International Journal of Science and Research (IJSR)
ISSN (Online): 2319-7064
Index Copernicus Value (2016): 79.57 | Impact Factor (2015): 6.391

Behaviour of Foundation in Layered Soils

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Abstract: ***General bearing capacity equations widely used are evolved by several investigators based on the conventional theories derived from the failure pattern of soil. This paper presents the behaviour of foundation resting on layered soils under vertical loading conditions which simulate the field conditions more accurately. The different modes of failure and the deformation patterns of foundation are determined by using finite element modeling. The parameters like thickness of soil layers, angle of friction and cohesion are varied in order to study their effect on failure pattern. The failure patterns of foundations on layered soils are found to be different from those from conventional theory. Different cases like a sand layer overlying clay soil, clay layer overlying sand layer, two clay layers with different values of cohesion were also analyzed by varying the thickness of overlying stratum (d). The failure patterns are explained for each case. In clay overlaying sand layer, the failure of the foundation is occurred mainly due to tilting, with more deflection at d/B =1, where B is the width of foundation. The maximum deflection occurred within the loading region. In sand overlaying clay layer, the displacement gradually decreased when d/B ratio is increased. The displacement is more at beyond the loading region. The stresses are increased gradually up to d/B ratio of 1.5. Failure is mostly by the punching type shear failure. Settlement was found to be reduced as angle of internal friction of the soil is increased. For cohesion ratio, (ratio of cohesion of first layer to second layer) C1/C2 = 0.5 (<1) the displacement was found to be decreased gradually with d/B ratio. The failure was initially by punching failure of soil (occurred at d/B = 0.5) and later the normal shear failure is observed. The displacement is less for C1/C2 = 10 (i.e. cohesion ratio >1) also the failure pattern was found to be by general shear failure.***

Keywords: Foundation, Layered soils, Settlement, Shear Failure

1. Introduction

Foundation design consists of two distinct parts: the ultimate bearing capacity of the soil under the foundation, and the tolerable settlement that the footing can undergo without affecting the superstructure. The ultimate bearing capacity aims at determining the load that the soil under the foundation can handle before shear failure; while, the calculation of the settlement caused by the superstructure should not exceed the limits of the allowed deformation for stability, function and aspects of construction.

Research on the ultimate bearing capacity problems can be carried out using either analytical solutions or experimental investigations. The former could be studied through theory of plasticity or finite element analysis, while the latter is achieved through conducting prototype, model and full-scale tests. A satisfactory solution is found only when theoretical results agree with those obtained experimentally.

While designing the foundation the properties of soils are considered to withstand the structure loads. Generally the soils are of different stratums in earth, they are not homogeneous in nature, different layers of subsoil's are occurred, they all have different soil properties. At many places there exists multi layered soil with different depths. Sometimes the hard strata overlay by the soft soil and vice versa. Properties like bearing capacity, settlement are considered while designing the foundation. The foundation will fail if the loading exceeds the bearing capacity of the soil. The failures are generally classified as general shear, local shear failure, and punching shear failures. In this paper the failure pattern of different properties of layered soils were observed. The finite element modeling software PLAXIS was used. PLAXIS software works on the principle of finite element method, the mechanical behavior of soils. The deformation, stress - strain relationship are shown in plaxis. Many researches were available to determine the ultimate bearing capacity of the layered soils, but very less study was available regarding the failure patterns in the layered soils. The motivation behind this research is to understand the failure pattern of the layered soils. For this purpose numerical modeling was done using the PLAXIS 2D software. In current study sand and clay were used. In this study the modeling of different soil layers were represented by clay overlaying sand and vice versa conditions. Deflection and deformation for the soil was observed under vertical loading condition. The behavior of foundation was studied for varying soil properties, angle of friction (Φ) and cohesive force (C), at different depth to width (d/B) ratio. In this study the finite element method (FEM) is used to determine the failure pattern and deformation of soil layers. PLAXIS 2D was used.

2. Literature Review

Omar et al. (1993) have conducted laboratory model test results for the ultimate bearing capacity of strip and square foundations on sand reinforced with geogrid layers. Based on the model test results, the critical depth of reinforcement and the dimensions of the geogrid layers for mobilizing the maximum bearing capacity ratio have been determined and compared. From this experiment, they have drawn conclusions that for development of maximum bearing capacity, the effective depth of reinforcement are 2B for strip footings and 1.4B for square footings. Further they have observed that maximum width of reinforcement layers for optimum mobilization of maximum bearing capacity ratio is 8B for strip footings and 4.5B for square footings.

