

# Behaviour of Strip Footing on Geogrid Reinforced Slope subjected to Eccentric Load

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**ABSTRACT:** A series of finite element analyses were carried out on eccentrically loaded surface strip footing placed on a geogrid reinforced sand slope to investigate the load-settlement behaviour and ultimate bearing capacity of footing. The strip footing was analysed for the five values of the load eccentricities *i.e.*  $e/B = 0, \pm 1/6, \pm 1/3$ . The footing width, slope height, slope inclination and geogrid parameters were kept constant and only the effect of load eccentricity was studied with varying location of the footing from crest of slope. A 2 m wide surface strip footing was placed on 10 m high slope of 1:1.5. Commercial geotechnical finite element software PLAXIS-2D was used for all the analyses. The results shows that the overall stability of the footing-slope system decreases due to eccentricity of the load and tilting of the footing occurs which results in a reduction of bearing capacity of footing.

**KEYWORDS:** Geogrid, Strip footing, Load eccentricity, PLAXIS-2D, Slope.

## I. INTRODUCTION

Civil engineering structures are often placed on slopes. The investigation of the bearing capacity of loaded slope is very important because they are more liable to fail than other types of earth structures. When footing is placed on slope, its bearing capacity decreases compared to the level ground. Slope stability can be improved in different ways, such as modifying the slope surface geometry, using soil reinforcement, or installing continuous or discrete retaining structures like walls or piles. Geosynthetics have proven to be an effective means of stabilizing active landslides as well as in marginally stable and unstable slopes. The performance of the structures depends upon the stability of slopes while the stability of slopes depends upon the forces acted on it. Therefore, the stability of slopes when the footing is constructed on it is one of the major problems in the field of geotechnical engineering. The present work focused on effect of load eccentricity on the surface strip footing located on unreinforced and reinforced slope.

## II. LITERATURE REVIEW

Selvadurai and Gnanendran<sup>1</sup> (1989) carried out series of experiments to determine the performance of a footing located at the crest of a sloped fill and that was influenced by the presence of a reinforcing layer within the body of the fill. It was concluded that the primary properties of geogrid reinforcement governs its effectiveness in improving the load carrying capacity of sloped fill and optimum depth of location of the reinforcement layer should be 0.5 to 0.9 times the width of footing.

Lee and Manjunath<sup>2</sup> (2000) performed a series of plane strain analysis using PLAXIS-2D on both reinforced and unreinforced sand slopes loaded with a rigid strip footing. From the numerical analyses, it was shown that the ultimate bearing capacity of the footings was considerably improved by the inclusion of a reinforcing layer. The optimum depth of the reinforcement layer was found to be 0.5 times the width of the footing for the maximum response of the reinforcement in terms of bearing capacity ratio (BCR).

EI Sawwaf<sup>3</sup> (2007) studied the performance of the surface strip footing on geogrid-reinforced sand over a soft clay slope. From experimental and numerical investigations it was concluded that, soil improvement of soft clay ground

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slope by partial replacement with sand layer significantly increases the load bearing capacity of a footing; the length of geogrid should be greater than or equal to five times the width of footing; the recommended number of geogrid layers was three and the recommended depth of first reinforcing geogrid layer and vertical geogrid spacing were 0.6 and 0.5 times the width of footing respectively.

Turker<sup>4</sup>*et al.* (2014) conducted a series of bearing capacity tests on model surface and shallow strip footings under eccentric loads and located close to reinforced finite sand slopes to investigate ultimate loads, failure surfaces, load–displacement curves and rotation of footing. A single woven geotextile strip sheet was placed horizontally below the footing base at a depth of half of the footing width to increase the ultimate loads in comparison with unreinforced cases. The results of plate load test shows that, the ultimate loads were decreases as eccentricity increases.

Patil and Pusadkar<sup>5</sup> (2017) performed a series of finite element analyses on a surface strip footing located on crest of geogrid reinforced sand slope in order to determine the optimum values of the geogrid parameters. The numerical analyses were carried out using finite element software PLAXIS-2D. It was observed that the first layer location at 0.5B gives maximum BCR. The vertical spacing between the successive layers which results in maximum BCR was found to be 0.5B. The optimum length of geogrid layer was found to be five times the width of footing and the optimum number of layers was found to be four. These optimum values of the geogrid parameters were used for the present work for the footing on reinforced slope and the emphasis was given to the eccentricity of the load.

