[40] Part-4:
  - ➢ Two thirds of the final load at which the total settlement attains a value of 12mm.20
  - ➢ Half of the final load at which total settlement equal to 10% of the pile diameter in the case of normal uniform diameter pile or 7.5% of base diameter in case of under-reamed pile.
- Butler and Hoy [41] states that the intersection of tangent at initial straight portion of the load-settlement curve and the tangent at a slope point of 1.27 mm/ton determines the arbitrary ultimate failure load.
- The Brinch Hansen [42] proposed a definition for ultimate load capacity as that load for which the settlement is twice the settlement under 90 percent of the full test load.
- Where failure occurs, the ultimate load may be taken to calculate the allowable load using a factor of safety of 2.0 to 2.5.

C. Estimation of pile capacity in Bangladesh

Researchers in Bangladesh showed keen interest regarding pile related issues. A number of projects have been carried out in Bangladesh by PWD (Public Works Department, Bangladesh) to estimate the ultimate load capacity of large diameter cast-in-situ piles and pre-cast piles of small and large dimension. Some projects have also been carried out on prestressed pile of small dimension. Load tests were performed on both test and service piles. Majority of the tests were carried out under the full time supervision of BUET (Bangladesh University of Engineering and Technology) consultants. The results of pile load tests have been reported by a number of researchers (Abedin [11], Ansary [10], Sadek [45], Khan[13]. Abedin et al. [11] reported that the small dimension concrete piles are viable alternative to replace the wooden piles that are prone to deterioration in alternative wetting and drying conditions. He also stated that static formula for pile capacity estimation in soft ground is in general conservative. He suggested for further study to generalize the ultimate static capacity of piles in Bangladesh. Ansary et al. [10] summarized the pile load test performed by BUET in different sites of Bangladesh as consultants of PWD between 1996 to 1999. Table 2.4 presents the summary of their pile load test data collection. Sadek [45] studied pile load tests on bored pile at three different sites of Dhaka city and compared them with the existing theoretical results. The variables considered are critical depth, loosening effect of soil and ground water level. But due to lack of sufficient data, Sadek [45] could not draw any correlation between theoretical results and the actual results from the pile load tests. Khan [13] studied the behavior of small size prestressed piles. Pile load tests on prestressed piles were carried out at four sites of Dhaka City. Pile load test results were compared with predicted pile capacities of static and dynamic methods. The measured capacities of piles through Dhaka Clay and resting on Dhaka Clay can be predicted quite well with λ method. On the other hand, α method is only good for predicting the skin friction of Dhaka Clay. Again the measured capacities of pile through Dhaka clay but resting on medium dense sand can be predicted well with a combination of λ and α methods. Khan [13] also observed that the ultimate capacity predicted by pile driving formulae such as Engineering news formula, Janbu formula and Hiley formula overestimate the ultimate pile capacity. Khan [17] has attempted to correlate ultimate pile capacity and settlement from static test data of twenty one precast RCC piles and twenty five RCC cast in situ piles. Similarly, Rahman [14] verified axial load capacity of cast in situ piles with static load test in stiff Dhaka clay. Prediction of load deformation behavior of axially loaded piles in sand was also done by Morshed [15]. Rahman [18] has studied performance of eight methods based on cone penetration test (CPT) for predicting the ultimate load carrying capacity of square precast RC concrete piles. Halder [16] considered application of dynamic load test in Bangladesh at several locations.

V. NUMERICAL MODELING OF PILE

Pile load test can be simulated in finite element based programs. In this study, PLAXIS 3D software was used to simulate Pile.

A. Defining Geometry

The soil layers are defined according to the soil investigation reports and laboratory investigation results. In this study, the Mohr-Coulomb model was used to define soil properties.