Dash et al. (2001) have presented the laboratory test results of strip footings on geocell reinforced sand beds with additional planar reinforcement. The test results show that a layer of planar geogrid placed at the base of the geocell mattress further enhances the performance of the footings in terms of the load carrying capacity and the stability against rotation. The beneficial effect of this planar reinforcement layer becomes negligible at large heights of geocell mattress. From the experiments they have drawn conclusions that the cumulative beneficial effect of geocell mattress and planar geogrid layer is found to be maximum for h/B = 2, where h = depth of reinforcement from the base of footing and B = width of footing. The overall performance improvement reduces with the reduction in the base friction and interlocking of the encapsulated soil in the geocell pockets with the sub-grade soil through the aperture openings of basal geogrid. Mandal and Manjunath (1994) have conducted an extensive program of monotonically loaded footings. The study is aimed at investigating the effects of a single layer of geosynthetics reinforcing material on the improvement of bearing capacity and settlement characteristics of strip footings under plane strain conditions supported by compacted sand and also to study the effectiveness of placing the reinforcing layer horizontally and vertically. The bearing capacity increase due to the use of a geosynthetic layer has been expressed in terms of a non dimensional bearing capacity ratio (BCR). The study shows that the BCR could be improved up to 1.8 times when reinforcement is suitably located relative to the footing. The horizontal reinforcement is found to be more effective in improving the bearing capacity as compared to the vertical reinforcement.

Button (1953) He analyzed the bearing capacity of a strip footing resting on two layers of clay. He assumed that the cohesive soils in both layers are consolidated approximately to the same degree In order to determine the ultimate bearing capacity of the foundation; he assumed that the failure surface at the ultimate load is cylindrical, where the curve lies at the edge of the footing. The bearing capacity factor used depends on the upper soil layer and on the ratio of the cohesions of the lower/upper clay layers.

Reddy and Srinivasan (1967) they extended the work of Button to include the effect of the non-homogeneity and anisotropy of soil with respect to the shear strength. The basic assumptions involved in determining the ultimate bearing capacity are: the failure surface is cylindrical, the coefficient of anisotropy is the same at all points in the foundation medium, the soil in each layer is either homogeneous with respect to the shear strength or the shear strength in each layer varies linearly with depth.

In both papers, the assumption of cylindrical potential failure surface led to values of Nc is 7% higher than the values obtained by the Prandtl solution in the case of homogeneous subsoil. In the case of an-isotropic and non-homogeneous subsoil, the values are even higher and the error increases with increasing non-homogeneity of the two layers.

Mosadegh.A In this paper, finite element method (FEM) is applied to calculate bearing capacity of a strip footing on one-layer and two-layer soil. Computations are carried out using commercial finite element software, ABAQUS to assess effect of various geotechnical and geometric parameters on soil failure mechanism under the footing. Soil profile contains two soil types including sand and clay. Soil behavior is represented by the elasto-plastic Drucker-Prager model and footing material is assumed isotropic and linear elastic. For a homogenous soil profile, the effect of soil properties such as dilation angel and initial condition as well as footing roughness are assessed on soil failure mechanism under the footing. For this case, the bearing capacity is also obtained which has a good agreement with Terzaghi’s calculation. For a layered soil, soft-over-strong soil, the effect of layer thickness, soil shear strength and material property on bearing capacity value and failure mechanism is studied. It is concluded that the bearing capacity of footing decreases as the height of clayey soil increases whilst the displacement under footing increases. However, the stronger bottom layer does not affect ultimate bearing capacity value of footing and displacement of footing after some thickness of clayey soil on top.

3. Finite Element Analysis

3.1 Introduction

Numerical analysis is a powerful mathematical tool that makes it possible to solve complex engineering problems. The finite-element method is a well-established numerical analysis technique used widely in many civil engineering applications, both for research and the design of real engineering problems.

PLAXIS is a FEM package used for analysis of stability and deformation of structure. It is developed at the Technical University of Delft. At the initial stage, this was used to analyses the soft soil river embankments of the lowlands of Holland. But later, a company named PLAXIS BV was formed, and expansion of the program was done to address a wide range of geotechnical issues. It requires advanced and anisotropic behavior of soils and rock for analysis purpose. As soil being a material with multiple phases, some additional methods are adopted to take care of hydrostatic and non-hydrostatic pore pressures within the soil. Here, the modeling of the soil is an important aspect. But many projects require the modeling of structures and the interaction between soil and structure.