The literature shows that the studies on effect of geosynthetic parameters on strip footing located near slope were carried out by various authors. The present work focused on the effect of eccentric load on strip footing located on unreinforced slope and slope reinforced with geogrid reinforcement.

### III. NUMERICAL MODELLING

The analyses of the surface strip footing located on geogrid reinforced slope under the centric load and eccentric load were carried out using the geotechnical finite element software PLAXIS-2D.

#### A. Finite Element Analyses

A series of two-dimensional finite element analyses (FEA) on a prototype footing-slope system were performed using finite element simulation program PLAXIS-2D. The deformation, stability and groundwater flow analysis can be done using PLAXIS. A wide range of geotechnical problems such as deep excavations, tunnels, retaining walls, slopes *etc.* can be analysed using PLAXIS software. The simple graphical input procedures enable a quick generation of complex finite element models and the enhanced output facilities provide a detailed presentation of computational results. The footing-slope system was analysed for the five types of eccentric loads including centric load *i.e.*  $e/B = 0$ ,  $\pm 1/6$ ,  $\pm 1/3$ , where, B is the width of footing. Figure 1 shows the geometry of the prototype footing-reinforced slope system where, 'L' is the length of first geogrid layer and subsequent layers were extended up-to the slope face.

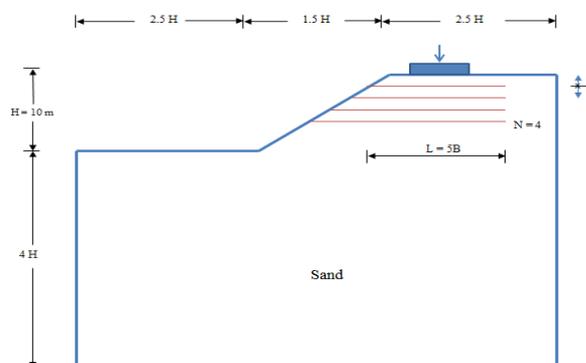


Fig.1 Geometry of Footing-Slope System for Present Study

The slope inclination of 1(V):1.5(H) and footing width of 2 m was kept constant throughout all the analyses. The effect of crest distance (b) was also studied. The footing was analysed for the crest distance,  $b/B = 0, 1, 2, 3, 4$  on both

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unreinforced and reinforced slope. Figure 2 illustrates the details of eccentricity of load. The '+ e' shows the eccentricity of the load towards the face of slope while '- e' shows the eccentricity of the load towards the bench of slope.

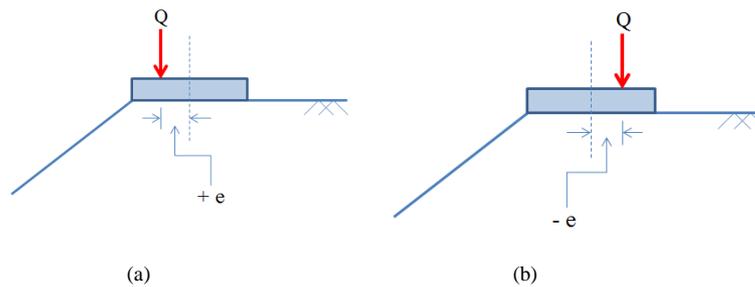


Fig. 2 Details of the Eccentricity of Load (a) Eccentricity towards Face of Slope (b) Eccentricity towards Bench of Slope

## B. Finite Element Modelling

Infinite element (FE) modelling the soil model is constructed in 'PLAXIS Input Stage' and it can be analysed in 'PLAXIS Calculation Stage'. The results of the analysed problem can be shown in 'PLAXIS Output Stage'.

- **Soil model:** The well-known Mohr-Coulomb model has been considered as a first order approximation of real soil behaviour and used for the present work. The properties given in Table 1 were assigned to this elasto-plastic soil model. The medium dense sand was considered for the analyses having Young's modulus of 30000 kN/m<sup>2</sup>.

