Bearing Capacity of Rectangular Footing Resting Over Geogrid Reinforced Sand under Eccentric Loading

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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. The purpose of this research work is to conduct model tests in the laboratory by utilizing rectangular surface foundation resting over the reinforced sand. The model tests have been conducted using rectangular footing with B/L=0.5 & 0.33. The average relative density kept up throughout all the tests is 69%. The sand is reinforced by multiple layers (2, 3 & 4) of geogrid. The eccentricity varies from 0 to 0.15B with an increment of 0.05B. Distance of first layer of geogrid layer from bottom of footing and the distance between two consecutive geogrid layers have been kept constant. The load settlement curve for each tests have been plotted to calculate ultimate bearing capacity. Parametric studies have been made to find the impact of eccentricity on bearing capacity of the foundation. The ultimate bearing capacity of eccentrically loaded square footings can be computed by knowing the ultimate bearing capacity of square footing under central load and a reduction factor (RkR) for reinforced condition. The reduction factor is developed based on the results of laboratory model tests on geogrid reinforced soil. The ultimate bearing capacity of eccentrically loaded rectangular footing resting over geogrid reinforced sand can be calculated by knowing the ultimate bearing capacity of rectangular footing resting over reinforced sand bed and subjected to central vertical load by using reduction factor (RkR). An equation for reduction factor for rectangular footing resting over geogrid reinforced sand is developed based on laboratory model test results. A comparison of the experiment and predicted ultimate bearing capacity for rectangular footings on reinforced sand bed by using concept of reduction factor is calculated using the derived relation. The maximum deviation of experimental from predicted is 7.14%.

Keyword: Ultimate Bearing Capacity, Reinforced Sand Bed, Eccentric Loading.

I. INTRODUCTION

The use of geosynthetic materials to improve the bearing capacity and settlement performance of shallow foundation has gained attention in the field of geotechnical engineering. For the last three decades, several studies have been conducted based on the laboratory model and field tests, related to the beneficial effects of the geo-synthetic materials, on the load bearing capacity of soils in the road pavements, shallow foundations, and slope stabilizations.

The first systematic study to improve the bearing capacity of strip footing by using metallic strip was by Binquet and Lee After Binquet and Lee's work, several studies have been conducted on the improvement of load bearing capacity of shallow foundations supported by sand reinforced with various reinforcing materials such as geogrids geotextile fibers metal strips and geocell Several researches have demonstrated that the ultimate bearing capacity and the settlement characteristics of the foundation can be improved by the inclusion of reinforcements in the ground.

The findings from several laboratory model tests and a limited number of field tests have been reported in the literature which relates the ultimate bearing capacity of shallow foundations supported by sand reinforced with multiple layers of geogrid. Recently, Yin compiled extensive literature in the handbook of geosynthetic engineering on reinforced soil for shallow foundation. For the design of shallow foundations in the field, the settlement becomes the controlling criteria rather than the bearing capacity. Hence, it is important to evaluate the improvement in the bearing capacity of foundations at particular settlement (s) level.

From the finding of numerous researchers, it can be concluded that the bearing capacity of soil also changed with various factors like type of reinforcing materials, number of reinforcement layers, ratios of different parameters of reinforcing materials, and foundations such as B (footing width), u/B (location of the 1st layer of reinforcement to width of footing), h/B (vertical spacing between consecutive geogrid layer to width of footing), b/B (width of the geogrid layer to width of footing), Df/B (depth of footing to width of footing), type of soil, texture, and unit weight or density of soil, Out of several studies, very few studies are available on the two-layer soils.

Generally, all the studies are ultimately related to improvement in the bearing capacity of soil using reinforcing materials and related to the effect of various parameters on bearing capacity.

II. LITERATURE WORK

Banoth Swarupa et al [2019] 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. The ultimate bearing capacity of eccentrically loaded square footings can be computed by knowing the ultimate bearing capacity of square footing under central load and a reduction factor (RkR) for reinforced condition. The reduction factor is developed based on the results of laboratory model tests on geogrid reinforced soil.