3.2 Testing Procedure

First a geometric model of dimension is created. The footing of size is placed on the top surface of the soil model at desired position at the center or a distance away from it according to different eccentricities. A very fine mesh is generated in the geometry. An incremental vertical load is applied on the surface of the footing, according to different loading conditions. Then the loading point of the soil model is selected for the analysis. The calculations are done until the failure of the soil. The load- settlement curve obtained from the output gave the ultimate bearing capacity & settlement of the circular footing by using different method for different loading conditions. Same procedure is adopted for different loading conditions.

Figure 1: General Procedure of Analysis

4. Methodology

4.1 Details of Current Model

In the present study the behavior of layered soils are studied systematically. The size foundation is 2.5m X 2.5m. The properties of soils changes for each case. The vertical uniformly distributed load of 50kN/m is applied. The properties of clay and sand taken from the Evaluation of strength - strain characteristics of fiber reinforcement soil through laboratory test.

Case 1. Clay layer is overlay in Sand layer vice versa:
In this the depth of clay layer is increased gradually and depth of sand layer is kept 5m. The different thickness of clay layers are 0.5 m, 1.25 m, 2.5 m, 3.75 m, 5 m. According to the depth (d) to width of foundation (B) ratio the deformation and settlement of soil is taken. The properties of clay and sand soils are giving Table-1.

Table 1: Properties of Clay and Sand

Parameter	C	Φ	E kN/m^2	$\gamma_u$nsat kN/m	γ_s at kN/m	ν
Clay	2	2	200	15	18	0.3
Sand	1	3	200	17	20	0

Using the above properties the models are made at different depth to width of foundation ratio (d/B) is 0.2, 0.5, 1.0, 1.5, and 2.0.

Case 2. Sand Over layer in clay with different angle of frictions (Φ)
In this case same values of clay and sand is taken but the angle of friction Φ value is changes as 20, 35, 40 degrees. The properties of clay and sand for different values of angle of friction shown in Table-2.

Table 2: The Properties of Clay and Sand with Different Angle of Friction for Sand.

Table 2(A): Angle of Friction for Sand is 20^0

Parameter	C	Φ	E kN/m	γuns	γsat	ν
Clay	2	25	200	15	18	0.3
Sand	1	20	200	17	20	0

Table 2(B): Angle of Friction for Sand is 35^0

Parameter	C	Φ	E kN/m^2	$\gamma_u$nsa	γ_s at	ν
Clay	2	25	200	15	18	0.3
Sand	1	35	200	17	20	0

Table 2(C): Angle of Friction for Sand is 40^0

Parameter	C	Φ	E kN/m^2	γunsat	γsat	ν
Clay	2	25	200	15	18	0.3
Sand	1	20	200	17	20	0

Case 3. Clay layers with the changing cohesion value (c)
In this case mainly the cohesion ratio of two layers is considered. Different cohesion ratio which is less than 1 (<1) and greater than 1 (>1) for different depth to width ratio (d/B).

a) For less than 1 (<1); (C1/C2=0.5):
The Cohesion values are different as show in Table-3(A).

Table 3(A): Clay1 & Clay 2 Properties

Parameter	C	Φ	E kN/m^2	γun sat	γsat	ν
Clay 1	1	43.	186	18	20	0.3
Clay 2	2	25	200	15.5	18	0.3

b) For greater than 1 (>1); (C1/C2=5); (C1/C2=10); (C1/C2=20):
In the clay 1 cohesion (C1) is changed and clay 2 properties are remain same, Table-3(B).

Table 3(B): Clay1 & Clay 2 Properties

Parameter	C	Φ	E	γun kN/ sat m^3	γsa kN/t m^3	ν
Clay 1	10	43.	186	18	20	0.3
Clay 1	20	43.	186	18	20	0.3
Clay 1	40	43.	186	18	20	0.3
Clay 2	2	25	200	15.5	18	0.3

5. Results and Discussions

Case-1: Clay Layer is overlay in sand layer vice versa

- In this case the Displacement is more for clay over lay by sand compared to the sand overlay by clay.
- In clay overlay by sand the failure of the foundation is occurred like tilted, the maximum deflection at d/B=1 occurred. The maximum deflection occurred at within the loading region.
- In Sand overlay by clay the displacement is gradually decreased if d/B ratio is increased. The displacement is more at beyond the loading region. The stresses are increased gradually up d/B ratio is 1.5.

