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Finite Element Analysis of Strip Footing in Layered Soil Using MATLAB

Dr. Dipika Devi
Assistant Professor, Department of Civil Engineering,
North Eastern Regional Institute of Science and Technology, Nirjuli, Arunachal Pradesh, India

Abstract:
A finite element analysis program is written using the powerful interactive language MATLAB. The program is used to analyze the deformation characteristics of soil under a strip footing. The soil is modeled as layered with uniform elastic constants for each layer. The results of the layered soil are compared with that of an equivalent uniform soil. The elastic constants of the equivalent uniform soil are determined by taking the weighted average of that of the layered soil. The analysis is also performed by modeling the constitutive behaviour of the equivalent uniform soil to be nonlinear. The nonlinear hyperbolic model is used for this purpose and the results are compared with that of linear analysis. The results show that analysis with a linear equivalent uniform soil may underestimate the settlement and overestimate the allowable loads.

Keywords: *MATLAB, Strip footing, Layered soil, Non linear soil, Bearing capacity.*

1. Introduction

MATLAB is interactive software, which is relatively easy to learn and doesn't require in–depth knowledge on operational principle of computer programming. The power of MATLAB is represented by the length and simplicity of the code. It has been used recently in various areas of engineering and scientific application. MATLAB can be very useful as a solution tool for implementing finite element method [4]. Finite element method is used extensively in the field of Geotechnical Engineering particularly for analysis of foundations, earth retaining structures and buried structures.

Many investigators performed the numerical analysis of foundations using FEM and a few of them used MATLAB as a programming language for implementing FEM. A very few work is done on the analysis of foundations resting on layered soil and in most of such studies the soil is modelled as linear elastic or linear elastic perfect plastic material [1, 2, 5**]**. A Brief review of literature is presented in the following section.

2. Review of Literature

Wang and Carter [8] studied the large deformation analysis to investigate the bearing response and failure mechanism of a horizontally layered cohesive soil under the action of vertically loaded rigid strip and circular footings using the AFENA finite element package. For a strip footing on a two layered soil with a specified value of H/B, a characteristic value of c2/c1 were observed for which the load displacement curve was almost the same to small deformation analysis. Here H is the depth of the soil layer, B is the width of the footing, c_1 and c_2 are the cohesion of the top layer and the bottom layer of the soil. For a value of c_2/c_1 greater than this characteristic value, the load displacement curve rises continuously until the footing penetrates in to the footing layer and a stable ultimate bearing capacity is achieved.

Shiau et al. [7] studied the finite element formulations of the limit analysis theorems to obtain rigorous plasticity solutions for the bearing capacity of a layer of sand on clay. The study covered a range of parameters, including the depth of the sand layer, the friction angle of the sand, the undrained shear strength of the clay and the effect of a surcharge. The influence of footing roughness and increasing strength with depth for the clay soil were also quantified rigorously. The upper and lower bound estimates of the normalized bearing capacity were compared with the semi empirical results suggested by different investigators.

Ming [2] evaluated the ultimate bearing capacity of a rough strip footing resting on two-clay layer soil. The soil was modelled as isotropic elastic perfectly plastic material satisfying Tresca failure criteria. Computation were performed by the commercial finite element analysis software ABAQUS. The study shows that at same strength ratio, the bearing capacity factor decreases as thickness of the top layer increases for a soft-over-strong clay profile, whereas an inverse trend for a strong-over-soft clay profile.

Ramthan [4] performed the finite element analysis of multilayered soil under strip footing using MATLAB, considering generalized Hook's law. The study revealed that the settlement at the center was much larger than the settlement at the edges of loaded area. The surface settlement for soils with modulus increasing linearly with depth, were found to be less than the settlement for soils with constant modulus.

Mohammed [3] studied the finite element analysis of silty clay soil under strip footing with modified Cam Clay model using MATLAB. In this study the silty clay soil was modelled with variable soil modulus. The study revealed that the settlement at the center was much larger than the settlement at the edge of the loaded area and the settlement profile was symmetric and parabolic in shape for the load increments. The immediate settlement at the center of the loaded area was found to be reduced when the strip footing was placed at some greater depth.

