International Journal of Science and Research (IJSR)
ISSN (Online): 2319-7064
Index Copernicus Value (2015): 78.96 | Impact Factor (2015): 6.391

Evaluating the Behavior of Ring Footing on Two-Layered Soil Subjected to Inclined Load

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Abstract: ***Evaluating the behavior of a ring foundation resting on multi-layered soil is one of the important issues facing civil engineers. Many researchers have studied the behavior of ring foundation rests on multi-layered soil with vertical loads acting on the foundation. In real life ring foundation can be subjected to both vertical and horizontal loads at the same time due to wind or the presence of soil. In this research, the behavior of ring footing subjected to inclined load has been studied using PLAXIS software. Furthermore, the effect of multi-layered soil has been simulated in the model. The results showed that both vertical and horizontal stresses are mainly affected when the inclination angle of the load exceeded 45 degrees with a reduction of (40-80) % when they compared to those with an inclination angle of 0 degrees. Furthermore, the bending moment and shear forces within the footing were affected by the ratio of inner diameter to the outer diameter and by the inclination angle of the load.***

Keywords: Ring Footing, Two-Layered soil, Load inclination, PLAXIS software.

1. Introduction

In different engineering problems preparation of foundation for construction of structure assumes many significant aspects such as strength of the foundation, bearing capacity of the soil, settlement of structure and foundation, and types of foundation. The decision of an engineer may depend on the geological map of the site, the type of soil, the type of structure, and the nature of the load. In the last few years, the use of ring footings is considered more suitable and economical for axisymmetric structures such as silos, water tower structures, chimneys, and storage tanks. Using a ring footing may fully utilize the soil capacity with less or no tension under the foundation. Moreover, the presence of multi-layered soil beneath the foundation can be considered one of the difficult issues facing geotechnical engineers. Many researches have been done regarding to this issue using finite element technique. Mehrjardi, G. T. [1] found that the ring footings are more suitable and economical than circular footings in supporting axisymmetric structures such as bridge piers, underground stops, water tower structures, TV antenna, silos, and chimney. The author made a comparison between circular footing and strip footing and he found that the failure scenario varies from general shear failure to punching failure when the ratio of inner to outer radius reaches (0.4).

Choobbasti, A. J. et al. [2] used PLAXIS software to evaluate the ultimate bearing capacity and settlement of ring footings and came up with the following findings:

1) Bearing capacity varies linearly with depth of footing.
2) N_c and N_q are decreased with the increment of the inner to the outer radius ratio.
3) When the ratio of inner to outer radius exceeds 0.6, the behavior of a ring footing approaches the behavior of a strip footing.

In 2012, Moayed, R. Z. et al. [3] computed the bearing capacity of ring footing, using ABAQUS software, rests on a two layered soil in which the upper were soft clay while the second layer was cohesionless sand. The effect of the clay layer thickness and the radius ratio were investigated and the following conclusions have been made:

1) The bearing capacity of the soil decreases as the radius ratio increases.
2) An increment in the depth of the clay layer reduces the bearing capacity gradually.

Prasad, N., and Reddy, M. [4] used simplified method with specific characteristics such as young modulus, Poisson's ratio, and diameter of the footing with two layered soil system to evaluate the stress distribution under the stiff layer in order to control the settlement and improve soil property. In 2013, Al-Sumaiday, H. G. and Al-Tikrity, I. S. [5] evaluated the bearing capacity of ring and circular footings on sand by laboratory model tests and study the effect of changing the radius ratio on it.