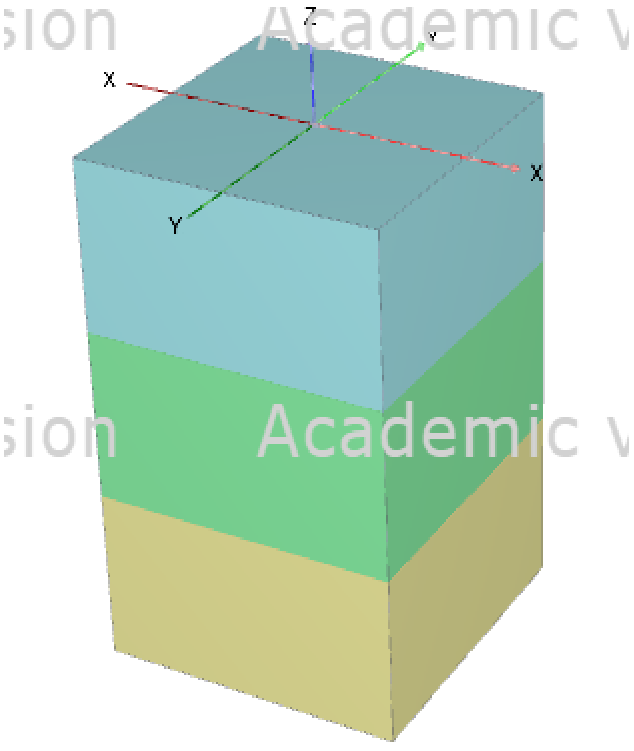

Fig. 7: Creation of sub-soil strata in PLAXIS software

B. Creation of Pile Structure and Meshing

After defining the soil layers concrete pile is defined as elastic material and interface is created between Pile and soil layers. Load is defined in structured mode which can be activated and intensity can be varied in different phases of analysis.

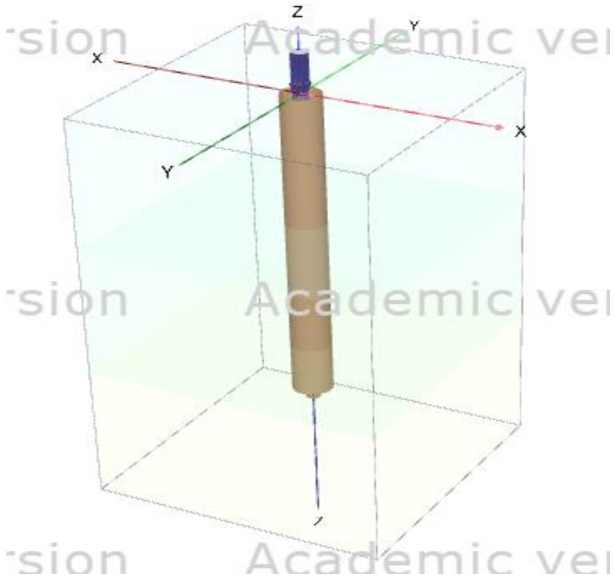

Fig. 8: Creation of Pile stucture

Then meshing is executed before staged construction phase. In this study medium mesh size was used for analysis.

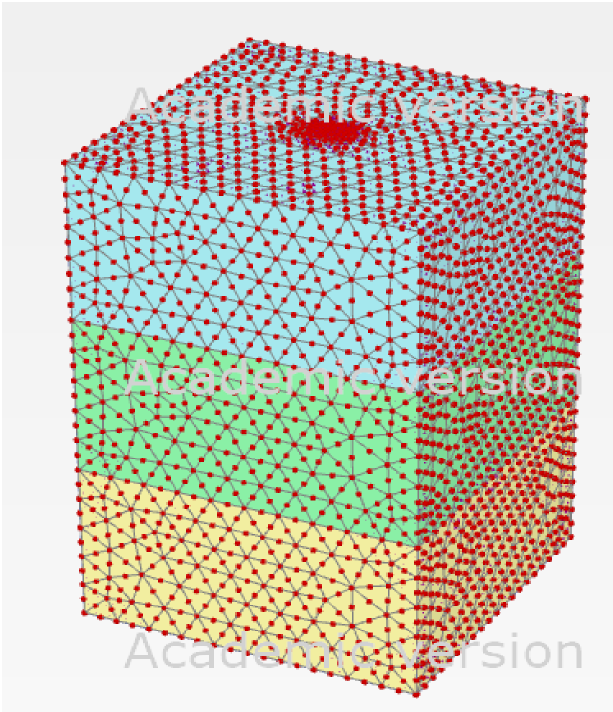

Fig. 9: Typical mesh connectivity

C. Geotechnical parameters

For numerical analysis total four piles, at different locations of Bangladesh, were selected. Properties of soil and pile material is presented in Table 3 presents the sample of sub-soil properties and Table 4 presents the properties of Pile material.,

Table 3 : Properties of soil at Jamiatul Falah Masjid, Chittagong

Pile ID	Project Name	Soil Type	Material model	Thickness (m)	SPT N value	Unit weight (γ) (kN/m^3)	Void ratio (e)	C_u (kPa)	Φ'(°)	G_{max} (MPa)
CTP 03	Jamiatul Falah Masjid, Chittagong	Clay	Mohr-Coulomb	3	6	15	0.8	24.5		33
		Sandy Silt	Mohr-Coulomb	2	9	16	0.7	-	36	58
		Silty Sand	Mohr-Coulomb	3	25	17	0.67	-	40	138
		Sand	Mohr-Coulomb	12	45	19	0.5	-	45	225