Rao et. al [6] studied a lower bound limit analysis in conjunction with finite elements and second order cone programming (SOCP). The soil was model using linear Tresca yield criterion. The bearing capacity of a rigid strip footing placed on two layered clay subjected to inclined or eccentric loading was determined, considering the footing to be founded on the free surface of the soil mass with no-surcharge applied. The study revealed that the size and shape of the failure envelopes were dependent on (1) the undrained shear strength ration of the top and bottom clay, and (2) the normalized thickness D/B of the upper clay, where D is the thickness of the top clay layer and B is the width of the footing.

3. Present Work

3.1. Introduction

In this study, a finite element (FE) program is formulated to study the deformation characteristics of layered soil under a footing considering the constitutive behaviour of the soil to be linear as well as nonlinear. As a programming language MATLAB is used. A strip footing is analysed using the FE program and the stress-strain and load settlement curves of the footing is compared for equivalent homogeneous soil and layered soil. For linear analysis generalized Hooke's Law is used. For nonlinear analysis the hyperbolic model is used. The footing analyzed is considered to be flexible with a size of 1.5m (*B*). The footing is placed centrally over a domain of soil of size 10Bx5B as shown in the Figure-1. The half of the domain of the soil is discretized into 450 number of constant strain triangular (CST) elements with 256 number of nodes. Three different types of soil are considered in the analysis: (i) A uniform deposit of soil with values of elastic constants increasing linearly with depth, (ii) A soil with discrete layers having uniform elastic constants for each layer, (iii) A layered soil converted into an equivalent uniform layer with weighted average value of elastic constants. In each case the load is applied with an increment of 50 kN/m^2 till an estimated ultimate load of 900 kN/m^2 or till an allowable settlement of 25mm is reached.

3.2. Hyperbolic Model

This model is also known as Duncan and Chang model. Here the stresses we calculated are related to the applied axial strain and can be applied for both undrained and drained boundary value problems. The incremental form of young's modulus is used in finite element analysis or other numerical method on differentiation of stresses. The original equation of this model is shown below:

$$\sigma_1 - \sigma_3 = \frac{\varepsilon}{a + b \, . \, \varepsilon}$$

(1)

Where, σ_1 ανδ σ_3 are the major and minor principal stresses, ε is the axial strain and *a*, *b* are the material constants. For finite element analysis, Equation. (1) has to be differentiated to get the variation of Young's modulus (E_t) with stresses.

$$E_t = \frac{\partial (\sigma_1 - \sigma_3)}{\partial \varepsilon} = \frac{a}{(a + b \, . \, \varepsilon)^2}$$

(2)

If the analysis is to be performed till failure, Mohr-Coulomb failure criterion can be used with this model to define the failure, for which c and ϕ will be required. In the present analysis, the analysis is performed till a predefined settlement of 25mm for the footing.

4. Numerical Examples

4.1. Analysis of a Strip Footing Resting on a Linear Soil

4.1.1. Layered Soil

In this analysis the soil domain is considered to be consisting of 3 layers each of 2.5 m thick. The Young's modulus considered are: 70x10^3 kNm^2 from base of the foundation to 2.5m depth, 40x10^3 kN/m^2 from 2.5m to 5 m depth and 20x10^3 kN/m^2 for remaining 2.5m depth. The Poisson ratio of 0.35 is assumed to be same for all layers.

4.1.2. Equivalent Uniform Soil

In this analysis the soil domain is considered to be uniform with an equivalent Young's modulus of 43.33x10^3 kN/m^2 (average of the values of the three layers) and Poisson's ratio of 0.35.

The results of the layered and equivalent uniform soils are compared in terms of variation of settlement, axial stress, and horizontal stress on the horizontal plane directly below the base of the footing. Figure 2-4 shows the results of these two analyses. The results are plotted corresponding to a load of 900 kPa applied vertically to the footing. It can be observed from the results that the settlement for the layered soil is more at the center and less at the edges. Both the vertical and horizontal stresses are almost same from both the analysis.