2. List of Symbols

Nc, Nq	Bearing capacity factors (non-dimensional)
$\gamma_{unsat.}$	Dry unit weight of soil
$\gamma_{sat.}$	Saturated unit weight of soil
E	Modulus of Elasticity
υ	Poisson ratio
C	Cohesion of soil
φ	Angle of internal friction of soil

3. Problem Definition

The problem in this research is shown in figure (1). The ring footing was simulated as an elastic model with inner radius (R_i) range from (0-1.2) m and outer radius of 2 m (R_o) with a thickness of 0.5 m rested on a two layer. The footing material was concrete with a compressive strength of 30 MPa, Passion's ratio of 0.2 as recommended by literature, and young modulus of $25.7 \times 10^6\ kN/m^2$.The upper layer was

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weak sand layer with saturated unit weight of (17 kN/m^3) which rests on strong clay layer with saturated unit weight of (19 kN/m^3).

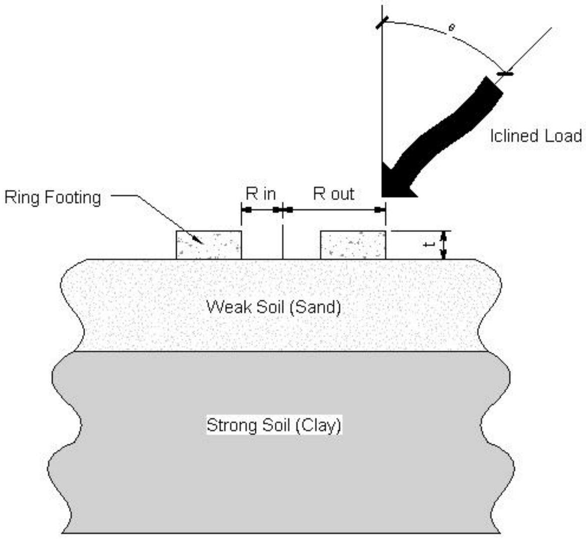

Figure 1: The model of the problem

The properties of both weak and strong soil layers are listed in Table (1). The simulated soil mass was limited to two times the outer diameter of the footing from each side and a depth of four times the outer diameter of the footing. The boundaries of the simulated soil mass, at which 95% of the load effects is dissipated, have been estimated based on analytical solution of theory of elasticity of semi-infinite media [6]. The boundary conditions have been selected as rollers on both sides of the soil mass and hinges at its bottom. An inclined load with angle varying from (0-90) degrees has been applied on the footing.

Table 1: Soil Layers Properties

Property	Weak Soil (Sand)	Strong Soil (Clay)
$\gamma_{unsat.}$	16 kN/m^3	18 kN/m^3
$\gamma_{sat.}$	17 kN/m^3	19 kN/m^3
E	40000 kN/m^2	80000 kN/m^2
υ	0.35	0.35
C	1 kN/m^2	35 kN/m^2
φ	25°	5°

4. The Model

In this research, the ring footing and the two –layered soil have been simulated in a finite element model using PLAXIS software as axisymmetric model. The footing was simulated by an elastic model while the soil layers modeled with Mohr-Coulomb model which implemented using sharp transition from one yield surface to another. A triangular element with 15-nodes has been used solving the equations with Gaussian integration concept as shown in Figure (2).

