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A SIMPLIFIED NUMERICAL APPROACH TO PREDICT BEARING CAPACITY OF SOIL FOR SHALLOW FOUNDATION

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ABSTRACT:

For the safe and economical design of a foundation under any civil engineering structure, precise estimation of the ultimate bearing capacity (UCB) of soil beneath the foundation is of significant concern. Numerous researchers have contributed to these field and proposed theories and equations to predict the subsoil's ultimate bearing capacity. But determining the approximate value of bearing capacity depends on soil type and its characteristics, groundwater table, types of loads, loaded area of footing, depth of footing, etc. Moreover, deciding the appropriate depth and size of footing is a crucial task. This paper aims to propose a simplified numerical approach to predict the bearing capacity of soil beneath the foundation (NABBSF) using MATLAB software. Considering shear failure and excessive settlement criteria, this model will predict the ultimate, safe, and allowable soil bearing capacity beneath an isolated footing at different depths. The validity and accuracy of the proposed model is verified by comparing it with real field data.

1. INTRODUCTION

The maximum paper length is restricted to 10 pages. Invited papers can be increased to 14 pages. The paper should have the following structure:

In developing countries like India, the increasing demand for infrastructure requires immense steps of planning, analysis & design, and cost estimation of the proposed engineering structure. The acquisition of subsoil information to recognize the bearing potential of underlying soil is regarded as a key parameter of the engineering structure design since the desirable size of the foundation depends primarily on the ability of soil bearing. Bearing capacity is the soil's ability that protects the underlying soil to cause shear failure or excessive settlement against external pressures from the structures. However, assessing the soil bearing capacity of the underlying soil requires a considerable challenge. Two approaches exist to address the issue of bearing capacity: using plasticity theory or finite element methodology and using laboratory model testing. In earlier times, Karl Terzaghi has presented a general theory for determining ultimate bearing capacity (UCB) for a shallow strip footing (Terzaghi, 1943). The proposed equation of bearing capacity of Terzaghi is based on the soil plasticity theory of Prandtl, 1921. Since Terzaghi's equation is only applicable to strip footing and useful for general shear failure alone, many researchers like Meyerhof (Meyerhof, 1951), Brinch Hansen (Brinch Hansen, 1970), Vesic (Vesic, 1973), Skempton (Skempton & Skempton, 1984) has contributed in this field and proposed modification. Meyerhof (Meyerhof, 1953) and Brinch Hansen (Brinch Hansen, 1970) have redesigned the equation proposed by Terzaghi and introduced new correction factors for the shape & depth of the footing and inclined load. Skempton (Skempton & Skempton, 1984) have derived an equation of bearing capacity applicable for cohesive soils only. Meyerhof has also studied the effect of eccentricity and inclination of load in 1963 (Meyerhof, 1963). Simple formulae have been proposed for bearing capacity of spread foundation applicable in the design of rigid and flexible foundations. The UBC equation, according to Meyerhof (Meyerhof, 1963), can be written as:

$$Q_{ult} = c\, N_c\, S_c\, d_c\, i_c + \gamma\, D_f\, N_q\, S_q\, d_q\, i_q + 0.5\, \gamma\, B\, N_\gamma\, S_\gamma\, d_\gamma\, i_\gamma \quad \text{(i)}$$

Where, Df = depth of foundation; B = width of footing; γ = unit weight of soil; Nc, Nq, Nγ = bearing capacity factors measured for the respective value of angle of internal friction (ϕ); Sc, Sq, Sγ = shape factors; dc, dq, dγ = depth factors; ic, iq, iγ = inclination factors; c= cohesion.

Meyerhof and Hanna in 1978 (Meyerhof & Hanna, 1978) has investigated UCB of shallow circular and strip footing resting on layered soil and studied different modes of soil failure. Based on the recommendations of (Meyerhof, 1951) and (Brinch Hansen, 1970), two general equations of net ultimate bearing capacity (q_{un}) are presented by BIS code: IS 6403-1981

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(IS:6403-1981, 1981) applicable for general shear failure and local shear failure separately:

For general share failure, $Q_{un} = c\ N_c\ S_c\ d_c\ i_c + \gamma\ D_f\ (N_q\text{-}1)\ S_q\ d_q\ i_q + 0.5\ \gamma\ B\ N_\gamma\ S_\gamma\ d_\gamma\ i_\gamma\ W'$ (ii)

For local share failure, $Q_{un} = \frac{2}{3}\ c\ N_c'\ S_c\ d_c\ i_c + \gamma\ D_f\ (N_q'\text{-}1)\ S_q\ d_q\ i_q + 0.5\ \gamma\ B\ N_\gamma'\ S_\gamma\ d_\gamma\ i_\gamma\ W'$ (iii)

Where, $\mathbf{W'}$ = water table correction factor; $\mathbf{N_c'}$, $\mathbf{N_q'}$, $\mathbf{N_\gamma'}$ = bearing capacity factors calculate for the respective value of $\phi' = \tan^{-1}(0.67\tan\phi)$.