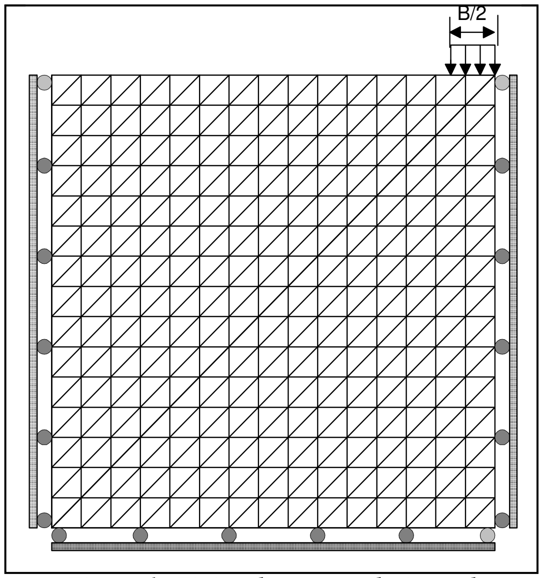

Figure 1: Finite element analysis mesh

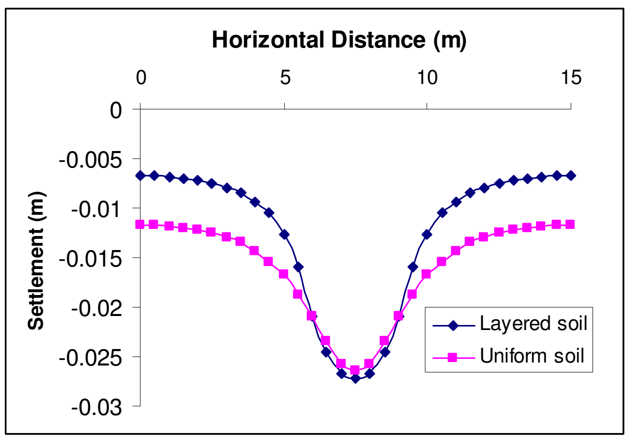

Figure 2: Settlement on the horizontal plane at the base of the footing for linear analysis (Horizontal distance measured from the left of the mesh)

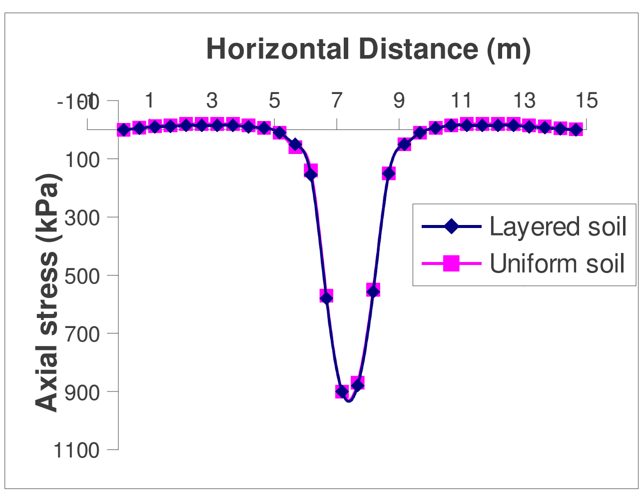

Figure 3: Axial stress on the horizontal plane at the base of the footing for linear analysis (Horizontal distance measured from the left of the mesh)

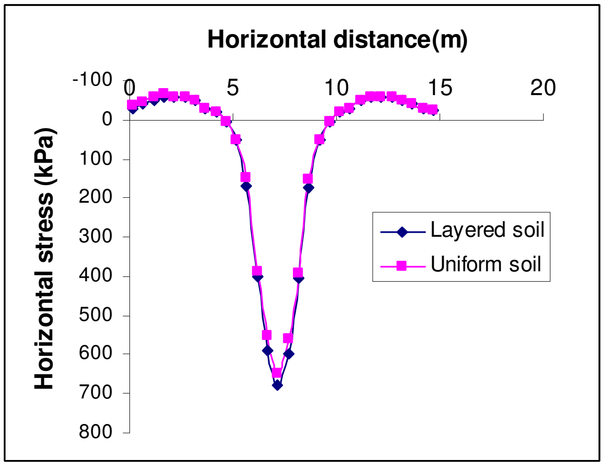

Figure 4: Horizontal stress on the horizontal plane at the base of the footing for linear analysis (Horizontal distance measured from the left of the mesh)