Singh Avtar et al [2018] There is number of works has been carried out for the evaluation of an ultimate bearing strength of shallow foundation, supported over geogrid reinforced sand and subjected to load on center. Some experimental has been study for calculation of the bearing strength of shallow foundation on geogrid reinforced sand under eccentric loading. However that the studies for strip footings. The main purpose of the research work is to conduct model tests under the laboratory with utilizing rectangular surface foundation rest over the reinforced sand. The true bearing capacity of eccentrically loaded rectangular footing resting over geogrid reinforced sand can be determined by knowing the ultimate bearing strength of rectangular footing resting over reinforced sand bed and subjected to central vertical load with using reduction factor (R kR).

Meyerhof et al [2018] extended the bearing capacity theory of foundation under the central vertical load to eccentric and inclined load and gave a theory which is referred as effective area method. Analysis result of eccentric vertical loads on horizontal foundation is correlated with the result of model footing test on clay and sand. Further the theory is extended to central inclined loads on horizontal and inclined foundation and compared with model test result of footing on clay and sand. Finally both results are combined for the analysis of foundation with eccentric inclined load.

Meyerhof et al [2018] proposed a generalized equation for ultimate bearing capacity of any shape of foundation (strip, rectangular or square) since Terzaghi (1943) do not report the case of rectangular footing and also do not consider the shearing resistance across the failure surface in soil above the bottom of foundation.

Vesic et al [2017] in his research, considered the effect of shape of footing, effect of shearing resistant of soil above the bottom of footing and proposed a relationship for shape factor. A number of researchers proposed different relationship for bearing capacity factor as well as shape and depth factor.

III. PROBLEM IDENTIFICATION

The basic objections of my hypothesis work are according to the accompanying:

1. To discover the height of fall of sand by allowing the sand to fall from different height to filling the tank up

to desired height.

2. Aspects related to shallow foundations could not be studied.

3. A generalized equation for ultimate bearing capacity of reinforced sand bed can be derived for shape of footing.

IV. OBJECTIVES

The basic objections of my hypothesis work are according to the accompanying:

1. To conduct load tests on model rectangular footings resting over reinforced sand bed subjected to vertical eccentric load.

2. Different layers of geogrids are used as reinforcement.

3. To develop the empirical correlation for bearing capacity of eccentrically loaded footings on reinforced sand by knowing the bearing capacity of footing under centric load.

V. PROPOSED METHODOLOGY

Internal dimension of the test tank is measured and weight of sand to fill the tank upto a specified height is calculated using working density of 1.46gm/cc. Now sever trials are made to discover the height of fall of sand by allowing the sand to fall from different height to filling the tank up to desired height. After filling the tank upto desired height using raining technique, density of sand filled in tank for different trials is calculated. Height of fall for which the density is same as working density is taken for sample preparation. After finding out the height of fall, weight of sand require for 2.5cm thick layer to maintain the working density is taken and poured into the tank from specified height of fall using sand raining technique. The depth of first layer u from bottom of footing is taken as 3.5cm and distance between each consecutive layer h is taken as 2.5cm. During the sample preparation, square shaped geogrid of size 4.5cm has been taken and placed below the footing with first layer at the depth of 3.5cm and other layers with 2.5cm distance between two consecutive geogrid layer.

Figure 1: Placement of geogrid during experiment

After preparation of reinforced or unreinforced sample, footing is placed over the top of sand bed in such a way so that footing is parallel to the wall of test tank. Proving ring of desired capacity is attached with the cylindrical shaft of static loading unit and brought into contact with footing through metallic ball in between shaft and footing. Before making contact between shaft and footing, ensure that shaft is vertical. Two dial gauge of same specification is placed at the diagonally opposite corner of the footing.

