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Evaluation on Bearing Capacity of Ring Foundations on two-Layered Soil

R. Ziaie Moayed[1], V. Rashidian[2],and E. Izadi[3]

***Abstract*—**This paper utilizes a finite element analysis to study the bearing capacity of ring footings on a two-layered soil. The upper layer, that the footing is placed on it, is soft clay and the underneath layer is a cohesionless sand. For modeling soils, Mohr–Coulomb plastic yield criterion is employed. The effects of two factors, the clay layer thickness and the ratio of internal radius of the ring footing to external radius of the ring, have been analyzed. It is found that the bearing capacity decreases as the value of $\boldsymbol{r_i / r_o}$ increases. Although, as the clay layer thickness increases the bearing capacity was alleviated gradually.

***Keywords*—**Bearing capacity, Ring footing, Two-layered soil

I. Introduction

BEHAVIOUR of shallow foundations on soil is one of the most interesting topics in geotechnical engineering. Up to now, many experimental and numerical studies have been made to determine the bearing capacity of shallow foundation on soils. In recent years, numerical methods, such as Finite Element Method (FEM) [3-6] and the Finite Difference Method (FDM) [7, 8], have been widely used to compute the bearing capacity of strip and circular footings.Nowadays, more and more ring footings are used in practice. They are usually used for symmetrical buildings like silos, chimneys, water tower, oil storages, tanks and etc. Therefore, the theoretical prediction of ultimate bearing capacity for ring footings is a requirement in the design of mentioned structures. Some experiments have also been performed to compute the bearing capacity of ring foundations [9-11]. Reference [12] determined the load deformation response of rigid ring footings by finite element method. Reference [13] investigated the bearing capacity factor Nc for both smooth and rough ring footings by using the method of characteristics, assuming that the interface friction angle between the footing base and the underlying soil mass increases gradually from zero along the footing centerline to along the footing bas.In this study, a finite element software, ABAQUS, will be used to determine how the bearing capacity of ring footing will be changed as the value of r_i / r_o increase; where r_i and r_o are the inner and outer radius of the ring foundation, respectively.

R. ZiaieMoayed, Associate Professor, Civil Engineering Department, Imam Khomeini International University (phone: 281-837-1153; fax: 281-837-1153; e-mail: R_ziaie@ikiu.ac.ir).
V. Rashidian, M.Sc. Student, Civil Engineering Department, Imam Khomeini International University (e-mail: Vahidrashidian@gmail.com).
E. Izadi, M.Sc. Student, Civil Engineering Department, Imam Khomeini International University (e-mail: Ehsanizadi@ikiu.ac.ir).

II. Problem definition

The problem for this study is defined as in Fig. 1. The relatively rigid ring footing is specified with internal radius r_i and external radiusr_o, respectively. The footing base rests on a two-layer soil with a horizontal ground surface. The first layer, which the footing is placed on it, is soft clay and the underneath layer is sand. The ring foundation is subjected to a vertical stress.

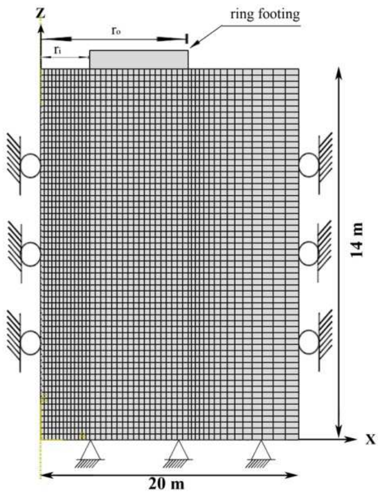

Fig. 1 Grid of axis-symmetric model and boundary conditions

When the ground is loaded with a uniform surcharge pressure (q), according to Terzaghi's [1] formula, the bearing capacity of a shallow, strip footing can be obtained from the following equation:

