FOUNDATION ENGINEERING AND DESIGN

Usama Khan (20162089)

M.Tech in Computer Aided Structural Engineering (CASE)

Arushi Singhal (201516178)

B.Tech in Civil Engineering and

MS by Research in Building Science and Engineering

International Institute of Information Technology Hyderabad

“ Comparative Study Of Available Static Methods for Bearing Capacity of Shallow Foundations ”

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ACKNOWLEDGMENTS

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ABSTRACT

The idea of the project is to demonstrate the programmable calculations as well as comparison of ultimate bearing capacity as per (IS: 6403-1981), calculated from different methods, for given load, soil properties using 'MATLAB' and 'MATLAB- GUI'.

A bearing-capacity analysis of shallow footings and for different shapes of foundations subjected to axial, eccentric, and inclined loading is presented for different types of soils.Firstly, the historical background is presented for the determination of allowable bearing capacity of shallow foundations. Secondly, based on a variety of case histories of site investigations, including extensive borehole data and laboratory testing, an empirical formulation is proposed for the determination of allowable bearing capacity of shallow foundations. Various soil profiles like homogeneous, multi-layer in pure cohesive, pure cohesionless and mixed c-Φ types of soil are considered in software.The software also gives the optimum size of foundation with the consideration of various soil parameters for a given soil profiles. Analysis results are helpful to designers for considering allowable bearing capacity, size of footing based on IS code considerations. The soil bearing capacity is affected by many factors such as type and strength of soil, foundation width and depth, soil weight in the shear zone, surcharge, shear parameter of soil ('c' and' φ'), type of loading, shape of footing and depth of influence zone below foundation. Variation in these parameters makes calculations complex. By using software these complex calculations can be optimized with consideration of economical aspects, safety and IS code. The results which will be obtained in this work will be compared with renowned books of the field and will only be present if found satisfactory.

INTRODUCTION

Bearing Capacity :- The bearing capacity of soil is defined as the capacity of the soil to bear the loads coming from the foundation. The pressure which the soil can easily withstand against load is called allowable bearing pressure.

Ultimate bearing :- Capacity is the theoretical maximum pressure which can be supported by soil without failure.

A foundation is the element of the super structure which connects it to the ground, and transfers loads from the structure to the ground. It includes the portion of the structure below the ground level and is built, so as to provide a firm and level surface for transmitting the load of the structure on a large area of the soil lying underneath.

All engineering structures are provided with foundations at the base to fulfill the following

Types of foundations:

1. Shallow foundations

2. Deep foundations

3. Pile foundations

Shallow Foundations :- A shallow foundation is a type of foundation which transfers building loads to the earth very near the surface, rather than to a subsurface layer or a range of depths as does a deep foundation. Shallow foundations include spread footing foundations, mat-slab foundations,etc.Shallow foundations are foundations where the depth of the footing is generally less than the width of the footing.

OBJECTIVES AND PURPOSE :

1) Take user input for the soil profile.
2) Calculate ultimate bearing capacity for different shape of foundation, using different methods.
3) Apply shape factors.
4) Calculate corrected ultimate bearing capacity.
5) Compare the results of bearing capacity obtained from different methods.

METHODS TO OBTAIN BEARING CAPACITY

a. Analytical methods
b. Empirical methods
c. In-Situ loading tests
d. Building Codes or Civil Engineering handbooks

LITERATURE REVIEW

1) INTERNATIONAL JOURNAL OF ENGINEERING SCIENCES & RESEARCH TECHNOLOGY (IJESRT)

Software for Design of Shallow Foundation using Matlab BY **Vaishali Patel (2014)**

This paper demonstrates programmable calculations of allowable bearing capacity as per (IS: 6403-1981), settlement according to (IS 8009(part-1)-1976), design of R.C.C footing as per (IS: 456-2000) for given load, moments, soil properties using 'MATLAB'.

https://www.academia.edu/6993316/Software_for_Design_of_Shallow_Foundation_using_Matlab

2) 13th World Conference on Earthquake Engineering

Bearing Capacity Formula For Shallow Foundations During Earthquake **BY Yoshito MAEDA, Tatsuo IRIE and Yasuyuki YOKOTA (2004)**

This paper proposes a formula widely applicable for calculating bearing capacity of shallow foundations, which can evaluate both inclined load action of superstructure and inclined bearing stratum during earthquake. The formula is derived using seismic coefficient method and admissible velocity field method from upper bound theorem.

http://www.iitk.ac.in/nicee/wcee/article/13_3293.pdf

3) Hindawi Publishing Corporation

Improvement of Bearing Capacity of Shallow Foundation on Geogrid Reinforced Silty Clay and Sand **BY P. K. Kolay, S. Kumar, and D. Tiwari (2013)**

Author performed number of model tests to evaluate the load-carrying capacity of a rectangular model footing supported on the silty clay soil overlaid with small thickness of sand and with inclusion of geogrids at different depths from the base of the footing.

https://goo.gl/Gr0a0T

4) ASCE

BEARING CAPACITY OF SHALLOW FOUNDATIONS ON NONCOHESIVE SOILS **By Bohdan Zadroga (1991-2008)**

The author discussed Bearing-capacity Analysis of Shallow Footings And Strip Foundations subjected to axial, eccentric, and inclined loading is presented for noncohesive soils and the influences of load eccentricity and inclination, subsoil surface inclination, depth and shape of foundation with regard to classical and new calculation are discussed.

http://ascelibrary.org/doi/pdf/10.1061/(ASCE)0733-9410(1994)120:11(1991)

5) Elsevier

Static and seismic bearing capacity of shallow strip footings **By Ernesto Cascone[a] , Orazio Casablanca(2016)**

In this study, the evaluation of static and seismic bearing capacity factors for a shallow strip footing was carried out by using the method of characteristics, which was extended to the seismic condition by means of the pseudo-static approach. The results, for both smooth and rough foundations, were checked against those obtained through finite element analyses. Under seismic conditions the three bearing capacity problems for N_c, N_q and N_γ were solved independently and the seismic bearing capacity factors were evaluated accounting separately for the effect of horizontal and vertical inertia forces arising in the soil, in the lateral surcharge and in the superstructure. Empirical formulae approximating the extensive numerical results are proposed to compute the static values of N_γ and the corrective coefficients that can be introduced in the well-known Terzaghi's formula of the bearing capacity to extend its applicability to seismic design of foundations.