Deformation of soil layers in Case 1 with Different d/B ratios:
1) *d/B = 0.5*

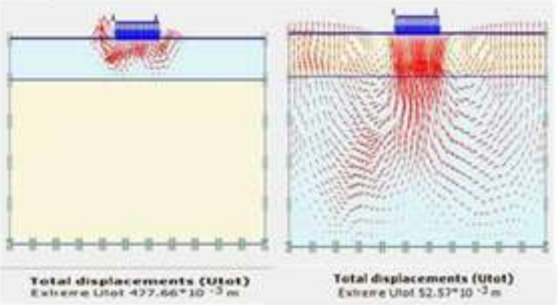

Figure 4.1: Deformation Model for Case 1 with D/B = 0.5

2) d/B = 1.0

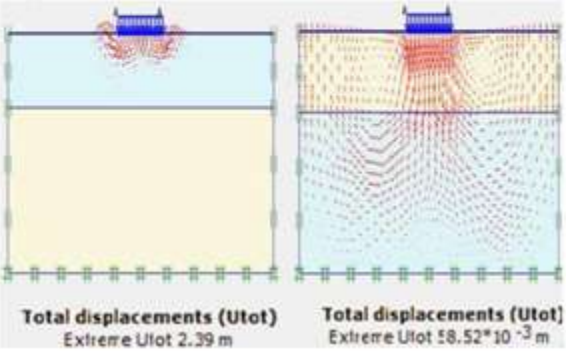

Figure 4.2: Deformation model for case 1 with d/B = 1.0

3) d/B= 1.5

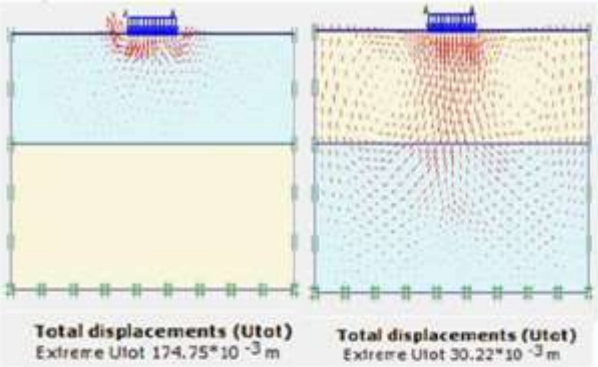

Figure 4.3: Deformation model for case 1 with d/B = 1.5.

4) At d/B = 2.0

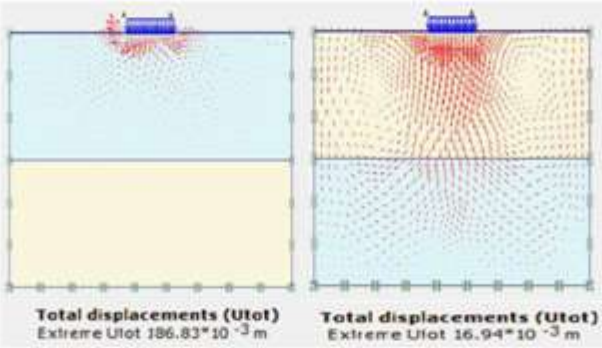

Figure 4.4: Deformation model for case 1 with d/B = 2.0.

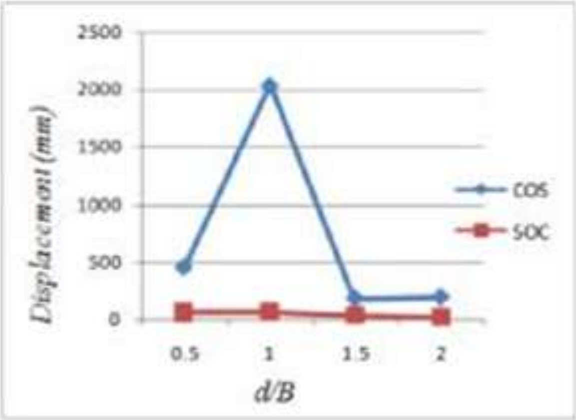

Figure 4.5: Displacement Vs d/B of clay overlay sand and vice versa.
COS - Clay overlay in sand
SOC - Sand overlay in clay

6. Conclusions

Hence the failure pattern of standard methods is not suitable for all types of soil properties. If the properties of soil changes the failure of foundation is changed.

- The failure pattern of layered soil is found to be entirely different as the thickness of the first layer is increasing.
- The behaviour of failure pattern when clay overlay sand was significantly different to a vice versa case.
- The cohesion and angle of friction value o the soil also found to alter the failure pattern.

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