A NUMERICAL STUDY OF FOUNDATION DEPTH ON CONTACT STRESSES AND SETTLEMENTS FOR VARIOUS SUB SOILS

D.R.C. BHASKAR¹, S.J. SHUKLA², S. DINESH³

ABSTRACT

The embedment depth of foundations has significant effect on distribution of contact stresses and settlement under footings. As embedded depth of foundation increases the bearing capacity of soils increases, because the surrounding soil of the footing confines the stressed soil under the footing. Previously the researchers studied the contact stress distribution experimentally and analytically without any depth of embedment. In addition, the most of settlement calculation methods that widely used by practical engineers didn’t consider the embedment depth of footings. This may affect the resulted distribution of the contact stresses and corresponding differential settlement. The numerical method like Boussinesq have an implied assumption that the contact pressure beneath the loading plate is uniform, although this may not be realistic. So there is the need of study on effect of footing embedment depth. The study was being carried out in finite element software PLAXIS 3D by placing footing at increasing depth in soil models of sand, clay, cohesive cohesion less and layered soils. Mohr-coulomb model was adopted to represent the soils. The contact stress distribution and settlement variation with increase of footing depth varies depending upon soil. The results will be useful for understanding exact contact stress distributions and settlements for practical foundation designs.

Keywords: Embedment depth, Contact stress distribution, Settlement, PLAXIS 3D.

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ABSTRACT: The embedment depth of foundations has significant effect on distribution of contact stresses and settlement under footings. Previously the researchers studied the contact stress distribution experimentally and analytically without any depth of embedment. In addition, the most of settlement calculation methods that widely used by practical engineers didn’t consider the embedment depth of footings. This may affect the resulted distribution of the contact stresses and corresponding differential settlement. The numerical method like Boussinesq have an implied assumption that the contact pressure beneath the loading plate is uniform, although this may not be realistic. So there is the need of study on effect of footing embedment depth. The study was being carried out in finite element software PLAXIS 3D by placing footing at increasing depth in soil models of sand, clay, cohesive cohesion less and layered soils. Mohr-coulomb model was adopted to represent the soils. The contact stress distribution and settlement variation with increase of footing depth varies depending upon soil. The stress results were compared with Boussinesq’s method and settlement variation on increasing footing depth is observed.

INTRODUCTION
Stress distribution in soils is very important in foundation or any sub structure designs. Not only the design but also the analysis of foundation settlement needs this information, especially the stress distributions of spread footing group that the overlap of pressure bulb may cause the failure.

The classical Boussinesq’s method [1] invented in 1883 is usually used for estimating stress distribution in soils mass due to surcharge load. It is the mathematical model that the soil is assumed to be semi-infinite solid and its strength parameters are not taken in to account. In other words the model assumption is doubted that soil type has no effect on stress distribution behavior. Contact pressure between rigid footing and soils was assumed to be uniform. Hansbo made the conclusion of the contact pressure in clay, silt and sand studied by some researchers, only the rigid footing on ground surface gave the contact pressure that agreed with Boussinesq’s method.

Finite element method is becoming popular along with the fast development of computer. It is the powerful device that could be used for any complicated soil model. The problem of finite element method is its difficulty, and then commercial program is necessary. Difficulty and price of the program obstruct engineers to use it.

The research presented in this paper was done to compare the stress distribution in various soil models due to the load acted on 3x3 m concrete spread footing with the outputs obtained from classical Boussinesq’s model and PLAXIS 3-D, the computer program based on finite element method. The settlement variation with increase of footing embedment depth for various sub soils is also studied.
METHODOLOGY

A finite element software PLAXIS 3D is used for determining stress distributions and settlements in soils under the spread footing. Mohr-Coulumb model [4] is considered for soil modelling. Various soils analysed in this are sand, clay, cohesive-cohesion less soil and layered soil. The medium coarse meshing is done to discretise the soil model with footing embedded into it. As the model is three dimensional the length and breadth boundaries of soil model were taken 5 times of footing dimensions as such that boundary conditions are neglected and the bottom is taken 3 times of the maximum depth of footing. The water table is lowered below the influence zone.

