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Eccentrically Loaded Small Scale Ring Footing on Resting on Cohesionless Soil

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Abstract
A number of works have been carried out for the evaluation of a ultimate bearing capacity of shallow foundation, supported by geogrid reinforced sand and subjected to centric load. Few experimental studies have been made on the calculation of bearing capacity of shallow foundation on geogrid-reinforced sand under eccentric loading. However these studies are for strip footings. This paper presents the behavior of ring footing under eccentric loading on sand. The model tests have been conducted using ring footing with ring radii ratio (Di/Do) = 0.4, 0.6, 0.8 for varring eccentricity ratio. Parametric studies have been made to find the impact of eccentricity ratio, ring radii ratio and geogrid reinforcement on bearing capacity of the foundation.
Keywords: Ultimate Bearing Capacity, Reinforced Sand Bed, Eccentric Loading

I. Introduction

For any load-based structure, the foundation is very important and has to be strong to support the entire structure. For the foundation to be strong, the soil around it plays a very critical role. The performance of a structure mostly depends on the performance of foundation. Since it is a very important part, so it should be designed properly. The ring foundations are more suitable and economical to provide support for axi-symmetric structures such as bridge piers, underground stops, water-tower structures, transmission towers, TV antennas, silos, chimneys, and storage tanks. With the increasing use of these foundations in many important projects, interest in their behavior has intensified. This behavior includes the load-displacement response and the ultimate bearing capacity.

This paper is organized as follows. Section II describes previous similar work done by various researchers. The material used for the test and the test procedure is given in Section III. Section IV presents experimental results. Finally, Section V presents conclusions.

II. Related Work

Several experimental, analytical and numerical analyses were performed on eccentrically loaded footing resting on soil which is unreinforced and reinforced by various authors.

Zhu (1998)[1] conducted a centrifuge modelling and numerical analysis of bearing capacity of ring foundations on sand to investigate the bearing capacity of ring footings on a dense sand under vertical loads. It was found that for eccentrically loaded ring footings, the bearing capacity decreases with load increase in eccentricity.

Mehrjardi (2008)[2] studied on Bearing Capacity and settlement of ring footings. The behavior of ring footing with circular footing are compared and presented its design method.

Sawwaf and Nazir (2012)[3] presented an experimental study of the behavior of an eccentrically loaded model ring footing resting on a compacted replaced layer of sand that overlies an extended layer of loose sand. Test results indicate that the behavior of an eccentrically loaded ring footing significantly improves with an increase in the depth and the relative density of the replaced compacted sand layer. However, the inclusion of soil reinforcement not only leads to a significant reduction in the depth of the replaced sand layer but also causes a considerable increase in the bearing capacities of the eccentrically loaded rings, leading to the cost-effective design of the footings.

Albusoda and Hussein (2013)[4] presents an experimental study to dertermine Bearing Capacity of Eccentrically Loaded Square Foundation on Compacted Reinforced Dune Sand over Gypseous Soil. It was found that Bearing capacity increases to (2.5-3.0) time after replacement and reinforcement of gypseous soil. For eccentric loads, the load carrying capacity decreases with the increase of eccentricity value.

Atalar *et.al* (2013)[5] presented the paper on Bearing capacity of shallow foundation under eccentrically inclined load. The results of a number of laboratory model tests conducted to determine the ultimate bearing capacity of a strip foundation supported by sand and subjected to an eccentrically inclined load with an embedment ratio varying from zero to one have been reported.

Dhar *et al.* (2013)[6] conducted a study on Behavior of Rigid Footing under Inclined and Eccentric loading. It was found that with increase of eccentricity of applied loading whether vertical or inclined, load carrying capacity also decrease. Irrespective of eccentricity the load carrying capacity of footing decreases with increase in the angle of inclination of loading.

Algin (2014)[7] conducted the study on Elastic Settlement under Eccentrically Loaded Rectangular Surface Footings on Sand Deposits. The analytical closed form solutions and the resulting influence factors were presented for estimating the elastic settlement under eccentrically loaded footing. The equations are also developed for the theoretical cases where the location of incompressible soil layer is infinitely deep

Geetha and Sreekumar (2014)[8] presents Behaviour of eccentrically loaded small scale ring footing resting on cohesionless soil. It was found that, bearing capacity of ring footing is found to be maximum at a radius ratio of 0.4 and bearing capacity decreases as eccentricity increases.