Figure 2: Equipment setup

Theoretical bearing capacity of the sand bed is calculated using Meyerhof's bearing capacity formula. Now this ultimate load is applied on the footing in 8 steps. Load to be applied in one steps is calculate by dividing the ultimate load by number of steps and then load in one step is again dividing by least count of proving ring used during the test to calculate the number of division in each step. Since the test is stress controlled, the load calculated in one step is applied on the footing and corresponding settlement is measured by taking average reading of both dial gauge fitted at two diagonally opposite corner of footing. After taking the reading on proving ring and dial gauge, load applied is calculated by multiplying the number of division on proving ring by it's least count and corresponding settlement is calculated by multiplying the dial gauge reading by it's least count i.e. 0.01. Now the load-settlement curve is drawn and using double tangent method, experimental bearing capacity is extracted.

VI. RESULTS AND ANALYSIS

The ultimate bearing capacity of reinforced sand for both cases i.e. B/L=0.33 and 0.5 with different values of *e/B* and *N* has been tabulated in Table 1 and Table 2.

$$R_{KR} = \alpha_1 \left(\frac{d_f}{B}\right)^{\alpha_2} \left(\frac{e}{B}\right)^{\alpha_3}$$

Where a1,a2a3 are dimensionless constants. The purpose of the present study is to find out the coefficient a1,a2a3 for rectangular footing by conducting a number of laboratory model tests using rectangular footing with B/L=0.5 & 0.33 resting over multi-layered geogrid reinforced sand bed.

Table 1: Experimental reduction factor for eccentrically loaded footing resting on reinforced with B/L=0.5

$\frac{B}{L}$	$\frac{d_f}{B}$	$\frac{e}{B}$	$q_{uR(e)}$ (kN/m^2)	$\frac{q_{uR(e)}}{q_{uR(e=0)}}$	$R_{KR} = 1 - \frac{q_{uR(e)}}{q_{uR(e=0)}}$
0.5	0.6	0.05	198	0.90	0.10
0.5	0.6	0.10	165	0.75	0.25
0.5	0.6	0.15	132	0.60	0.40