4.2. Analysis of a Strip Footing Resting on a Nonlinear Soil

In this analysis the soil is modelled using nonlinear hyperbolic model. Newton-Raphson method is used to iteratively solve the nonlinear finite element equations. The constant of this model, a and b are assumed to be 0.023 and 0.002 respectively. The soil was considered to be uniform throughout the domain. The load was applied with an increment of 40 kN/m^2 till a settlement of 25mm was achieved. The results so obtained are compared with the results of the linear analysis of uniform soil. Figure 5-6 shows these results. It can be observed from the analysis that (i) linear analysis underestimate the settlement and (ii) overestimate the load corresponding to a given settlement.

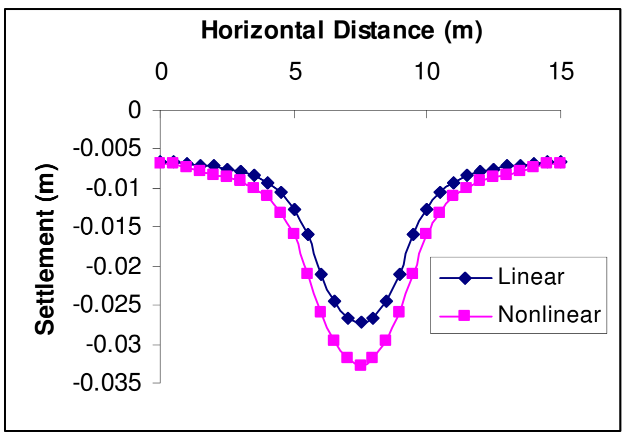

Figure 5: Settlement on the horizontal plane at the base of the footing (Horizontal distance measured from the left of the mesh)

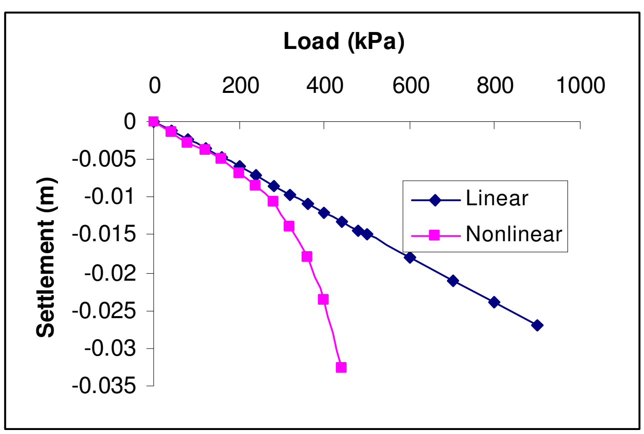

Figure 6: Load vs settlement at the base along the centerline of the footing (Horizontal distance measured from the left of the mesh)

5. Conclusion

In this study, a finite element (FE) program is formulated to study the deformation characteristic of layered soil under a footing considering the constitutive behaviour of the soil to be linear as well as nonlinear. As a programming language MATLAB is used. A flexible strip footing is analysed using the FE program and the stress-strain and load settlement curves of the footing are compared for equivalent linear homogeneous soil, layered soil and nonlinear homogeneous soil. For linear analysis generalized Hooke's Law is used. For nonlinear analysis the hyperbolic model is used. The analysis of the results for a layered and equivalent uniform soil shows that the settlement at the center of the footing is less for the uniform soil as compared to the layered soil. The vertical stress directly below the centerline of the footing is almost similar from both the soil. From the comparison of the results of the nonlinear soil with that of the liner uniform soil, it can be observed that, settlement is underestimated by the linear analysis. Whereas, the load corresponding to linear analysis at 25mm settlement is found to be more than that from the nonlinear analysis.

6. References

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