Alam (2014)[9] conducted a study on bearing capacity of rectangular footing resting over geogrid reinforced sand under eccentric loading. It was concluded that the ultimate bearing capacity of the foundation for un-reinforced and reinforced soil decreases with the increase in eccentricity ratio i.e. e/B and the ultimate bearing capacity of the foundation increases with the increase in number of reinforcement layer.

Sawwaf (2015)[10] conducted a parametric study on the behavior of an eccentrically loaded strip footing resting on geosynthetic reinforced sand experimentally and analytically. Test results indicate that the footing performance could be appreciably improved by the inclusion of layers of geogrid leading to an economic design of the footing. However, the efficiency of the sand-geogrid system is dependent on the load eccentricity ratio and reinforcement parameters.

III. Methodology

The main objective of experiment is to study the behavior of eccentrically loaded small-scale ring footings resting on reinforced soil.

1. Test Material and their Properties

- **Test Sand**

For the model tests, cohesionless, washed, dried, and sorted by particle size was used as the foundation material. It was composed of rounded to sub-rounded particles, as shown in fig.1.

Figure 1: Sand

The geotechnical and engineering properties of sand such as Bulk density, specific gravity, coefficient of uniformity, etc. are shown in table1.

Table 1: Properties of Sand

Sr. No.	Properties	Value
1	Specific Gravity	2.69
2	Υ_{max}	16.254 kN/m^3
3	Υ_{min}	15.76 kN/m^3
4	Bulk Density (kN/m^3)	15.953 kN/m^3
5	Angle of Internal Friction	32°
6	Coefficient of Uniformity C_u	2.234
7	Coefficient of Curvature C_c	1.021
8	Effective Size D_{10}	0.47
9	I.S. Classification	Medium sand, SP grade

- **Model Footing**

The model ring was fabricated by using mild steel plate. Model footing consists of ring footing of 100 mm outer diameter and different inner diameters was considered. The inner diameters 40 mm, 60 mm, 80 mm were considered.

- **Reinforcement**

Commercially available continuous biaxial geogrid was used for reinforcing the sand bed. It is usually made from polymer materials, such as polypropylene, polyethylene or polyester. The size of biaxial geogrid reinforcement used was four times the size of the footing. The top surface of the sand was leveled and the biaxial geogrid reinforcement was placed. The geogrid used for the test is as shown in Fig. 2.

Figure 2: Geogrid

The various properties of geogrid such as ultimate tensile strength, elongation at break, aperture size etc., are mention in table 2.

Table 2: Properties of Geogrid

Property		Test method	TGB-30
Ultimate Tensile Strength (kN/m)	MD	ASTM D 6637 EN ISO-10319	30
	CD		30
Elongation at break (%)	MD		13
	CD		13
Tensile Strength at 2% strain (kN/m2)	MD		7
	CD		6.5
Tensile Strength at 5% strain (kN/m2)	MD		13
	CD		12
Aperture Size (mm)	MD X CD		26 X 26

2. Procedure for Test Setup

The detailed test procedure adopted for experimental investigation is explained below-

- **Preparation of Sand Bed**

The tank of 600 mm x 600 mm x 450 mm was filled with the dry sand of 2 mm passing and retaining on 450 µ sieve up to a depth of 100 mm tank by using the sand raining technique (hopper method). Prior to that, the side walls of the tank was made smooth by coating with a lubricating gel to reduce the boundary effects. Whenever the sand is deposited up to the location of the desired layer of reinforcement, the top surface of the sand was leveled and the geogrid reinforcement was placed. The length of reinforcement(L) was taken as four times the outer diameter of footing (4Do). The number of reinforcing layer (N) was taken as 3. The spacing of reinforcing layer (s) and the depth of top layer of reinforcement (u) adopted was 0.3 times the outer diameter of footing (0.3 Do).