Table 1: Soil Properties

Sr. No.	Properties	Value
1	Unsaturated Unit Weight	18 kN/m <sup>3</sup>
2	Young's Modulus	30000 kN/m <sup>2</sup>
3	Cohesion	0.5 kN/m <sup>2</sup>
4	Angle of Internal Friction	34°
5	Dilatancy Angle	04°
6	Poisson's Ratio	0.3

- **Strip footing:** The rigid strip footing of width 2 m was modelled using the properties as given in Table 2. The modulus of elasticity of the footing was evaluated using the formula for short term elastic modulus of concrete which is given as  $5000 \times f_{ck}^{0.5}$ . The characteristics strength ( $f_{ck}$ ) of the concrete was considered as a 25 MPa.

Table 2: Footing Properties

Sr. No.	Properties	Value
1	Unit Weight	24 kN/m <sup>3</sup>
2	Axial Stiffness (EA)	$5 \times 10^6$ kN/m
3	Flexural Rigidity (EI)	4170 kN-m <sup>2</sup> /m
4	Equivalent Thickness	0.1 m
5	Poisson's Ratio	0.15

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- **Geogrid Modelling:** Geogrids are slender structures with a normal stiffness (axial) but with no bending stiffness. Geogrids can only sustain tensile forces and no compression. An axial stiffness of 2000 kN/m was assigned to the geogrid for present study.
- **Interface Elements:** The soil-structure interaction is typically modelled in PLAXIS-2D using a suitable value of strength reduction factor ( $R_{int.}$ ). For present study, an interface element between the soil and geogrid having the value of  $R_{int.} = 0.80$  was used. The ends of the interface elements were extended by 0.2 m beyond the ends of the geogrid in the soil to avoid the ends of the geogrid becoming fixed to the soil.
- **Mesh generation and prescribed loading:** The accuracy of the results depends upon the coarseness of the mesh. As the mesh will be varies from coarser to finer, the results may converges to the approximate solution. The finer mesh for the given problem takes larger time for analysis. The medium coarseness of the mesh was selected for the present problem. The boundary conditions were assumed such that the vertical boundaries are free vertically and restrained horizontally while the bottom horizontal boundary is restrained against both horizontal and vertical movement. The initial stress condition of the footing-slope system was established first by applying the gravity loading. An external prescribed footing load was then applied in increments accompanied by the iterative analysis up to failure. The ultimate bearing capacity (UBC) of the footing was evaluated by drawing the tangents to the load-settlement curve. Figure 3 shows the analysed footing-slope geometry and generated mesh. The software enables to show the element numbers and node numbers of the generated mesh. After generation of mesh, the initial stage in PLAXIS-2D *i.e.* PLAXIS-Input Stage was supposed to be completed and one can go for the next stage *i.e.* PLAXIS-Calculation Stage. In calculation stage, the external loading was applied in increments to find out the failure load. As the failure load was obtained the load-settlement curve was drawn for that failure load in PLAXIS-Output Stage.