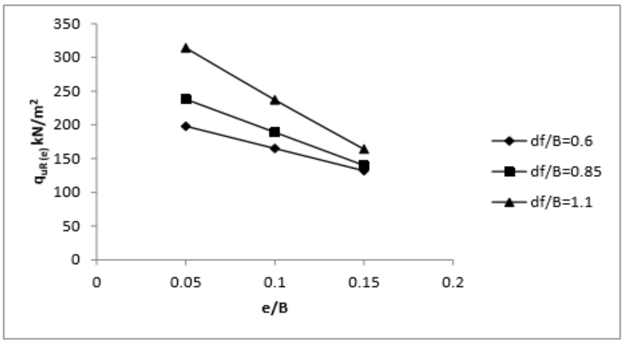

Figure 3: Variation of quR(e) with e/B for B/L=0.5

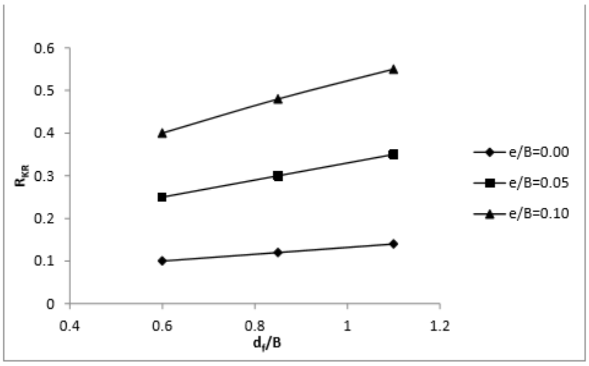

Figure 4: Variation of RKR with df/B for B/L=0.5

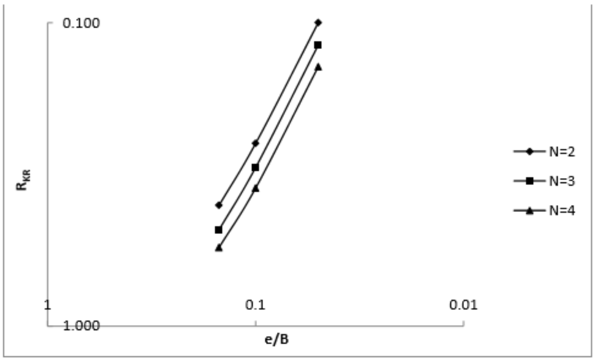

Figure 5: Variation of RKR with e/B for B/L=0.5

ANALYSIS OF RECTANGULAR FOOTING WITH B/L=0.33

Same procedure has been followed to derive the empirical relation for reduction factor for footing with B/L=0.33.

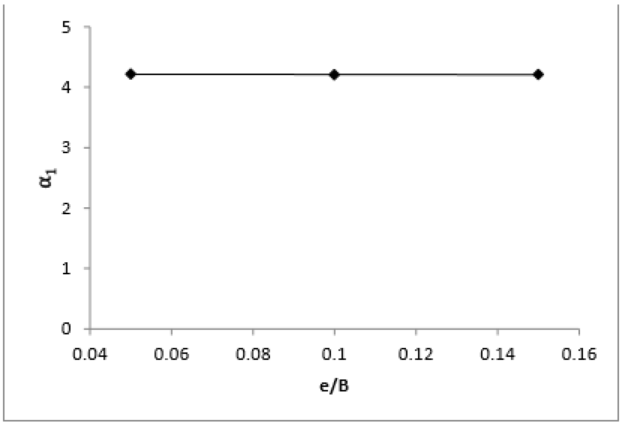

Figure 6: Variation of a1 with e/B for B/L=0.33

Table 1: Experimental reduction factor for eccentrically loaded footing resting on reinforced sand bed with B/L=0.33

B/L	d_f/B	e/B	$q_{uR(e)}$ (kN/m^2)	$\frac{q_{uR(e)}}{q_{uR(e=0)}}$	$R_{KR} = 1 - \frac{q_{uR(e)}}{q_{uR(e=0)}}$
0.33	0.6	0.05	201	0.89	0.11
0.33	0.6	0.10	171	0.76	0.24
0.33	0.6	0.15	140	0.62	0.38
0.33	0.85	0.05	242	0.88	0.12
0.33	0.85	0.10	195	0.71	0.29
0.33	0.85	0.15	151	0.55	0.45
0.33	1.1	0.05	323	0.85	0.15
0.33	1.1	0.10	251	0.66	0.34
0.33	1.1	0.15	182	0.48	0.52

VII. CONCLUSION

A number of laboratory model tests have been conducted to determine the ultimate load bearing capacity of rectangular model footings resting over geogrid reinforced sand and subjected to vertical eccentric load. All the tests have been conducted for footing resting on the surface.

Following are the summarized results of present research work.

- The ultimate bearing capacity of the foundation for un-reinforced and reinforced soil decreases with the increase in eccentricity ratio i.e. *e/*B.
- The ultimate bearing capacity of the foundation increases with the increase in number of reinforcement layer.
- Reduction factor for the footing with B/L=0.5 & 0.33 has been derived separately and then combined to get a simple generalized equation of reduction factor for rectangular footing as shown in Equation 5.11.
- A comparison of the experiment and predicted ultimate bearing capacity for rectangular footings on reinforced sand bed by using concept of reduction factor is calculated using the derived relation and presented in Table 5.9. The maximum deviation of experimental from predicted is 7.14%.

VIII. FUTURE SCOPE

The present research work is related to bearing capacity of eccentrically loaded rectangular footing with B/L = 0.5 & 0.33 resting over reinforced sand bed. Due to time constraint, other aspects related to shallow foundations could not be studied. The future work should consider the below mentioned points:

- The present work can be extended for footing with different B/L ratio and the result can be correlated with the result of present work.
- A generalized equation for ultimate bearing capacity of reinforced sand bed can be derived for any shape (i.e. square, rectangular and strip)

of footing.

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