Table 4 Properties of Pile material

Material Name	Material model	γ_{sat} (kN/m^3)	γ_{unsat} (kN/m^3)	E_{ref} (kN/m^2)	ν
Pile	Linear elastic	25	25	30e6	0.3

D. Simulation of Pile load test

In Pile load test in field, 200% load is applied with 25% increment and settlement is observed. Then from load-settlement graph Pile capacity estimated using different methods. In numerical analysis load can be applied on pile in small increment to identify load-settlement curve more preciously. Fig. 10 shows the possible load increment steps for a pile of 2500kN estimated allowable load.

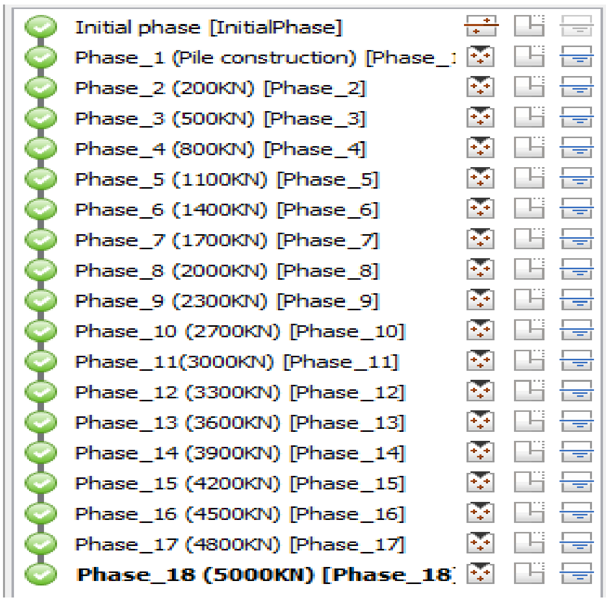

Fig. 10: Application of load on Pile in different stages

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The Pile behavior is observed (plastic analysis) after the completion of analysis for a predefined time period. Fig. 11 shows the settlement result of the Pile after a particular load application.

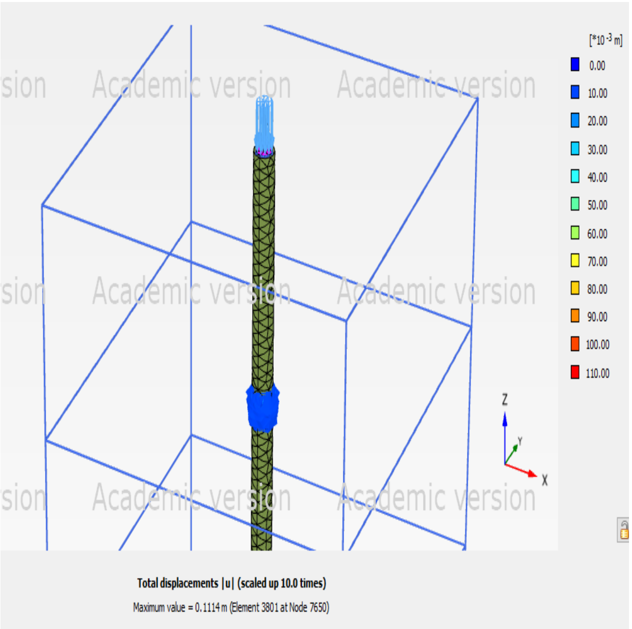

Fig. 11: Settlement of Pile due to the application of load

Then, load vs settlement graph is plotted for every load increament to identify capacity of the Pile.