http://www.sciencedirect.com/science/article/pii/S026772611600049X

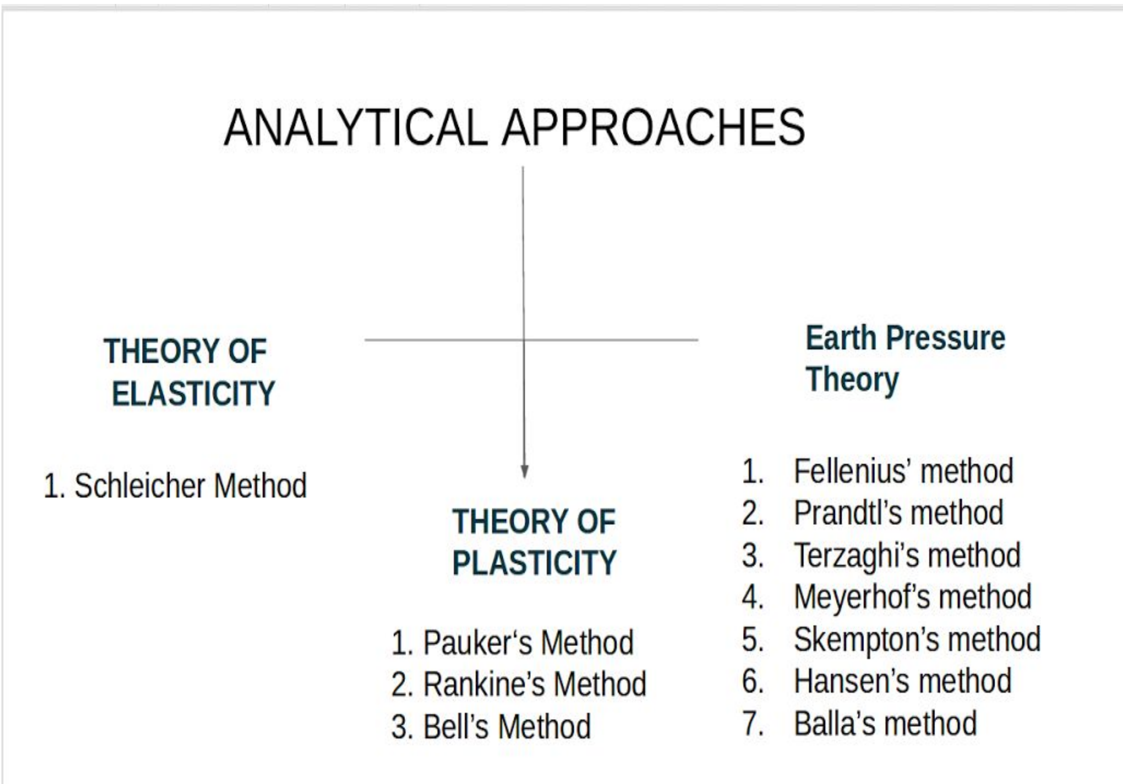
6) Japanese Geotechnical Society

Bearing Capacity Predictions Of Sand Overlying Clay Based On Limit Equilibrium Methods by **Mitsu Okamura, Jiro Takemura (1988)**

For cases where a sand layer is used as a bearing stratum with limited thickness, it becomes a difficult for the designers to judge its capacity when it is underlain by a soft clay deposit. Many factors need be taken as to reach a sane consensus about its bearing capacity. In this paper, these factors are calculated and the validity of the respective papers is checked at par with the assumptions.

THEORY

4.1 Analytical Approach to Calculate Bearing Capacity



4.2 Keywords and Standard Notifications

q_u	Ultimate Bearing Capacity of Soil
γ	Unit Weight of Soil
B	Width/Diameter of the Foundation of Soil
ϕ (in degrees)	Friction Angle

L	Length/Diameter of Foundation
c	Cohesion
D_f	Depth of Footing measured from the ground surface
D_w	Depth of Water table measured from the ground surface
$q_{net(u)}$	Net ultimate Bearing Capacity
FS	Factor of Safety
γ_{sat}	Saturated unit weight of soil
γ_W	Unit weight of water
$q = \gamma D_f$	Effective stress at the level of the bottom of the foundation
LSF	Local Shear Failure
GSF	General Shear Failure
Cohesionless Soil	c = 0
Fcs , Fqs , Fgs	Shape Factors
Fcd , Fqd , Fgd	Depth Factors
Fci , Fqi , Fgi	Load Inclination Factors
Nc, Nq, $N\gamma$	Bearing capacity Factors
N_ϕ	$tan^2 (45 + \phi/2)$
$K_{p\gamma}$	Passive Pressure Coefficient
c_a'	Adhesion
k_s	Punching Shear Coefficient
q_b	Bearing capacity of bottom layer soil

4.3 Pauker's Method

- Cohesionless Soil
- Strip Footing
- Homogenous Soil

$$q_u = \gamma D_f \tan^4(45^o + \frac{\phi}{2})$$

4.4 Pandtl's Method

- Plastic Failure
- Rigid Foundation
- Homogenous, Isotropic and weightless Soil
- Not applicable for cohesionless soil
- Strip Footing

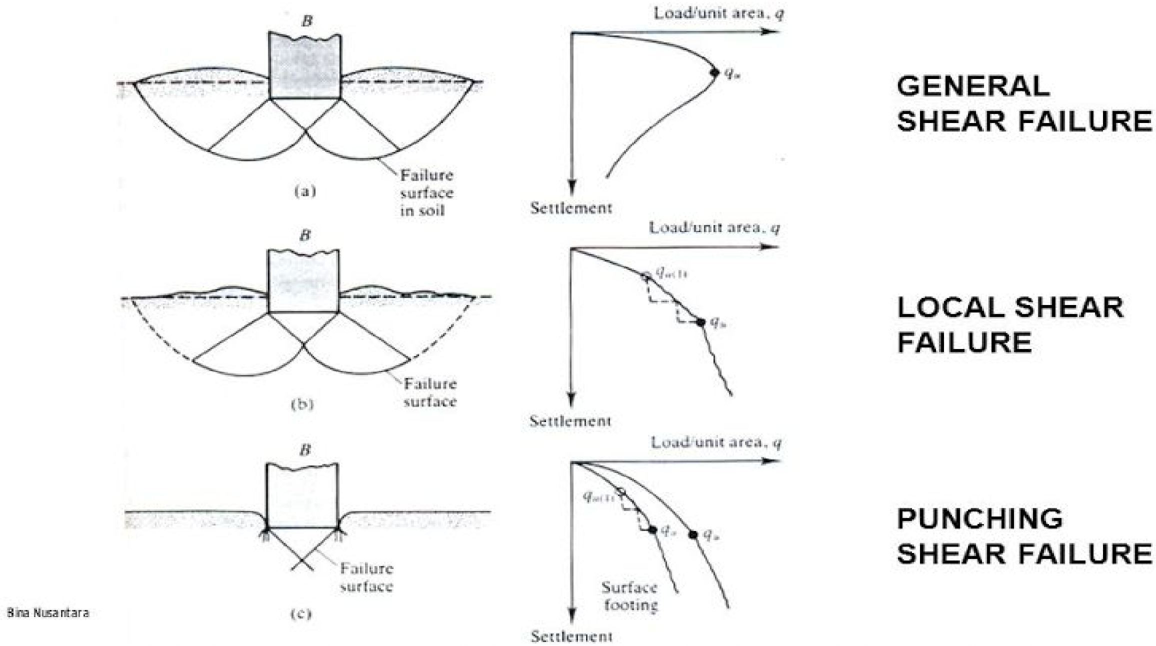
$$q_u = c\cot\phi\left[\tan^2(45^o + \frac{\phi}{2})e^{\Pi\tan\phi} - 1\right]$$

For $\phi=0$ soil

$$q_u = (\Pi+2)c = 5.14c$$

4.5 Terzaghi's method

- Homogenous Soil
- First to present a comprehensive theory for the evaluation of the ultimate bearing capacity of rough shallow foundations.
- Took weight of the soil into consideration.
- Considered two types of failure LSF and GSF.