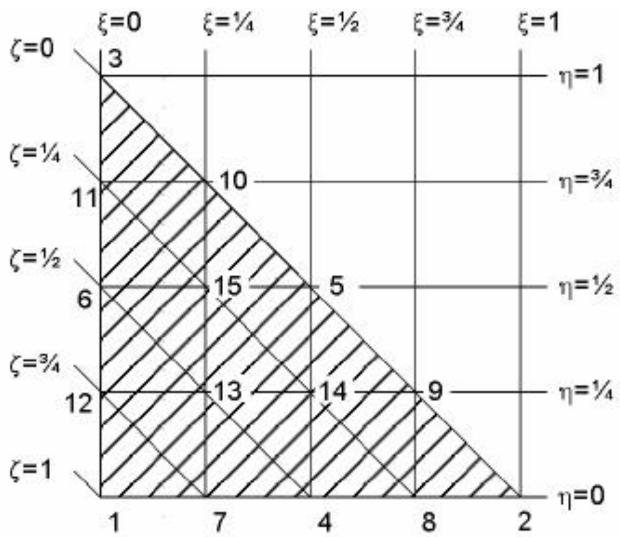

Figure 2: Local Numbering and Positions of Nodes

The effect of the load inclination has been studied through this model by changing the angle of the applied load to be (0,30, 45, 60, and 90) degrees. Also, the effect of the inner diameter to the outer diameter of the ring footing has been investigated by changing the ratio from 0 up to 0.6 with an increment of 0.2. The properties of the soil layers, the footing, and the applied loads have been kept fixed to focus on the effects of the load inclination, and the ratio of the inner diameter to the outer diameter of the footing. A model has been conducted for each inclination angle and radius ratio.

5. The Results

Based on the finite element models described in the previous sections, the horizontal stresses and vertical stresses were obtained for 8 points as shown in Figure (3).

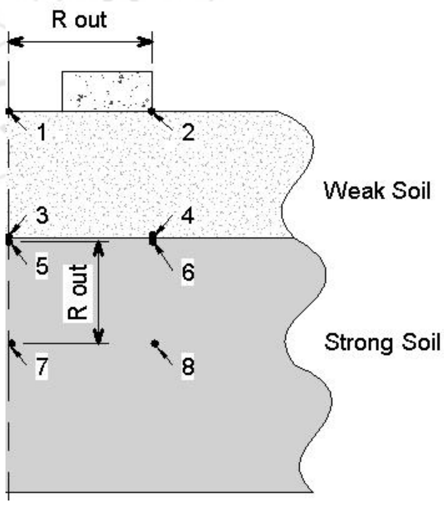

Figure 3: Locations of Selected Points of Interest

The results obtained from the PLAXIS were normalized by dividing the stresses obtained from the inclined cases on the related stresses from those with vertical loads only. The normalized results for the horizontal stresses at the selected points are presented in Tables (2) up to Table (9). While the normalized results for the vertical stresses at the selected

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points are presented in Tables (10) up to Table (17)

Table 2: Horizontal S_{xx} stresses for Point (1)

R_{in} / R_{out}	0	0.2	0.4	0.6
θ, deg	$S_{xx_{Inclined}} / S_{xx_{Vertical}}$			
0	1.00	1.00	1.00	1.00
30	0.86	0.70	0.26	0.71
45	0.69	0.46	0.41	-0.17
60	0.49	0.22	0.91	-0.08
90	0.09	-0.09	0.12	-0.04

Table 3: Horizontal S_{xx} Stresses for Point (2)

R_{in} / R_{out}	0	0.2	0.4	0.6
θ, deg	$S_{xx_{Inclined}} / S_{xx_{Vertical}}$			
0	1.00	1.00	1.00	1.00
30	0.84	0.83	0.80	0.81
45	0.81	0.65	0.60	0.64
60	0.68	0.42	0.39	0.44
90	0.38	0.19	0.17	0.21

Table 4: Horizontal S_{xx} Stresses for Point (3)

R_{in} / R_{out}	0	0.2	0.4	0.6
θ, deg	$S_{xx_{Inclined}} / S_{xx_{Vertical}}$			
0	1.00	1.00	1.00	1.00
30	0.88	0.86	0.88	0.92
45	0.68	0.68	0.72	0.83
60	0.54	0.56	0.63	0.72
90	0.43	0.45	0.51	0.60

Table 5: Horizontal S_{xx} Stresses for Point (4)

R_{in} / R_{out}	0	0.2	0.4	0.6
θ, deg	$S_{xx_{Inclined}} / S_{xx_{Vertical}}$			
0	1.00	1.00	1.00	1.00
30	0.99	1.05	1.04	1.00
45	1.07	1.11	1.05	1.01
60	1.09	1.12	1.06	1.01
90	1.10	1.13	1.07	1.02

Table 6: Horizontal S_{xx} Stresses for Point (5)