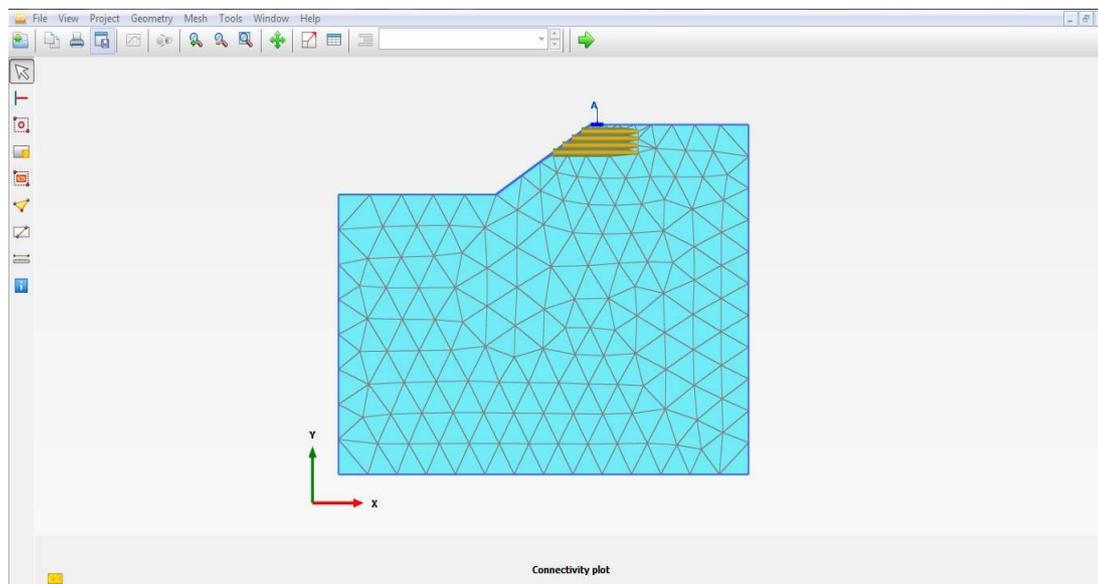


Fig. 3 Geometry of Footing-Slope System and Generated Mesh

## C. Analysis Program

The bearing capacity analysis was carried out for each case. The footing was subjected to the external loading and the loading was increases in increments to find out the failure load of footing. The load-settlement curve for this failure load was drawn and the ultimate bearing capacity of the footing was estimated by tangent line method. For each load

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eccentricity, the analyses were carried out for the footing on both unreinforced and reinforced slope with varying crest distances.

## IV. RESULTS AND DISCUSSION

The bearing capacity analysis on the strip footing located on both unreinforced and reinforced slope was carried out. The effect of eccentric load on UBC of the strip footing was studied in detail and presented using non-dimensional factor, called bearing capacity ratio due to eccentric load ( $BCR_e$ ). This factor is defined as the ratio of UBC of the strip footing under eccentric load ( $q_e$ ) to the UBC of the strip footing under centric load ( $q_c$ ). Figure 4 shows the typical load-settlement curve for the footing on crest of unreinforced slope subjected to centric and eccentric load which gives the value of  $BCR_e = 36/47.5 = 0.76$ .

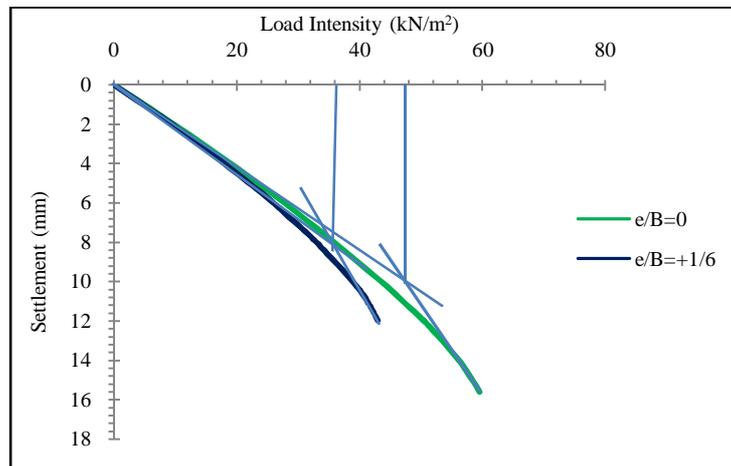


Fig. 4 Typical Load-Settlement Curve for Footing on Crest of Unreinforced Slope showing the effect of Load Eccentricity

Similarly the effect of inclusion of geogrid reinforcement on UBC of the strip footing was presented using non-dimensional factor, called bearing capacity ratio due to reinforcement ( $BCR_r$ ). This factor is the ratio of UBC of the footing on reinforced slope to the UBC of the footing on unreinforced slope. Figure 5 shows the typical load-settlement curve for the footing on crest of unreinforced and reinforced slope subjected to centric load which gives the value of  $BCR_r = 77/47.5 = 1.62$ .