So far, numerous works related to numerical analysis of soil bearing potential issue can be found. (Cherubini 2000) have proposed a possible application of probabilistic methods to study shallow foundations reliability concerning their bearing capacity. (Kawa and Puła 2019, Das et al., 2021; Hinge et al., 2021)) has examined a three-dimensional model analysis of load bearing capacity of square and strip footing considering a rigid type of foundation with smooth surface and it has been found that three-dimensional model analyses is suitable for strip footing problem. The effect of interaction between closely spaced square footings resting on granular soil on their bearing capacity has also been studied by Fuentes et al. using three-dimensional boundary value problems constructed with the software Abaqus standard (Fuentes et al. 2019). Chwala and Pula in 2020 also have presented a probabilistic approach for evaluation of bearing capacity of surface footing applicable for two-layered soil (Chwała and Puła 2020). (Gupta and Mital 2021) have used PLAXIS 3D to study load- settlement behavior of eccentrically inclined loaded rectangular foundation on unreinforced and geo-grid reinforced sand. A numerical analysis was performed using MATLAB software by Mahdi O. Karkush, Mahmood D. Ahmed et.al. to produce thematic maps with coordinates and depths for the bearing capacity variation of the soil considering 135 borehole data (Karkush et al. 2020) and

Researchers also studied soil bearing capacity under strip and circular footings using numerical approach (Dash, Sireesh, and Sitharam 2003). In the present study, different share failure conditions and permissible settlement criteria are also taken into account to study the soil bearing potential of isolated square foundation. In practice, the first bearing capacity for a particular footing is determined based on the BIS code's recommendation (IS:6403-1981 1981a). A check must then be done to verify whether the settlement may cause by the input bearing pressure within the permissible limit or not (of Indian Standards 1976). For settlement calculation, the pressure bulb is considered to be extended up to a depth twice the width of the foundation.

2. AIM AND OBJECTIVE

Prediction of ultimate and safe bearing capacity of soil beneath a footing may vary in the field as it depends on many factors such as type of subsoil and its characteristics, ground water level and drainage condition, the magnitude and direction of the load acting on the footing etc. The depth and size of footing also affect the bearing capacity of the subsoil. Moreover, a footing may fail due to shear failure or differential settlement. Hence, we need to insure that the design foundation is safe against shear failure as well as excessive settlement. All these factors make an approximate estimation of the bearing capacity of the subsoil as delicate and time-consuming. In the present study, all the governing equations are summarized accepted by the BIS code (IS:6403-1981 1981b). All the factors affecting the process of predicting the ultimate, safe, and allowable bearing capacity of soil beneath a footing and prepare a numerical model to calculate the bearing capacity of soil for an isolated footing at different depths below ground level (NABBSF).

3. METHODOLOGY

This paper aims to estimate the ultimate bearing capacity of subsoil for an isolated footing using a simplified mathematical model that can be used to evaluate ultimate and safe bearing capacity for an isolated shallow foundation at any given depth below ground level. The equations (ii) & (iii) are joined together by introducing new parameters, K1 and K2, to simplify the mathematical code. These two parameters (K1 and K2) are selected as multiplying constant for the equation of ultimate bearing capacity of subsoil for general share failure case and local share failure case, respectively. Values of K1 and K2 for different failure condition are:

i. For general share failure condition, K1 = 1 and K2 = 0

ii. For local share failure condition, K1 = 0 and K2 = 1

iii. For transition zone between local and general share failure condition, K1 = K2 = 0.5

For the present work, at each depth level, we have considered six virtual footings of sizes (0.5× 0.5 m, 1.0 × 1.0 m, 1.5 × 1.5 m, 2.0 × 2.0 m, 2.5 × 2.5 m, and 3.0 × 3.0 m.) and ultimate and safe bearing capacity will be calculated considering shear criteria as per the recommendation of (IS:6403-1981 1981b). Moreover, for a particular footing size, assuming that the pressure bulb for significantly stressed zone extended up to a depth of two times the width of footing, the expected settlement is calculated (Indian Standards 1976). MATLAB software is used for framing the numerical model for the prediction of the bearing capacity of subsoil based on the shear and settlement criteria. The detailed methodology of the process is represented in the form of a flowchart in figure1. For stability and accuracy, the model is verified by considering real field data.