Apart from regular soil models a 5 layered soil model is taken for study. The layered soil represents the actual soil conditions in site as bore log. The water table is at 3.5 m below the ground surface. The properties adopted for layered soil [2] is as shown below table.

<table>
<thead>
<tr>
<th>Thickness(m)</th>
<th>Loose to Medium Sand</th>
<th>Dense Sand</th>
<th>Peat</th>
<th>Very Dense Sand</th>
<th>Stiff Clay</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>8</td>
<td>3</td>
<td>6</td>
<td>8</td>
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</tbody>
</table>

The footing is modelled as linear-elastic material to represent concrete footing. The properties like unit weight is 24 kN/m$^3$, Young’s modulus of concrete is 27000 MN/m$^2$ and Poisson’s ratio is 0.15. The length and breadth of footing are 3m x 3m and thickness is 0.5 m determined by the IS: 456 method [5]. A load of 500 kPa is applied on footing acting as column load.

A soil interface is created under the footing and strength reducing factor is applied to the soil.
RESULTS AND DISCUSSIONS

The results were taken for footing embedment depth at 1m, 1.5m, 2m, 2.5m, 3.5m, 5m for all sand, clay, cohesive cohesion less soil and layered soils. Total 24 models were analysed. Contact stresses are total normal stresses and settlements are deformations in z-axis were acting on the interface.

The stress distributions and deformations were taken at centre cross section of the whole model.

In the above fig 5 the stresses are maximum at edges and minimum at centre. The settlements decrease by 30.69% as increase of footing embedment depth form 1m to 5m are shown in figure below.

Same as above the results were plotted for clay, cohesive cohesion less soil and layered soils. For clayey soil the stresses were maximum at centre and minimum at edges. There is decrement of 51.6% of settlements by increasing embedment depth 1m to 5m. For c-φ soils the results are near to sandy soil as it sandy clay, the settlements are decreased by 32.57% as increase in footing depth.
As the top layer of layered soil is loose sand the stress distribution is similar to sandy soil but percentage decrement of settlements is more as there is change in layer at 5m depth.

All the stresses were compared by conventional Boussinesq’s method [3]. The equation considered for vertical stress ($\sigma_z$) at any point in soil by load acting on surface is

$$\sigma_z = \frac{q}{2\pi} \left[ \frac{mn}{\sqrt{m^2 + n^2 + 1}} - \frac{m^2 + n^2 + 2}{m^2 + n^2 + m^2n^2 + 1} \right] + \sin^{-1} \left( \frac{mn}{\sqrt{m^2 + n^2 + m^2n^2 + 1}} \right)$$

Where

$m=b/z$ = breadth of footing
$n=l/z$ = length of footing
$z$ = depth of footing

A graph is plotted between stresses and vertical depth comparing the results obtained by Boussinesq’s method and PLAXIS 3D of finite element method.

![Stress vs Depth Graph](image)

Fig 7: Comparing Boussinesq’s stresses with PLAXIS 3D stresses with increasing vertical depth

The stresses obtained by PLAXIS 3D were 3-4 times more than the stresses obtain by using Boussinesq’s equation.

CONCLUSIONS

Most of the researchers studied the contact stresses and settlements at soil surface that is at zero embedment depth of footing, this leads to inappropriate simulation of real behavior of contract stress distribution. The stresses obtained by FEM where 3-4 times more than the stresses obtained by Boussinesq’s method. There is significant decrement in settlements as footing embedment depth increases. The uneven distribution leads to maximum bending moment at footing more calculated by uniform stress distribution therefore for safe and reliable design it advised to do numerical analysis for stresses and settlement calculations.

REFERENCES

5. IS: 456-2000 “Plain And Reinforced Concrete -Code Of Practice”