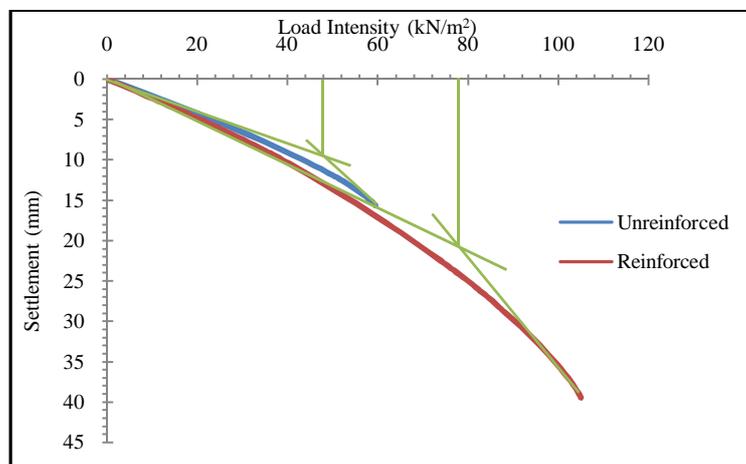


Fig. 5 Typical Load-Settlement Curve for Footing on Crest of Unreinforced and Reinforced Slope showing the effect of Reinforcement

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## A. Effect of Eccentricity of Load:

The effect of eccentric load was studied in detail for the five values of load eccentricity including centric load. The results were shown in terms of UBC to systematically understand the effect of eccentric load. Further the results were also presented in terms of  $BCR_e$  to study the reduction in UBC due to eccentric load. Figure 6 (a) shows the variation of UBC with load eccentricity for different location of footing on unreinforced slope while Figure 6 (b) shows the variation of  $BCR_e$  with load eccentricity for different location of footing on unreinforced slope.

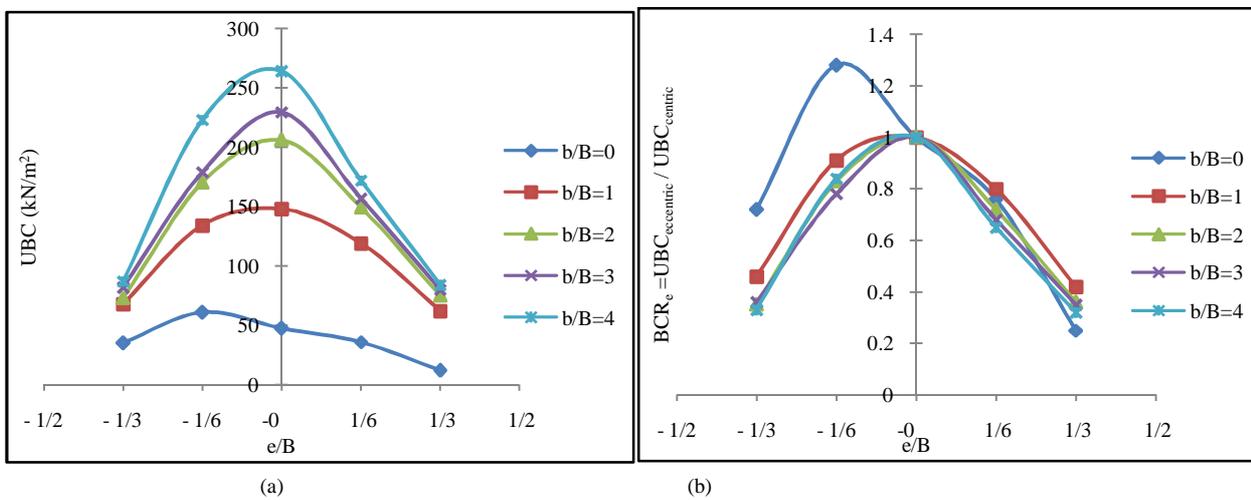


Fig. 6 Effect of Load Eccentricity on (a) UBC and (b)  $BCR_e$  for Footing on Crest of Unreinforced Slope

Similarly, Figure 7 (a) shows the variation of UBC with load eccentricity for different location of footing on reinforced slope while Figure 7 (b) shows the variation of  $BCR_e$  with load eccentricity for different location of footing on reinforced slope.