4. ALGORITHM OF THE MODEL "NABBSF"

Considering length unit as meter and force unit as KN, the algorithm of the model (NABBSF) is as follows:

Initialization: Depth of foundation, Do = 0.5 m and varies as Dn = Dn-1 + 0.5 till maximum value of Dn = 3m. Width of foundation, Bo = 0.5 m and varies as Bn = Bn-1 + 0.5 till maximum value of Bn = 3m. Length of foundation, Lo = Bo and varies as Ln = Bn (assuming square footing).

Input parameters into the model: Soil cohesion (c), angle of shearing resistance (Ø), load inclination angle (α), bulk unit weight of soil (γ), unit weight of water (γ_w), effective unit weight of soil (γ/), depth of water table from the ground (D_w), natural moisture content (w), the specific gravity of soil solids (G), degree of saturation (S_r), compression index (C_c)

permissible settlement in mm (S_L), bearing capacity factors (Nc, Nq, Nγ), the factor of safety (F).

The general expression of ultimate bearing capacity recommended by Bureau of Indian Standard code has been modified considering general and local shear failure in the present work.

Q_{ult} = K1 (c Nc Sc dc ic + γ/ Df Nq Sq dq iq + 0.5 γ B Nγ Sγ dγ iγ W/) +K2 (0.67 c Nc/ Sc dc/ ic + γ/ Df Nq/ Sq dq/ iq + 0.5 γ B Nγ/ Sγ dγ/ iγ W/) (iv)

K1 and K2 are two arbitrary constant, and their values depend on the types of shear failure.

For general shear failure (ϕ > 36°): K1 = 1 and K2 = 0
For local shear failure (ϕ < 29°): K1 = 0 and K2 = 1
And for the transition zone (29° < ϕ < 36°): K1 = 0.5 and K2 = 0.5.

The Proposed System Flowchart for "NABBSF" is presented in figure 1.

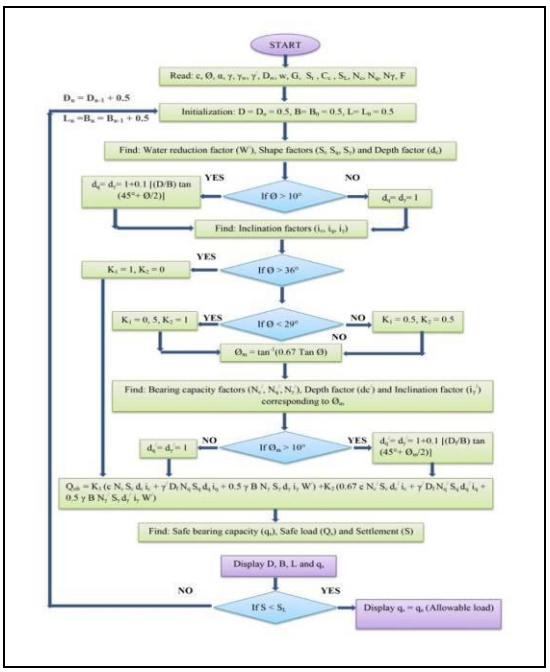


Figure 1. System flowchart

5. MODEL IMPLEMENTATION AND OBSERVATION

The proposed numerical model can be utilized to precisely estimate the safe bearing capacity of soil beneath any shallow foundation effortlessly as per the standard norms (IS: 6403-1981). The model can also estimate the approximate amount of settlement that may cause by the load calculated from the shear criteria (IS 8009-1, 1976). To check the proposed model's validity and accuracy, it is compared with a real field geotechnical survey data. All the input parameters are adopted from real field data.

Geotechnical survey data: A target site near the Noonmati region of Guwahati City was selected for the geotechnical investigation to verify the proposed model's accuracy. The subsurface investigation procedure was followed as per the BIS code specification (IS: 1892-1979). The composite program comprises both field and laboratory tests in accordance with the relevant BIS code of practice. The traditional penetration test method (IS: 2131-1981 1981) was used to collect disturbed as well as undisturbed soil samples from a borehole at different depth interval up to 15 m from the natural ground surface to obtain the underlying soil profile, and necessary laboratory test are also conducted to determine index properties and strength parameters of soil at different depth.

Field investigation: Field investigation consisted of vertical boring in one location covering the plot's proposed area. The soil stratification is represented in the borehole logs in Table 1.