$$q_u = cN_c + qN_q + 0.5\gamma BN_\gamma \quad (1)$$

Where c is cohesion; q represents the equivalent surcharge; $\gamma$is unit weight; B is footing width, N_c, $N_q$and $N_\gamma$are the bearing capacity factors, which are dependent solely on the friction angle. For the axially loaded circular footings, which has a width of B and rests on the surface of the soil (no surcharge) with a unit weight γ, Erickson and Drescher [14] proposed the generalized bearing capacity formula as follows:

$$q_u = F_{cs}cN_c + 0.5F_{\gamma s}\gamma BN_\gamma \quad (2)$$

Where $N_c$and N_γ are bearing capacity factors of strip footings; $F_{cs}$and $F_{\gamma s}$ are factors accounting the shape of footings. In the literature, there are expressions and tables for the bearing capacity and shape factors [1, 15-18]. But the characteristics of most of these factors are almost the same. According to [14], the shape factors can be considered to modify the bearing capacity factors by $N_c' = F_{cs}N_c$ and $N_\gamma' = F_{\gamma s}N_\gamma$. For strip footings $F_{cs} = F_{\gamma s} = 1$ and $N_c' = N_c$ and $N_\gamma' = N$. However, for the ring footings, the bearing capacity factors depend not only on the frictional angle ϕ but also on the internal radius r_i, the external radius r_o and the ratio of r_i/r_o.

III. Numerical Simulation

In the present model, the ratio of internal radius r_i to external radius r_o is taken 0, 1/3 and 2/3 .Also the value of external radius is considered 3m, 5m and 8m. The total soil depth is 20m and the clay layer depth which is the upper layer will be 2m, 5 m and 9 m. In numerical simulations, the Young's modulus of clay considered being 5MPa, and the sand Young's modulus is 30MPa. The unit weight of clay, γ_c is 16 kN/m^3 and the sand unit weight, γ_s is 18 kN/m^3 . The clay's cohesion, c = 20 kPa. The sand layer is cohesionless and its friction angle, ϕ =30°. The dilation angle, ψ, for the clay layer and sand layer are 0° and3°, respectively.

Since the model is axis-symmetric, only symmetrical plane of the problem domain is considered. For making the ''boundary condition'' on the estimation of the collapse load negligible, the domain is given a depth of 20 m and extends 14 m from the centerline of the ring footing. The domain is divided into nearly 2200 square element.

The left vertical side of the domain is axis-symmetry axis and in right and left vertical sides only vertical displacement is allowed. The bottom edge is constrained in vertical and horizontal direction. Also the right vertical side is constrained in horizontal direction. The soil –footing interaction has ''tangential'' and ''normal'' behavior using penalty type of formulation with the coefficient of 0.6. Before loading the footing, the initial gravitational stresses are simulatedby attributing an initial stress state to the soil at the clay-sand interface and at the deepest depth of the sand. Stress in the vertical direction is equal to the product of unit self-weight of soil and the distance of mentioned depth from the surface. Horizontal stresses are obtained by using the coefficient of earth at rest, K_0, which is calculated from Jacki's formula. According to Jacki's formula for sand

$$K_0 = 1 - \sin\phi = 0.5 \tag{3}$$

And for clay

$$K_0 = 0.95 - \sin\phi = 0.85 \tag{4}$$

So for the sand which friction angle is30°, K_0 will be 0.5 and for the clay which friction angle is5°, K_0will be 0.85.

In this study, because the objective is to find the maximum load which soil can undergo, the admissible values of settlement have been disregarded.

IV. Analysis and Discussion

Load versus r_i/r_o ratio curves for different external radius and clay layer thickness are illustrated in Fig. 2-4. It is observed that the bearing capacity of ring footing decrease with an increase in r_i/r_o ratio when external radius of ring is 5 or 8. However when the external radius of ring is 3 the procedure is almost opposite. Furthermore, from this figure, it is obvious as the clay layer depth increases the soil reach the failure state earlier and this means the bearing capacity decreases.