Strip Footing

- GSF

  $q_u = cN_c + q\,N_q + 0.5\gamma BN_\gamma$

- LSF $q_u = \frac{2}{3}cN_c + q\,N_q + 0.5\gamma BN_\gamma$

Rectangular Footing

- GSF

  $q_u = cN_c(1 + 0.3\frac{B}{L}) + q\,N_q + 0.5\gamma BN_\gamma(1 - 0.2\frac{B}{L})$

- LSF

  $q_u = \frac{2}{3}cN_c + 0.2cN_c(\frac{B}{L}) + q\,N_q + 0.5\gamma BN_\gamma(1 - 0.2\frac{B}{L})$

Square Footing

- GSF

  $q_u = 1.3cN_c + q\,N_q + 0.4\gamma BN_\gamma$

- LSF

$$q_u = 0.867cN_c + q\,N_q + 0.4\gamma BN_\gamma$$

Circular Footing

- GSF

$$q_u = 1.3cN_c + q\,N_q + 0.3\gamma BN_\gamma$$

- LSF

$$q_u = 0.867cN_c + q\,N_q + 0.3\gamma BN_\gamma$$

For GSF the equations the equation of N_c, N_q, N_γ are given below and if the failure is LSF than replace ϕ with $tan^{-}(\frac{2}{3}tan(\phi))$

The bearing capacity factors N_c, N_q, and N_γ are defined by

$$N_c = \cot\phi'\left[\frac{e^{2(3\pi/4 - \phi'/2)\tan\phi'}}{2\cos^2\left(\frac{\pi}{4} + \frac{\phi'}{2}\right)} - 1\right] = \cot\phi'(N_q - 1)$$

$$N_q = \frac{e^{2(3\pi/4 - \phi'/2)\tan\phi'}}{2\cos^2\left(45 + \frac{\phi'}{2}\right)}$$

$$N_\gamma = \frac{1}{2}\left(\frac{K_{p\gamma}}{\cos^2\phi'} - 1\right)\tan\phi'$$

$K_{p\gamma}$ = passive pressure coefficient.

Considering Water Table

If $D_w \le D_f$ then replace q with $\overline{q} = \gamma\ D_w + (D_f - D_w)(\gamma_{sat} - \gamma_w)$

If $D_f < D_w \le D_f + B$ then replace γ with $\overline{\gamma} = (\gamma_{sat} - \gamma_w + \frac{(D_f - D_w)}{B}(\gamma - \gamma_{sat} + \gamma_w)$

4.6 Skempton's method

- Purely Cohesive soil
- Homogenous soil
- Found N_c as function of depth and shape of foundation

The net ultimate bearing capacity $q_{net\ ult} = c \, . N_c$

wherein N_c is given as follows:

Strip footing	$N_c = 5\,(1 + 0.2\,D_f/b)$	with a limiting value of N_c of 7.5 for $D_f/b > 2.5$
Square or circular footing	$N_c = 6(1 + 0.2D_f/b)$	with a limiting value of N_c of 9.0 for $D_f/b > 2.5$
Rectangular footing	$N_c = 5\left(1+0.2\frac{b}{L}\right)\left(1+0.2\frac{D_f}{b}\right)$	for $D_f/b \le 2.5$
	$N_c = 7.5\,(1 + 0.2\,b/L)$	for $D_f/b > 2.5$

4.7 General Bearing Capacity Equations

$$q_u = cN_cF_{cs}F_{cd}F_{ci} + qN_qF_{qs}F_{qd}F_{qi} + 0.5\gamma BN_\gamma F_{\gamma s}F_{\gamma d}F_{\gamma i}$$

$$N_q = \tan^2\left(45 + \frac{\phi'}{2}\right)e^{\pi \tan \phi'}$$

$$N_c = (N_q - 1)\cot \phi'$$

$$N_\gamma = 2(N_q + 1)\tan \phi'$$

Meyerhof and Hanna (1981))

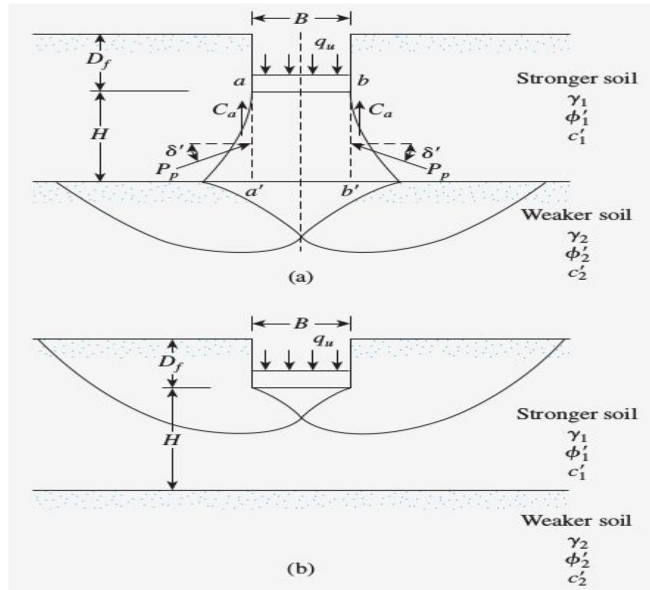
Factor	Relationship
Shape	$F_{cs} = 1 + \left(\frac{B}{L}\right)\left(\frac{N_q}{N_c}\right)$ $F_{qs} = 1 + \left(\frac{B}{L}\right) \tan \phi'$

Inclination	$F_{ci} = F_{qi} = \left(1 - \frac{\beta^\circ}{90^\circ}\right)^2$ $F_{\gamma i} = \left(1 - \frac{\beta}{\phi'}\right)$ β = inclination of the load on the foundation with respect to the vertical