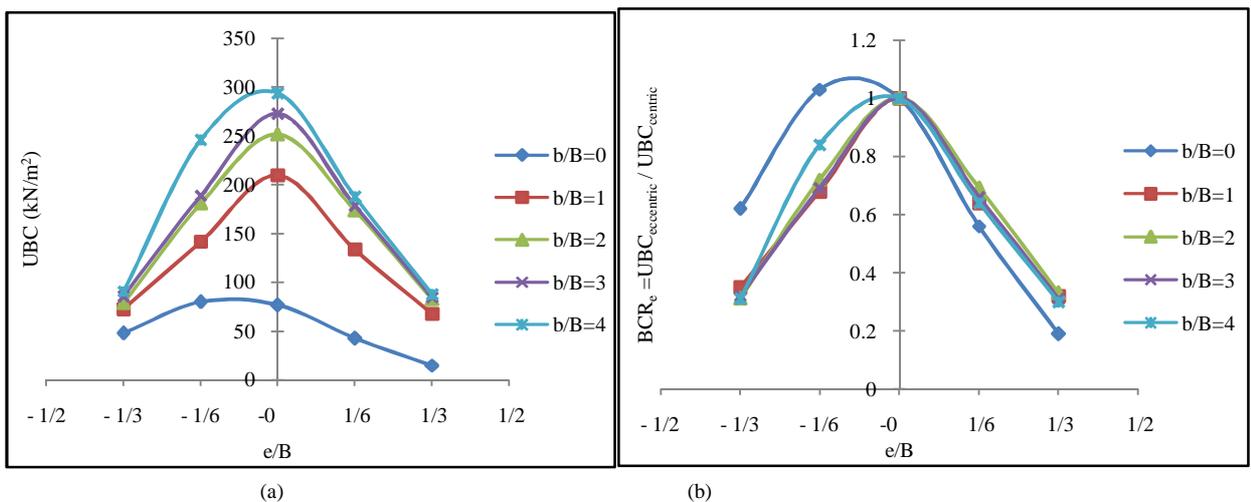


Fig. 7 Effect of Load Eccentricity on (a) UBC and (b)  $BCR_e$  for Footing on Crest of Reinforced Slope

From Figure 6 and 7, it was observed that, the UBC of the strip footing decreases as the load eccentricity increases. Also it was seen that, the strip footing on unreinforced and reinforced slope subjected to eccentric load acting away from the slope-face side ( $-e/B$ ) has more UBC than that of the strip footing under eccentric load acting towards slope-face side ( $+e/B$ ).

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## B. Effect of Location of Footing:

The effect of location of footing from crest of slope was studied for the five values of crest distance ( $b/B$ ). Figure 8 shows the variation of UBC of the strip footing with crest distance ( $b/B$ ).