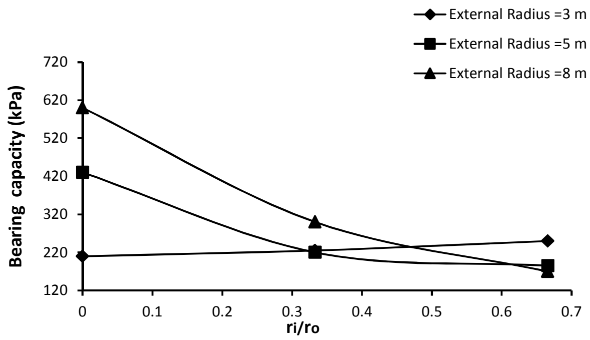

Fig. 2 Bearing capacity changes with increase in ri/ro ratio when clay layer thickness is 2 (m)

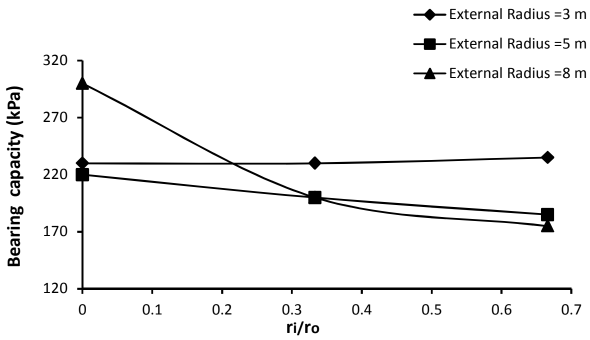

Fig. 3 Bearing capacity changes with increase in ri/ro ratio when clay layer thickness is5 (m)

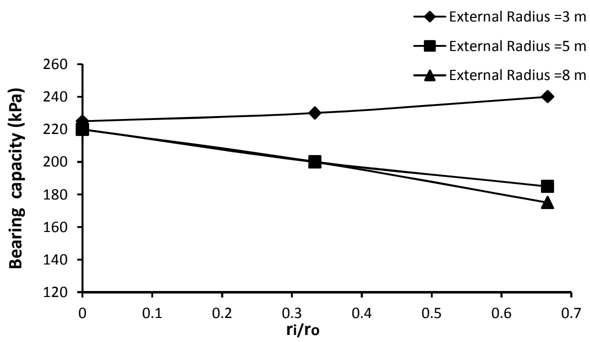

Fig. 4 Bearing capacity changes with increase in ri/ro ratio when clay layer thickness is 9 (m)

Load versus clay layer thickness curves are shown in Fig. 5 -7.It is found that the bearing capacity changes are tangible when ri/ro ratio is zero. When ri/ro is 1/3, bearing capacity is not influenced significantly by changing in clay layer thickness compared with when ri/ro is zero. Also it is found that when ri/ro is 2/3, changing in clay layer thickness has almost no effect on bearing capacity.

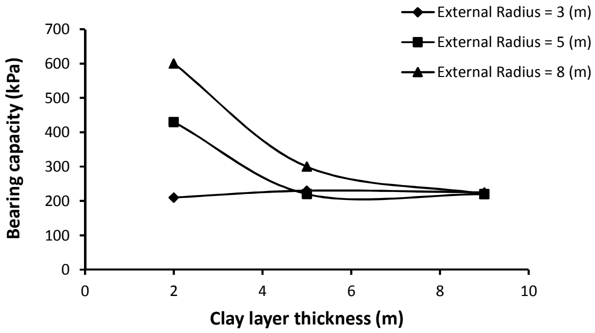

Fig. 5 Bearing capacity changes with increase in clay layer thickness when ri/ro ratio is 0

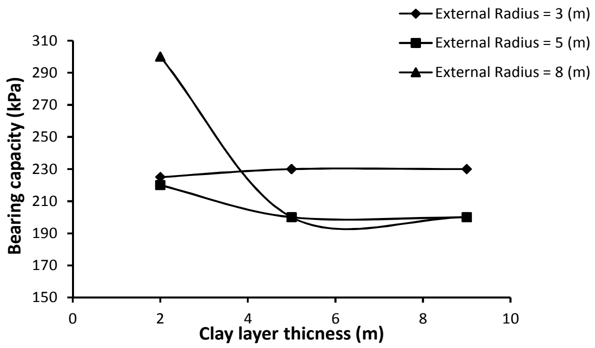

Fig. 6 Bearing capacity changes with increase in clay layer thickness when ri/ro ratio is 1/3