Depth	$\frac{D_f}{B} \le 1$ For $\phi = 0$: $F_{cd} = 1 + 0.4\left(\frac{D_f}{B}\right)$ $F_{qd} = 1$ $F_{\gamma d} = 1$ For $\phi' > 0$: $F_{cd} = F_{qd} - \frac{1 - F_{qd}}{N_c \tan \phi'}$ $F_{qd} = 1 + 2 \tan \phi' (1 - \sin \phi')^2 \left(\frac{D_f}{B}\right)$ $F_{\gamma d} = 1$ $\frac{D_f}{B} > 1$ For $\phi = 0$: $F_{cd} = 1 + 0.4 \underbrace{\tan^{-1}\left(\frac{D_f}{B}\right)}_{\text{radians}}$ $F_{qd} = 1$ $F_{\gamma d} = 1$ For $\phi' > 0$: $F_{cd} = F_{qd} - \frac{1 - F_{qd}}{N_c \tan \phi'}$ $F_{qd} = 1 + 2 \tan \phi'(1 - \sin \phi')^2 \underbrace{\tan^{-1}\left(\frac{D_f}{B}\right)}_{\text{radians}}$ $F_{\gamma d} = 1$	Hansen (1970)

4.8 Bearing Capacity Of Footing on Layered Soil

Layer	Soil properties		
	Unit weight	Friction angle	Cohesion
Top	γ_1	ϕ_1'	c_1'
Bottom	γ_2	ϕ_2'	c_2'



$$q_u = q_b + \frac{2c_aH}{B} + \gamma_1 H^2\left(1 + \frac{2D_f}{H}\right)\left(\frac{k_s \tan(\phi_1')}{B}\right) - \gamma_1 H \le q_t$$

Where, $q_t = c_1' N_{c(1)} + q_{(1)} N_{q(1)} + 0.5\gamma_1 B N_{\gamma(1)}$

Special Cases

1) Rectangular Footing

$$q_u = q_b + \left(1 + \frac{B}{L}\right)\left(\frac{2c_aH}{B}\right) + \gamma_1 H^2\left(1 + \frac{B}{L}\right)\left(1 + \frac{2D_f}{H}\right)\left(\frac{k_s \tan(\phi_1')}{B}\right) - \gamma_1 H \le q_t$$

Where

$$q_b = c_2' N_{c(2)} F_{cs(2)} + \gamma_1 (H + D_f) N_{q(2)} F_{qs(2)} + 0.5\gamma_2 B N_{\gamma(2)} F_{\gamma s}$$

2) Top Layer is strong and bottom is saturated soft clay ($\phi_2 = 0$)

$$q_b = \left(1 + 0.2\frac{B}{L}\right)5.14c_2 + \gamma_1(D_f + H)$$

and

$$q_t = \gamma_1 D_f N_{q(1)} F_{qs(1)} + \tfrac{1}{2}\gamma_1 B N_{\gamma(1)} F_{\gamma s(1)}$$

Hence,

$$q_u = \left(1 + 0.2\frac{B}{L}\right)5.14c_2 + \gamma_1 H^2\left(1 + \frac{B}{L}\right)\left(1 + \frac{2D_f}{H}\right)\frac{K_s \tan\phi_1'}{B} + \gamma_1 D_f \leq \gamma_1 D_f N_{q(1)} F_{qs(1)} + \frac{1}{2}\gamma_1 B N_{\gamma(1)} F_{\gamma s(1)}$$

where c_2 = undrained cohesion.

3) Top Layer is strong sand and bottom layer is weaker

$$q_u = \left[\gamma_1(D_f + H)N_{q(2)}F_{qs(2)} + \frac{1}{2}\gamma_2 B N_{\gamma(2)} F_{\gamma s(2)}\right] + \gamma_1 H^2\left(1 + \frac{B}{L}\right)\left(1 + \frac{2D_f}{H}\right)\frac{K_s \tan\phi_1'}{B} - \gamma_1 H \leq q_t$$

of Layered Soils: Stronger Soil Underlain by

4.9 Terminologies

Net Safe Bearing capacity:
Maximum net intensity of loading that the soil can safely support without the risk of shear failure. $q_{ns} = \frac{q_{nu}}{FOS}$

Gross Safe Bearing capacity:
Maximum gross intensity of loading that the soil can safely support without the risk of shear failure. $q_{gs} = q_{ns} + \gamma D_f$

Safe Bearing Pressure:
Maximum net intensity of loading that can be allowed on the soil without settlement exceeding the permissible limit. q_{ps} from settlement analysis

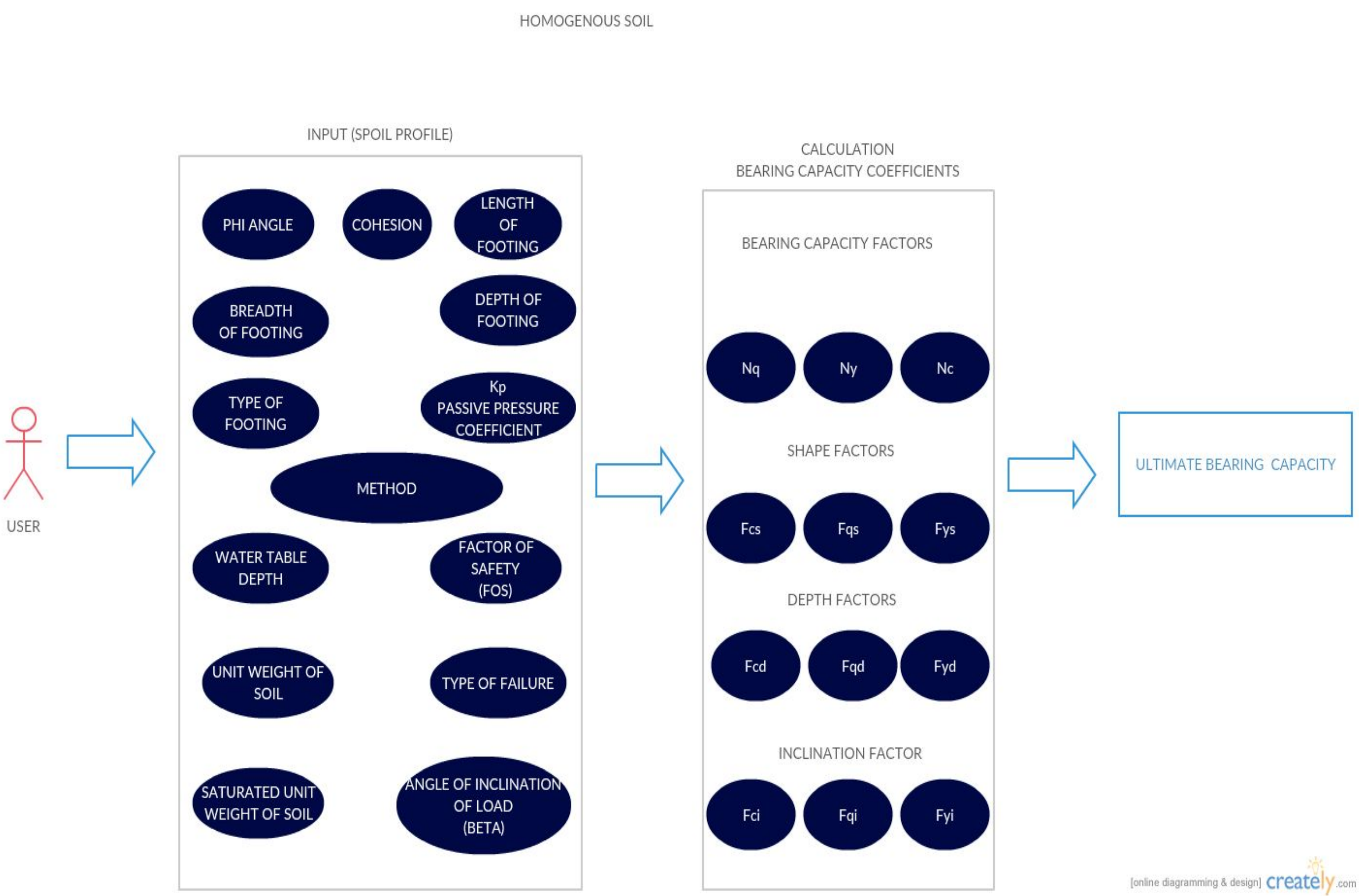
Allowable Bearing Pressure:
Maximum net intensity of loading that can be allowed on the soil with no possibility of shear failure or settlement exceeding the permissible limit. q_{a-net} Minimum of bearing capacity and settlement analysis