R_{in} / R_{out}	0	0.2	0.4	0.6
θ, deg	$S_{xx_{Inclined}} / S_{xx_{Vertical}}$			
0	1.00	1.00	1.00	1.00
30	1.03	0.39	2.40	1.08
45	1.11	0.70	-0.18	-0.11
60	-0.20	-0.05	1.23	1.24
90	0.27	0.11	0.54	0.39

Table 7: Horizontal S_{xx} Stresses for Point (6)

R_{in} / R_{out}	0	0.2	0.4	0.6
θ, deg	$S_{xx_{Inclined}} / S_{xx_{Vertical}}$			
0	1.00	1.00	1.00	1.00
30	0.87	0.87	0.89	0.91
45	0.74	0.74	0.77	0.81
60	0.59	0.60	0.65	0.81
90	0.42	0.44	0.51	0.67

Table 8: Horizontal S_{xx} Stresses for Point (7)

R_{in} / R_{out}	0	0.2	0.4	0.6
θ, deg	$S_{xx_{Inclined}} / S_{xx_{Vertical}}$			
0	1.00	1.00	1.00	1.00
30	0.80	0.80	0.86	1.00
45	0.64	0.66	0.78	1.04
60	0.58	0.62	0.81	1.06
90	0.52	0.55	0.73	1.01

Table 9: Horizontal S_{xx} Stresses for Point (8)

R_{in} / R_{out}	0	0.2	0.4	0.6
θ, deg	$S_{xx_{Inclined}} / S_{xx_{Vertical}}$			
0	1.00	1.00	1.00	1.00
30	0.99	1.00	1.00	1.00
45	1.01	0.99	0.99	1.00
60	1.00	0.98	0.98	0.99
90	0.98	0.97	0.97	0.98

Table 10: Vertical S_{yy} stresses for Point (1)

R_{in} / R_{out}	0	0.2	0.4	0.6
θ, deg	$S_{yy_{Inclined}} / S_{yy_{Vertical}}$			
0	1.00	1.00	1.00	1.00
30	0.85	1.05	1.40	0.05
45	0.69	0.83	1.67	-1.90
60	0.49	0.37	3.39	-2.44
90	0.08	-0.01	0.70	-0.65

Table 11: Vertical S_{yy} Stresses for Point (2)

R_{in} / R_{out}	0	0.2	0.4	0.6
θ, deg	$S_{yy_{Inclined}} / S_{yy_{Vertical}}$			
0	1.00	1.00	1.00	1.00
30	0.90	0.84	0.85	0.92
45	0.77	0.66	0.68	0.83
60	0.61	0.47	0.52	0.69
90	0.31	0.24	0.28	0.43

Table 12: Vertical S_{yy} Stresses for Point (3)

R_{in} / R_{out}	0	0.2	0.4	0.6
θ, deg	$S_{yy_{Inclined}} / S_{yy_{Vertical}}$			
0	1.00	1.00	1.00	1.00
30	0.92	0.91	0.91	0.93
45	0.79	0.77	0.79	0.84
60	0.63	0.62	0.67	0.72
90	0.32	0.32	0.39	0.46

Table 13: Vertical S_{yy} Stresses for Point (4)

R_{in} / R_{out}	0	0.2	0.4	0.6
θ, deg	$S_{yy_{Inclined}} / S_{yy_{Vertical}}$			
0	1.00	1.00	1.00	1.00
30	0.94	0.97	0.97	0.96
45	0.90	0.94	0.91	0.93
60	0.82	0.85	0.84	0.88
90	0.66	0.70	0.71	0.78

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Table 14: Vertical S_{yy} Stresses for Point (5)

R_{in} / R_{out}	0	0.2	0.4	0.6
θ, deg	$S_{yy_{Inclined}} / S_{yy_{Vertical}}$			
0	1.00	1.00	1.00	1.00
30	0.82	0.57	1.89	1.04
45	0.87	0.87	-0.04	-0.05
60	-0.04	-0.03	1.10	1.47
90	0.05	0.02	0.44	0.40

Table 15: Vertical S_{yy} Stresses for Point (6)