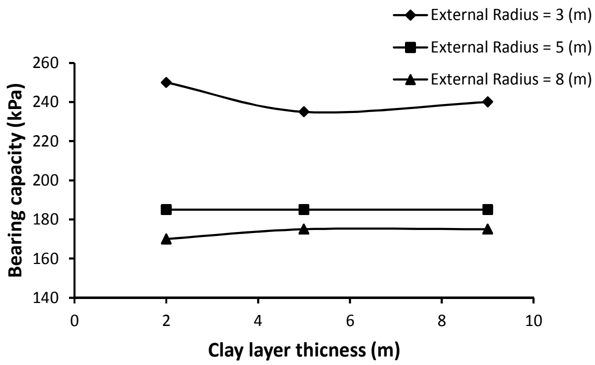

Fig. 7 Bearing capacity changes with increase in clay layer thickness when ri/ro ratio is 2/3

Fig. 8-13 show the displacement vector field according to ultimate state of shear failure for different clay layer depth. The displacement increases with loading steps until soil reaches failure state and when the soil beneath the ring footing reaches the state of failure, the evident steady plastic flow occurs. It is also observed that displacement vectors dominantly remain in clay layer; it means as the clay layer depth increase the displacement vectors also propagate in clay layer and almost do not enter the sand region and when the clay layer depth decrease the displacement vector also being restricted in clay layer.

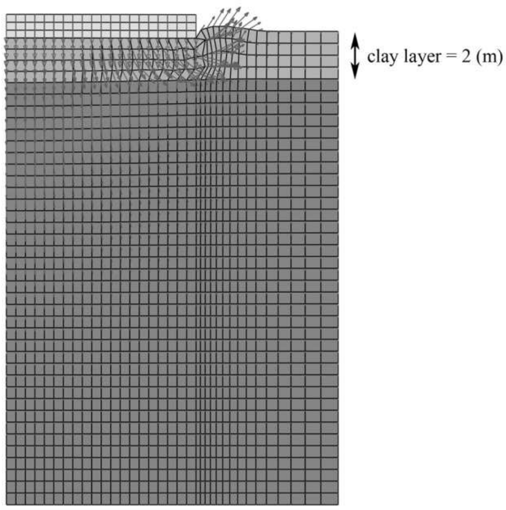

Fig. 8 Displacement vector field for r_i/r_o= 0, clay layer thickness = 2 (m) and external radius = 8 (m)

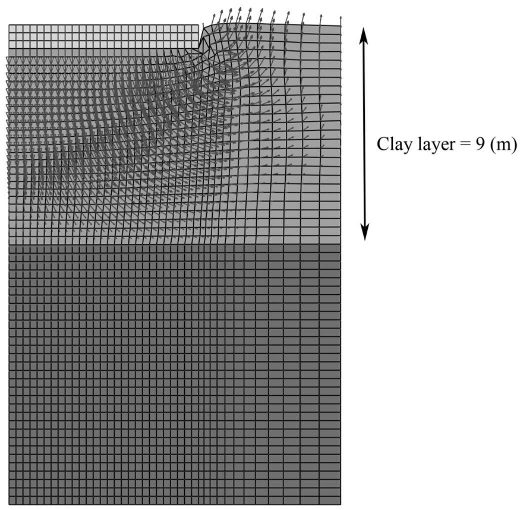

Fig. 9 Displcement vector field for r_i/r_o= 0, clay layer thickness= 9(m) and external radius = 8 (m)

It is observed that the bearing capacity decreases as the clay layer thickness increases. The reason for this phenomenon is when the clay layer thickness is low (e.g. 2m or less) the underneath sand layer contribute more in the stress distribution. Regarding the stiffness of the underneath sand layer is relatively high, it takes more energy and as a consequence more stress.