PROJECT DESCRIPTION

In this project the Results of Ultimate Bearing Capacity obtained from various methods suggested by Different Investigators for various types of soil profile, considering many factors like shape,inclination etc. are calculated.

INPUT:- USER will give the Soil Profile as INPUT.

OUTPUT:- Soil ultimate bearing capacity.



Use Case Diagramm of Software

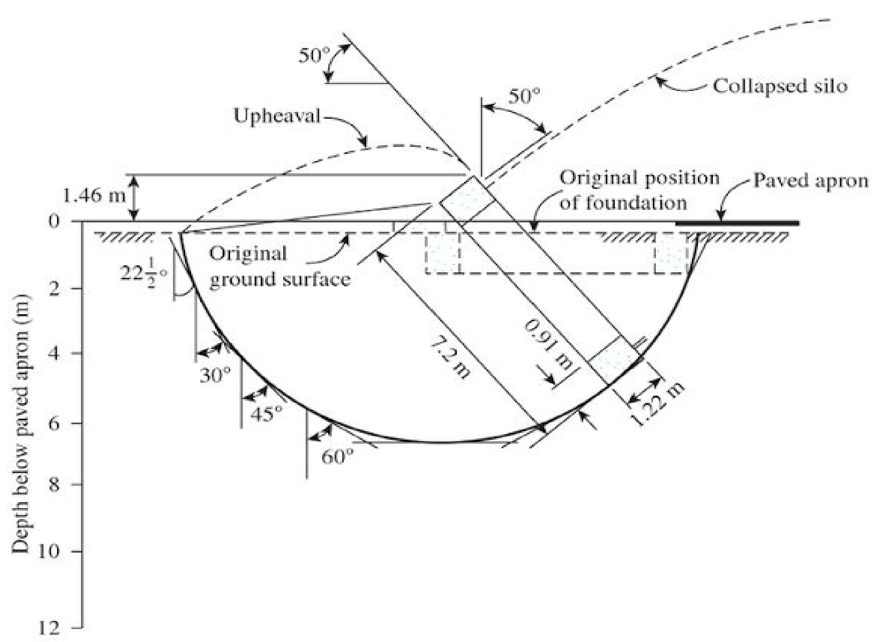
CASE STUDY AND RESULTS

Foundation Failure of a Concrete Silo

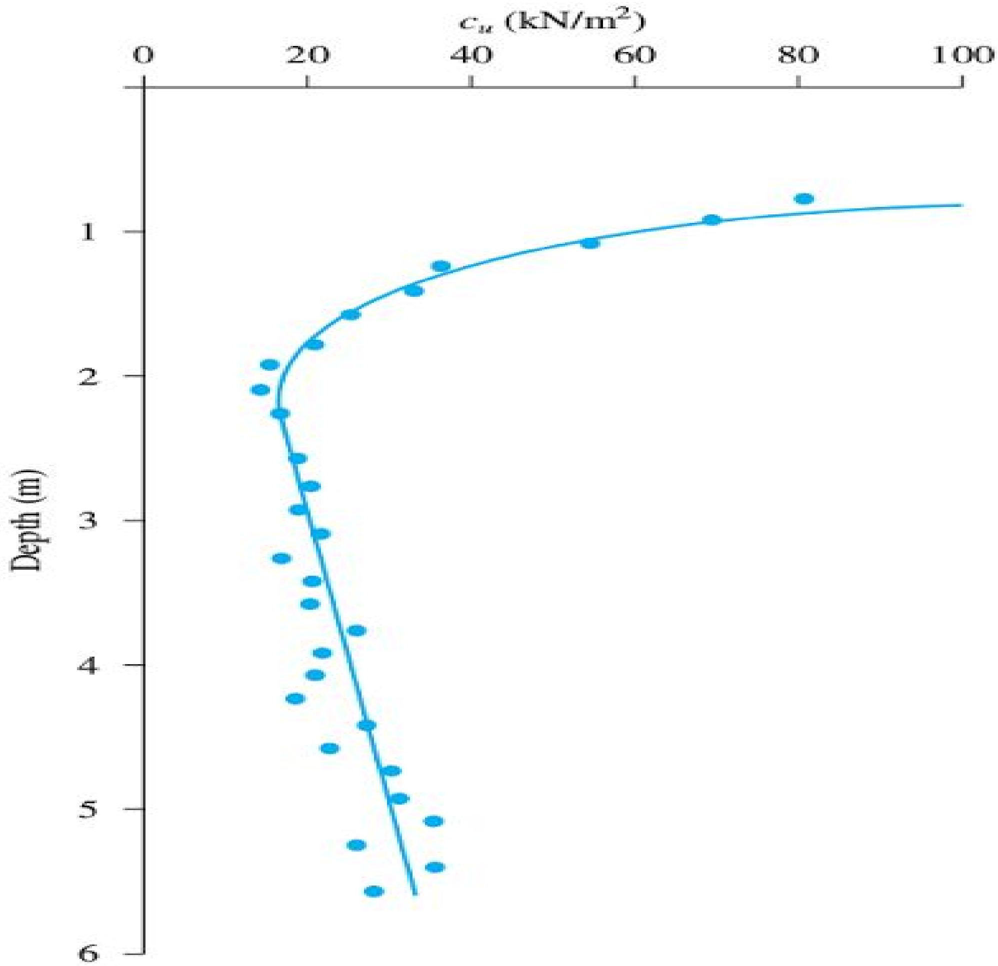
An excellent case of bearing capacity failure of a 6-m diameter concrete silo was provided by Bozozuk (1972). The concrete tower silo was 21 m high and was constructed over soft clay on a ring foundation. Figure below shows the variation of the undrained shear strength (cu) obtained from field vane shear tests at the site. The groundwater table was located at about 0.6 m below the ground surface. On September 30, 1970, just after it was filled to capacity for the first time with corn silage, the concrete tower silo suddenly overturned due to bearing capacity failure. Figure shows the approximate profile of the failure surface in soil. The failure surface extended to about 7 m below the ground surface. Bozozuk (1972) provided the following average parameters for the soil in the failure zone and the foundation:

Load per unit area on the foundation when failure occurred ≈ 160 kN $/m^2$

Average plasticity index of clay (PI) ≈ 36



In this figure B ≈ 7.2 m and D_f ≈ 1.52 m.