Figure 3: Test Arrangement

- **Model Plate Load Test Procedure**

For the experimental work, the model plate load tests were conducted on sand as per IS 15284 (Part 1): 2003 to evaluate the bearing capacity and settlement. After preparation of sand bed, the model footing was placed at the centre of the tank. Then two dial gauges placed on the flanges of the footing. The load was applied on the footing with the help of screw jack in increments. Each load increment was approximately equal to 1/5th of the expected ultimate load. The load transferred to the footing was measured through proving ring placed between the footing and screw jack. Footing settlements was measured through two dial gauges placed on either side of the centre line of the footing. The footing settlement was reported as the average value of the readings taken at the two different points. The experimental test setup is shown in Figure 4.

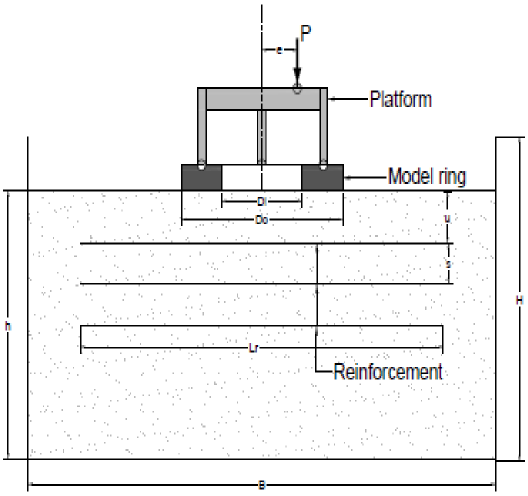

Figure 4: Equipment Setup

where, e = Eccentricity
P = Load intensity
D_i = Inner diameter of footing
D_o = Outer diameter of footing
h= Depth of sand
B = Width of tank
H = Height of tank
Di/Do= Inner to outer diameter ratio (Ring radii ratio)
e/Do = Eccentricity to outer diameter ratio.

IV. Experimental Results

The various parameters for study include inner to outer diameter ratio, and eccentricity of loading and length of reinforcement. The details of parameters study is given in table3.

Table 3: Details of Size of Model Footing

Sr. No.	Outer Diameter (D_o)	Inner Diameter (D_i)
1	100 mm	-
2	100 mm	40 mm
3	100 mm	60 mm
4	100 mm	80 mm

The test was conducted on circular footing and ring footing of different ring radii ratios (Di/Do) 0.4, 0.6, 0.8 with different ratio of eccentricity e/Do = 0, 0.05, 0.1, 0.15 on unreinforced as well as reinforced sand. The corresponding load settlement graph is drawn. The results obtained from these are briefly discussed below:

4.2.1 Effect of Ring Radii Ratio of Ring Footing

The results are obtained for the bearing capacity improvement for circular footing and different ring radius ratios of ring footing for reinforced and unreinforced sand. These ring radii ratio (Di/Do) are 0.4, 0.6 and 0.8. Figure 4.2.1.1 shows load intensity of footing corresponding to different ring radii ratio of footing.

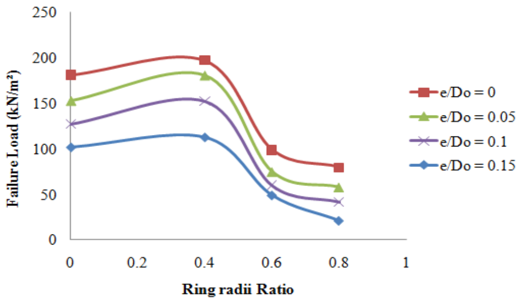

Figure 4.2.1.1: Variation of ring radii ratio for Various Load Eccentricity on Sand Bed

When the effect of the ring radius ratio of ring footing was taken in to account it was found that as ring radii ratio of footing increases, failure load increases up to certain value thereafter it goes on decreasing. Bearing capacity of ring footing of ring radii ratio 0.4 was slightly more than the circular footing.