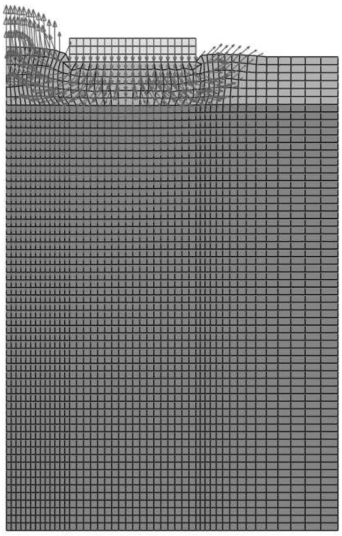

Fig. 10 Displacement vector field for r_i/r_o= 1/3, clay layer thickness = 2 (m) and external radius = 8 (m)

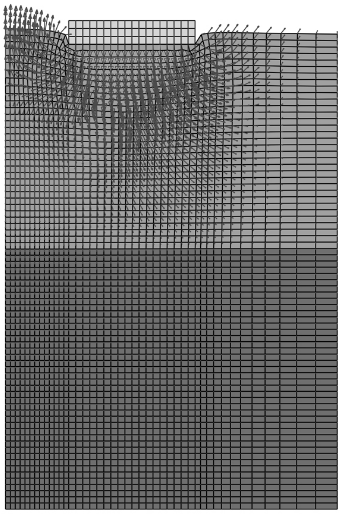

Fig. 11 Displacement vector field for r_i/r_o= 1/3, clay layer thickness = 9 (m) and external radius = 8 (m)

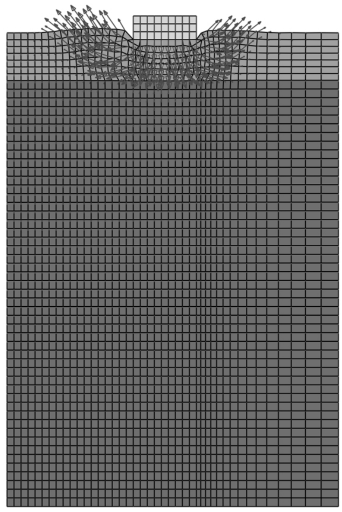

Fig. 12 Displacement vector field for r_i/r_o= 2/3, clay layer thickness = 2 (m) and external radius = 8 (m)

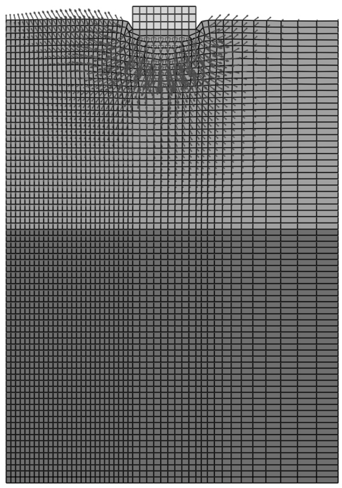

Fig. 13 Displacement vector field for r_i/r_o= 2/3, clay layer thickness = 9 (m) and external radius = 8 (m)

V. Conclusion

The numerical simulation for computing the two-layer soil ultimate bearing capacity which is beneath the rigid ring footing is presented. The soil is modeled as an elastic-plastic material obeying Mohr-Coulomb yield criterion. Bearing capacity of ring footing is computed using finite element software, ABAQUS.

From the result of numerical simulation, it is found that the bearing capacity decrease as the r_i/r_o ratio increase. Also it is found that as the clay layer, which the ring footing is simulated on it, increases in depth, the bearing capacity decreases gradually. Furthermore, as the r_i/r_oratio increases, changing in clay layer thickness has no significant effect on bearing capacity.Also it is found from the displacement vector field, as the clay layer depth increase the displacement vectors also propagate in clay layer and almost do not enter the sand region and when the clay layer depth decrease the displacement vector also being restricted in clay layer.

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