Average undrained shear strength (c_u) from 0.6 to 7 m depth obtained from field vane shear tests $\approx$ 27.1 kN$/m^2$

We can now calculate the factor of safety against bearing capacity failure. From Eq. (3.19)

$$q_u = c'N_cF_{cs}F_{cd}F_{ci} + qN_cF_{qs}F_{qd}F_{qi} + \tfrac{1}{2}\gamma B\, N_\gamma F_{\gamma s}F_{\gamma d}F_{\gamma i}$$

For $\phi = 0$ condition and vertical loading, $c' = c_u$, $N_c = 5.14$, $N_q = 1$, $N_\gamma = 0$, and $F_{ci} = F_{qi} = F_{\gamma i} = 0$. Also, from Table 3.4,

$$F_{cs} = 1 + \left(\frac{7.2}{7.2}\right)\left(\frac{1}{5.14}\right) = 1.195$$

$$F_{qs} = 1$$

$$F_{cd} = 1 + (0.4)\left(\frac{1.52}{7.2}\right) = 1.08$$

$$F_{qd} = 1$$

Thus,

$$q_u = (c_u)(5.14)(1.195)(1.08)(1) + (\gamma)(1.52)$$

Assuming $\gamma \approx 18\ \text{kN/m}^3$,

$$q_u = 6.63c_u + 27.36 \tag{3.23}$$

According to Eqs. (2.34) and (2.35a),

$$c_{u(\text{corrected})} = \lambda\, c_{u(\text{VST})}$$

$$\lambda = 1.7 - 0.54 \log [\text{PI}(\%)]$$

For this case, PI $\approx$ 36 and $c_{u(\text{VST})} = 27.1\ \text{kN/m}^2$. So

$$\begin{aligned} c_{u(\text{corrected})} &= \{1.7 - 0.54 \log [\text{PI}(\%)]\}c_{u(\text{VST})} \\ &= (1.7 - 0.54 \log 36)(27.1) \approx 23.3\ \text{kN/m}^2 \end{aligned}$$

Substituting this value of c_u in Eq. (3.23)

$$q_u = (6.63)(23.3) + 27.36 = 181.8\ \text{kN/m}^2$$

The factor of safety against bearing capacity failure

$$\text{FS} = \frac{q_u}{\text{applied load per unit area}} = \frac{181.8}{160} = 1.14$$

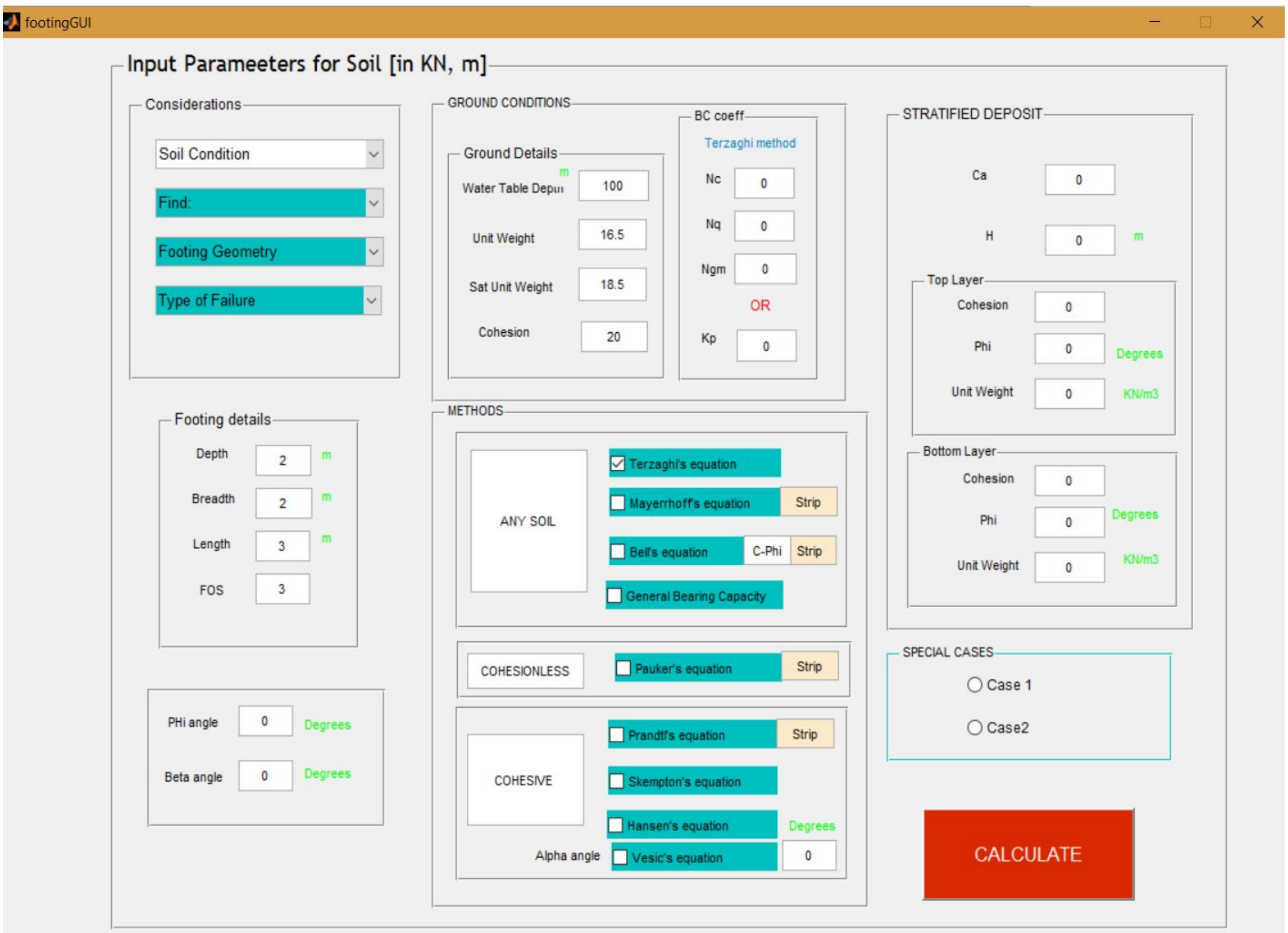
This factor of safety is too low and approximately equals one, for which the failure occurred.