4.2.2 Effect of Load Eccentricity on Footing

To study the effects of load eccentricity on Circular footing and ring footing resting over unreinforced and reinforced sand bed, the results from load tests for circular footing were compared using B.C.R factor. Figure 4.2.2.1 shows the variation of load intensity for various load eccentricity on reinforced sand for circular as well as ring footing.

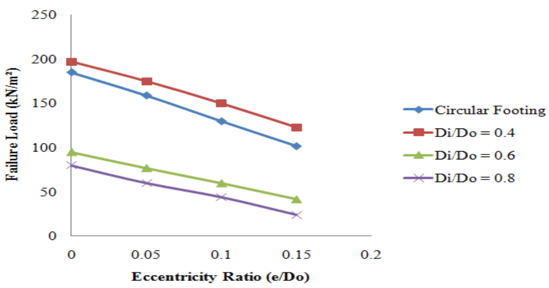

Figure 4.2.2.1: Variation of Load Eccentricity for Various Ring Radii Ratio on Sand Bed

From figure, it was observed that, as the eccentricity ratio (e/Do) increases the failure load decreases. Failure load decreases with increase in ring radii ratio from 0.4 to 0.8. Table 4.2.2.1 shows percentage decrease in failure load for different eccentricity ratio.

Table 4.2.2.1: Percentage Decrease in Failure Load for Different Eccentricity Ratio

Ring Radii Ratio (Di/Do)	% decrease in failure load for different eccentricity ratio			
	0	0.05	0.1	0.15
0	-	24	50	87
0.4	-	8	30	74
0.6	-	32	65	102
0.8	-	26	50	220

The result from the table shows that as the eccentricity ratio increases the failure load goes on decreasing. The unequal settlement of footing increases with increase in load eccentricity. The unequal settlement causes tilting effects of the footing. The tilting effects may cause failure of the footing.

4.2.3 Effect of Length of Reinforcement

The results obtained from tests conducted were used to study the effects of length of reinforcement on footing resting over unreinforced and reinforced sand bed ring footing of ring radii ratio 0.4. Fig. 4.2.3.1 shows the variation of load intensity for various length of reinforcement at different load eccentricity on reinforced sand bed.

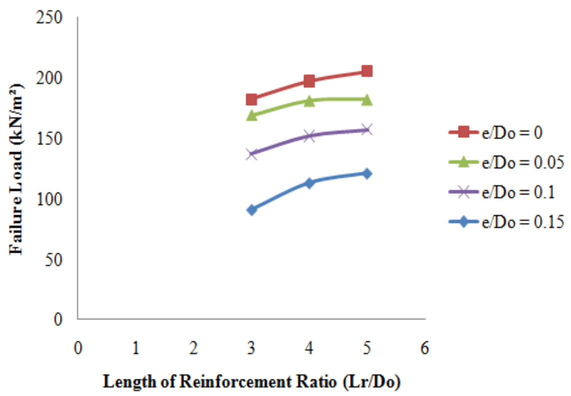

Figure 4.2.3.1: Variation of Length of Reinforcement Ratio for Various Load

Eccentricity on Sand Bed

The result shows that the failure load increases as the length of reinforcement ratio (Lr/Do) increases from 3 to 5. But there is marginal increment in failure load for different length of reinforcement ratio. Table 4.2.3.1 show percentage increase in load intensity for different length of reinforcement.

Table 4.2.3.1: Percentage Increase in Load Intensity for Different Length of Reinforcement.

Length of Reinforcement ratio (Lr/Do)	% increase in load intensity for different eccentricity ratio			
	0	0.05	0.1	0.15
3	-	-	-	-
4	8.24	7.1	10.94	24.1
5	4	1.1	3.2	7

V. Conclusion

Based on experimental investigation the following conclusions can be drawn-

- Bearing capacity of ring footing at ring radii ratio of 0.4 is found to be optimum, and its bearing capacity is greater than that of circular footing with similar properties on sand.
- The bearing capacity of circular and ring footing decreases as eccentricity of load increases for unreinforced and reinforced soil.
- The bearing capacity of ring footing increases as the length of reinforcement to diameter ratio (Lr/Do) increases, however the effect is not significant.
- As the eccentricity ratio increases settlement of ring and circular footing decreases.

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