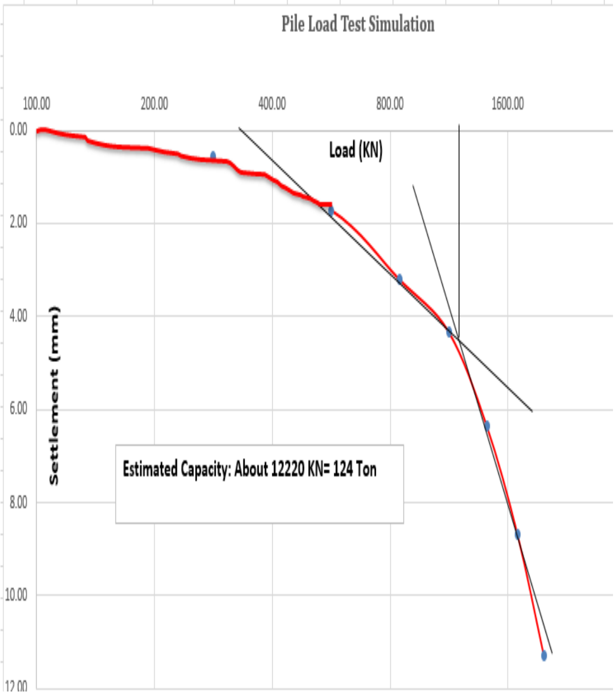

Fig. 12: Estimated Pile capacity based on PLAXIS model result (Location: Chittagong Islamic Center, Pile ID: CTP03)

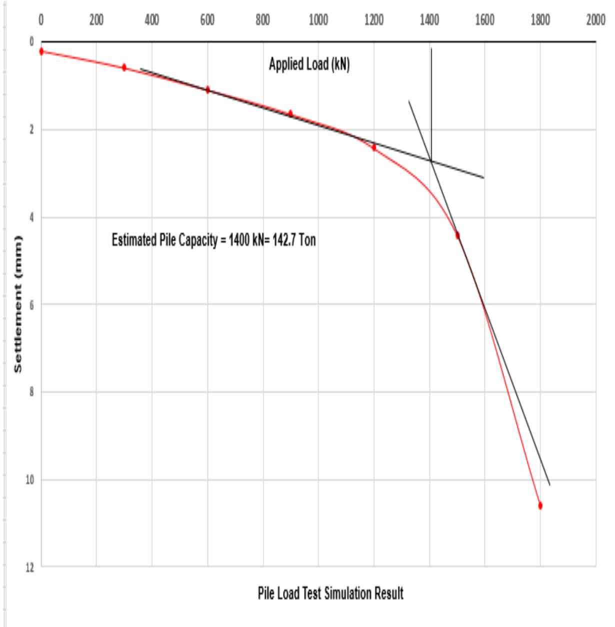

Fig. 12: Estimated Pile capacity based on PLAXIS model result (Location: RDA Bhaban, Raishahi, Pile ID: PTP02)

Table 5 presents the result of Pile capacity estimation by static method, Pile load test method, and numerical analysis in finite element method. From the result it is clear that regardless of method of estimation, ultimate pile capacity estimated based on field load test is very close. Whereas, the static methods over estimates the ultimate load capacity. Ultimate load capacity estimation based on finite element method slightly overestimates the capacity than the field test method but the model result gives more realistic result than the static methods.

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Table 5: Calculation of Pile capacity in different methods

Pile ID	Project Name	Pile Length, Size	Ultimate Pile Capacity from Pile Load Test				Ultimate Pile Capacity from Static Analysis (Ton)				Pile Capacity from PLAXIS Analysis (Ton)
		Length(m) and size (mmxmm)	Davisson	Butler and Hoy	British Standard	Average	α method	β method	λ method	Average	
CTP 03	Jamiatul Falah Masjid, Chittagong	L= 12m; D= 00mm	122	112	115	116	149	147	151	149	124
CTP 24	Divisional Public Library, Sylhet	L=14m; D= 50mm	120	115	125	120	114	113	115	114	124
PTP 02	RDA Bhaban, Rajshahi	L=10.67m; Size= 300mmx300mm	110	103	120	111	102	97	112	101.3	142
PTP-14	Imam Training Centre, Khulna	L=15.5m; Size= 350mmx350mm	109	100	115	108	176	156	181	171	120

VI. CONCLUSION AND RECOMMENDATION

Pile is used as a mode of foundation where the soil condition is poor to support load with shallow foundations. However, estimation of Pile capacity is a great concern for geotechnical engineers. Although there are numerous static and dynamic methods available to estimate ultimate Pile capacity, the estimated values differ significantly from one method to another method. Nowadays, with the improvement of computational facilities numerical methods are playing vital rules to solve complex geotechnical engineering problems. The use of finite element method to estimate ultimate pile capacity was assessed in this study. The results show competence of finite element method for predicting ultimate pile capacity. In some cases, PLAXIS 3D, the finite element program shows better result than static methods. Arranging pile load test is challenging and time consuming. As finite element method can mimic the field load test of pile it can be used to reduce the number of piles to be tested in real projects.

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