Type: Manual Boring	G.W.L = 1.9 m	
Description	Depth (m)	N-value
Filled up soil with brick bats etc. from G.L. up to 1.4m.		
Bluish silty clay with trace of sand from 1.4m up to 1.8m.	-1.5	05
Bluish clayey silty sand from 1.8m up to 2.5m.	-3.0	02
Bluish silty clay from 2.5m up to 4.2m.	-4.5	01
Bluish sandy clay from 4.2m up to 7.3m.	-6.0	04
Bluish silty clay from 7.3m up to 8.7m.	-7.5	09
Grayish silty clay from 8.7m up to 10.2m.	-9.0	18
Bluish sandy clay from 10.2m up to 11.5m.	-10.5	13
Grayish silty clay from 11.5m up to 13.2m.	-12.0	22
Bluish sandy clay from 13.2m up to 14.5m.	-13.5	12
Blackish silty clay from 14.5m up to 15m.	-15.0	10

Table 1. Bore log information

Laboratory Investigation: Selected soil samples were analysed in the soil laboratory. The main objectives of laboratory analysis were to identify the subsoil's physical properties and shear properties. Accordingly, for the determination of physical properties of soil following tests was carried out:

i. Grain size distribution analysis, (IS:2720 (Part 4) 1985).

ii. In-situ moisture content determination, (w) (IS:2720-Part 2 1973).

iii. In-situ bulk density determination, (γ) (BIS 1974).

iv. Determination of specific gravity of soil solids, (G) (IS:2720-3-2 1980).

v. Determination of liquid limit and plastic limit of soil.(IS: 2720 (part 5) 1985).

To determine the shear properties of soil depending upon the soil drainage and loading conditions, following tests were performed:

i. Unconfined compression test, (UC)(IS: 2720 (Part 10) 1991).

ii. Consolidated drained tri-axial test, (CD) (ASTM International 2011) and,

iii. Direct shear test (BIS 1986).

From field and laboratory test results, the soil information used in the proposed numerical model are as follows:

Soil layer 1(From the existing ground level up to 1.5 m): Cohesion (c) and angle of internal friction (ϕ) = neglected, γ = 16.0 KN/m3 (filled up soil + loose bearing strata)

Soil layer 2 (From 1.5 m to 5.5 m):
c = 22.00 KN/m2 (BIS 1993) and ϕ = 2° (BIS 1993), γ = 19.40 KN/m3, γd = 15.60 KN/m3, specific gravity (G) = 2.70 (IS.2720.3.2.1980 1980), Compression Index (Cc) = 0.11 (BIS 1993), ground water level ((Dw) = 1.9 m, natural moisture content (w) = 24.33 % (IS: 2720-Part 2 1973), Factor of safety (F) = 3.0.

6. OBSERVATION

After giving the input in the numerical model (NABBSF), it is allowed to run for a few minutes, and the final result output is compared with the field results shown in table 2 and figure 2.

Footing Type	Depth of foundation (m)	Footing Dimension (m)	Safe Bearing Capacity (KN/m^2)	
			Field	NABBSF
Shallow isolated	2.00	1.5 ×1.5	63.17	62.28
		2.0 × 2.0	60.83	60.12
		2.5 × 2.5	59.43	58.93
	2.50	1.5 × 1.5	70.35	68.77
		2.0 × 2.0	67.41	67.01
		2.5 × 2.5	65.66	64.21

Table 2. Result output of field and model

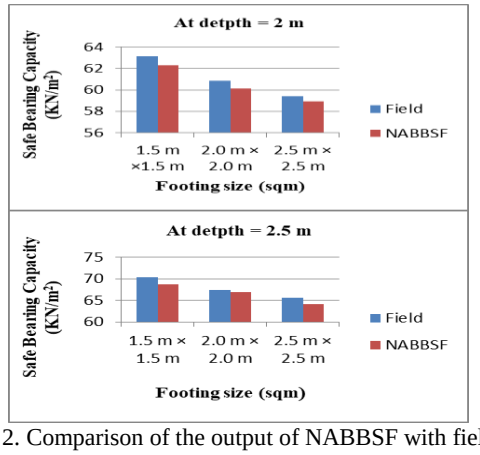


Figure 2. Comparison of the output of NABBSF with field data at depth = 2.0 m and 2.5 m

7. CONCLUSION

The main aim of this paper is to propose a numerical model to simplify the process of prediction of bearing capacity of soil beneath a shallow foundation. The model is prepared using MATLAB software in such a manner that determination of bearing capacity of subsoil considering different virtual size footings at different depth is possible. The present work considers shallow square footing with sides ranges between 0.5 m to 3 m and depth varies up to 3 m below ground level. Comparing the numerical model (NABBSF) with the real field data of a Geotechnical survey, it is found that the model gives nearly similar results and it is also observed that in both cases, for a particular depth the bearing capacity increases with the increase in contact surface area. As further extend, this model can be used for strip and circular foundation.

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