R_{in} / R_{out}	0	0.2	0.4	0.6
θ, deg	$S_{yy_{Inclined}} / S_{yy_{Vertical}}$			
0	1.00	1.00	1.00	1.00
30	0.92	0.92	0.93	0.93
45	0.83	0.83	0.85	0.86
60	0.73	0.74	0.77	0.80
90	0.52	0.53	0.57	0.62

Table 16: Vertical S_{yy} Stresses for Point (7)

R_{in} / R_{out}	0	0.2	0.4	0.6
θ, deg	$S_{yy_{Inclined}} / S_{yy_{Vertical}}$			
0	1.00	1.00	1.00	1.00
30	0.92	0.92	0.92	0.93
45	0.83	0.83	0.84	0.87
60	0.73	0.74	0.77	0.80
90	0.52	0.53	0.57	0.62

Table 17: Vertical S_{yy} Stresses for Point (8)

R_{in} / R_{out}	0	0.2	0.4	0.6
θ, deg	$S_{yy_{Inclined}} / S_{yy_{Vertical}}$			
0	1.00	1.00	1.00	1.00
30	0.97	0.97	0.97	0.98
45	0.96	0.94	0.94	0.96
60	0.91	0.89	0.90	0.92
90	0.80	0.79	0.81	0.85

The normalized vertical and horizontal stresses of point (3) have been presented in Figures (4 and 5).

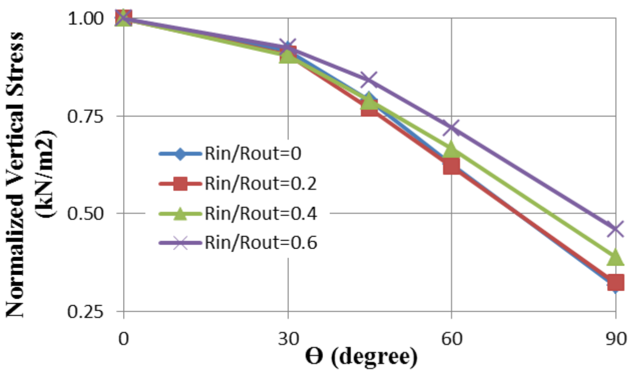

Figure 4: Normalized Vertical Stress for Point (3)

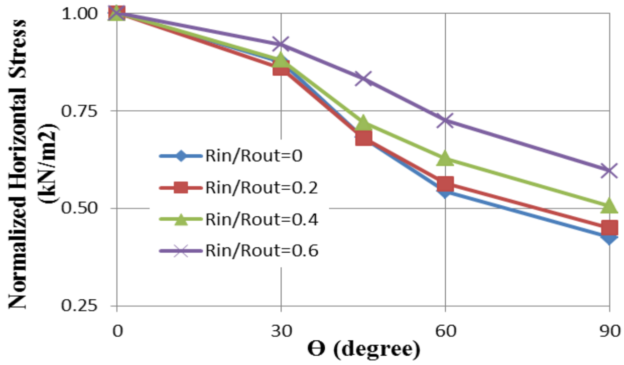

Figure 5: Normalized Horizontal Stress for Point (3)

6. Conclusions

As discussed before, the soil has been modeled as an elasto-plastic material by using Mohr-Coulomb Model. Based on the obtained results, the following conclusions can be made:

1) At the same (R_{in} / R_{out}), as the angle of load inclination increases, both the normalized vertical and horizontal stresses decrease.
2) At the same inclination angle and when $(x / R_{out}) = 0$, as the ratio of (R_{in} / R_{out}) increases, the horizontal stresses increase while the vertical stresses decrease.
3) At the same inclination angle and when $(x / R_{out}) = 1$, as the ratio of (R_{in} / R_{out}) increases, both the horizontal and the vertical stresses decrease.
4) As (z / R_{out}) increases, both the horizontal and vertical stresses increase.

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IJSR
ISSN (Online): 2319-7064

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