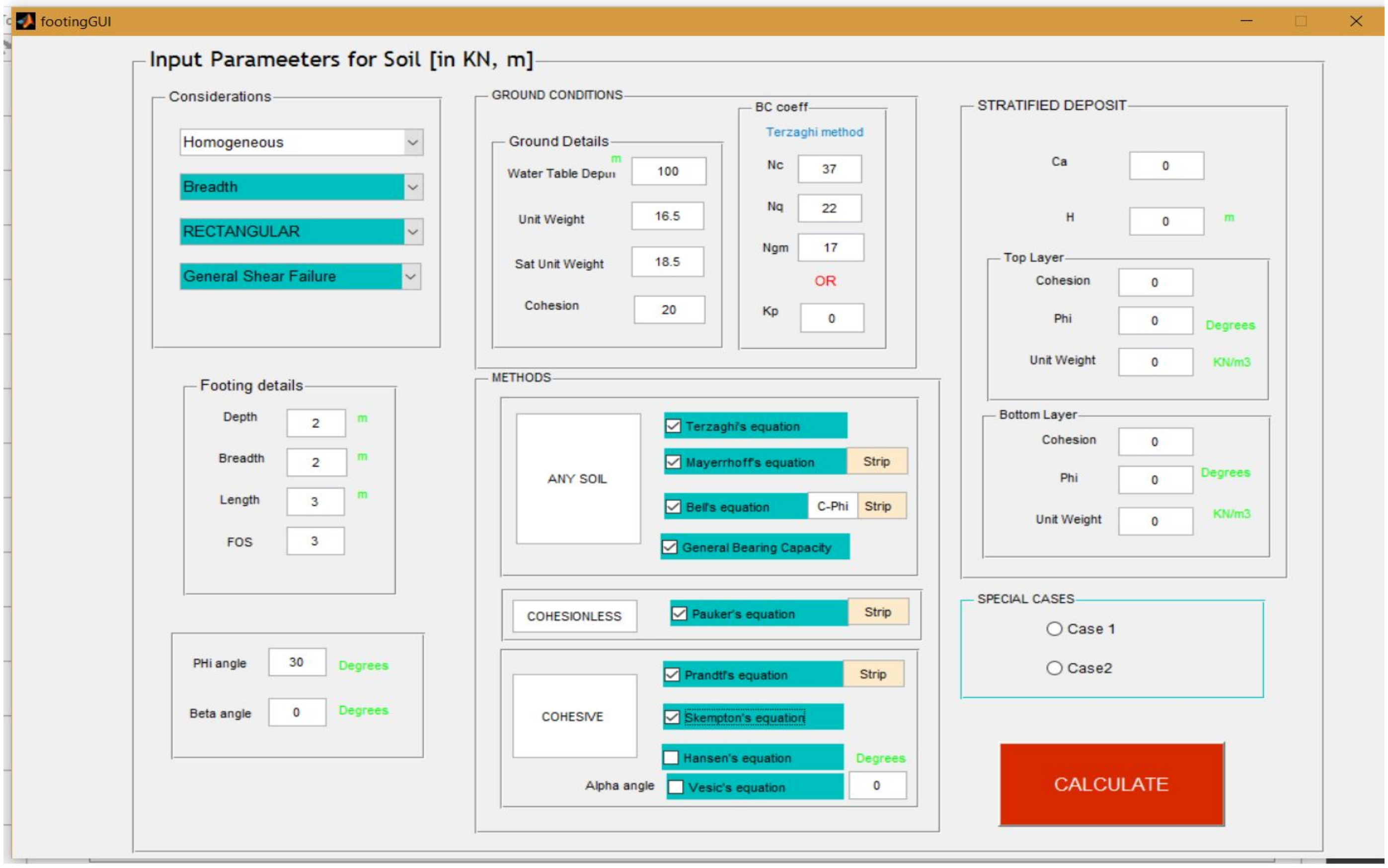
RESULTS

GUI panel

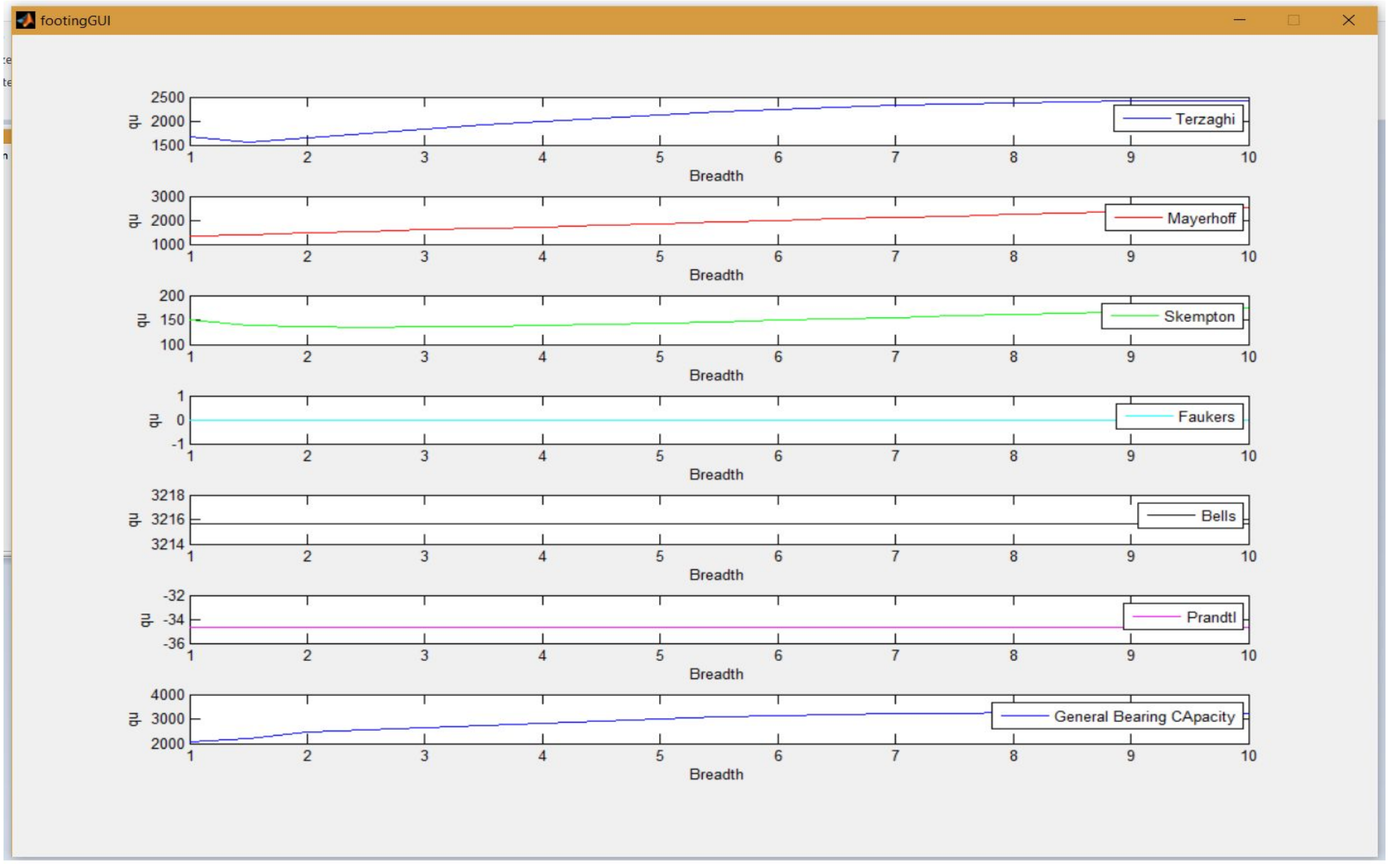
The panel hence designed is user friendly and allows for ample customizations as per the user's discretion. The input are put through the input text slots and must be user verified for values which are dependant.

The user gets to choose the soil condition and from thence he can either choose a homogeneous or a stratified soil deposit. The user has the liberty choose what is the required output, is it the breadth comparison from different shallow foundation methods or the comparison of ultimate bearing capacity values obtained.





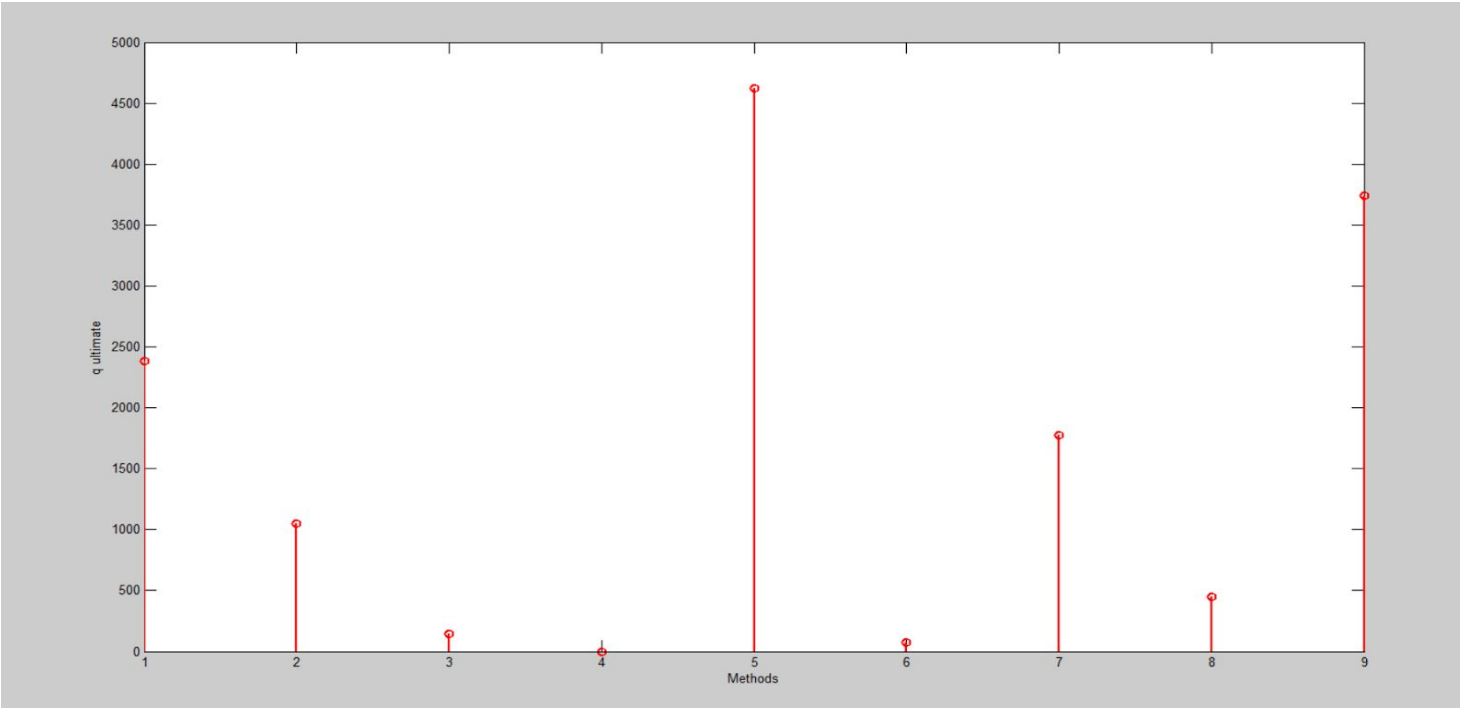
The gui panel is now input through the user and values as per user's discretion are input one by one in different text boxes as seen. In this example, all methods are checked for the comparison of the ultimate bearing capacity values for variating width-values.



The above graph displays the ultimate bearing capacity values for variation of width. The user can ascertain as to what will be the bearing capacity of the footing for different width dimensions.

The values have been input through the GUI panel and subsequently the results are obtained.

The above graphs are for a homogeneous soil checked for GENERAL SHEAR FAILURE in terzaghi's equation for a Phi value of 30 degrees and respective bearing capacity factors. Since the soil is homogeneous and not stratified, the stratified deposit panel has been left undisturbed.



This graph is the final result of the comparison of results obtained from different shallow foundation methods . some of the values in the graph display a zero value, which is for those cases wherein the method conditions do not allow and hence that method is out of comparison; hence the default zero value.

CONCLUSIONS

1. The analysis indicates that in general the bearing capacity increases with size, depth, and roughness of the base, and depends on the shape of the foundation. The bearing capacity is reduced by compressibility of the material leading to local shear failure, and this effect is at present best taken into account by an empirical reduction of the shearing strength. The influence on the soil properties of the method of installing the foundation is also based on empirical evidence.
2. The mechanism depends first of all on the relative thickness of the platform but also on the effective angle of friction of the platform and the undrained shear strength of the soft subgrade as well.
3. Analysis of the failure mechanisms for different relative thickness of the working platform on soft subgrade confirms that the punching failure in the platform material can be observed for (h/B) not larger than 1.5. For higher (h/B) values the generalized failure mechanism within platform material takes place.
4. If the foundation under consideration rests on sand or clayey soil of medium compaction, an increase in the load on the foundation will also be accompanied by an increase in settlement.

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Thank You