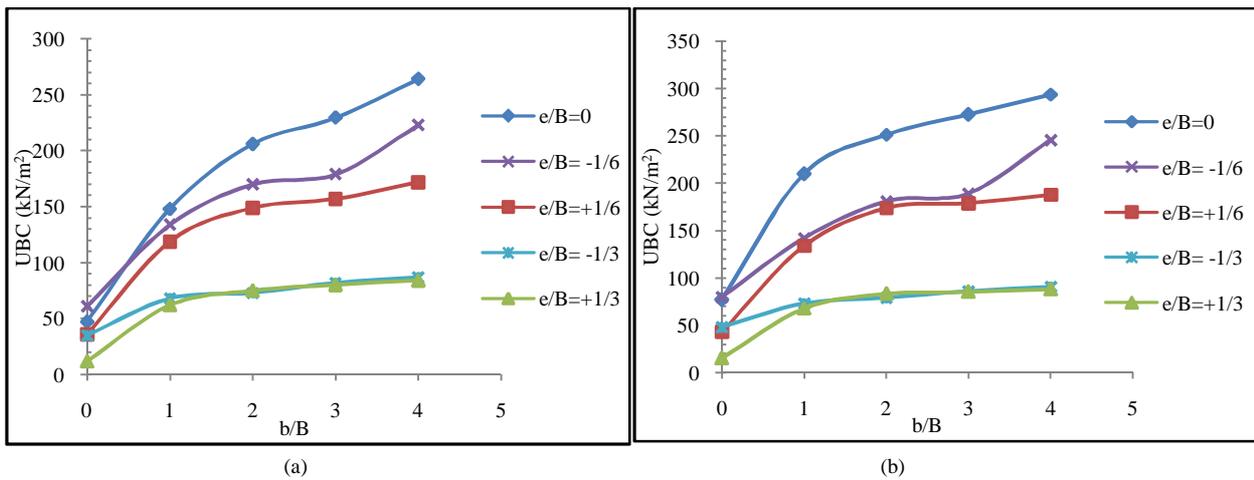


Fig. 8 Variation of UBC with Crest Distance (a) Unreinforced (b) Reinforced Slope

From Figure 8, it was observed that, the UBC of the strip footing under centric and eccentric load on both unreinforced and reinforced slope increases as the footing location from the crest of slope increases.

## C. Effect of Inclusion of Geogrid Reinforcement:

The geogrid reinforcement was used to increase the stability of the slope. The optimum values of the geogrid parameters for the maximum response of the geogrid were taken from the literature. The effect of inclusion of geogrid reinforcement in slope is shown in terms of non-dimensional factor called bearing capacity ratio due to reinforcement ( $BCR_r$ ). The  $BCR_r$  is the ratio of the UBC the strip footing on reinforced slope to the UBC of the strip footing on unreinforced slope keeping all other parameters constant. The variation of the  $BCR_r$  with the crest distance for different eccentricity of load is shown in Figure 9.

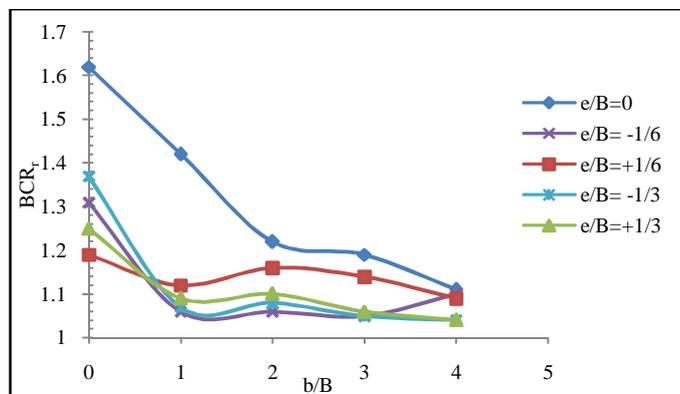


Fig. 9: Variation of  $BCR_r$  with Crest Distance for Different Load Eccentricity

From Figure 9, it was observed that, in terms of  $BCR_r$ , the geogrid reinforcement is more effective when footing is loaded under centric load while the  $BCR_r$  for the eccentric load is lesser. The strip footing located at the crest of slope

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*i.e.* at  $b/B = 0$  has the maximum value of  $BCR_r$  compared to footing located away from the slope crest for any load eccentricity.

## V. CONCLUSIONS

From the numerical analysis of the surface strip footing on both unreinforced and reinforced slope under centric and eccentric load, the following conclusions are drawn:

1. The UBC of the strip footing decreases as the load eccentricity increases.
2. The strip footing under eccentric load acting away from the slope-face side ( $-e/B$ ) has more UBC than that of the strip footing under eccentric load acting towards slope-face side ( $+e/B$ ).
3. The UBC of the strip footing under centric and eccentric load on both unreinforced and reinforced slope increases as the crest distance increases.
4. In terms of  $BCR_r$ , the geogrid reinforcement is more effective when the footing is loaded under centric load while the  $BCR_r$  for the eccentric load is lesser.
5. The strip footing located at the crest of slope has the maximum value of  $BCR_r$  compared to footing located away from the slope crest for any load eccentricity.

## REFERENCES

- [1] Selvadurai, P. S., and Gnanendran C. T., "An Experimental Study of A Footing Located on A Sloped Fill: Influence of A Soil Reinforcement Layer", Canadian Geotechnical Journal, Vol. 26, pp. 467–473, 1989.
- [2] Lee, K. M., and Manjunath, V. R., "Experimental and Numerical Studies of Geosynthetic-Reinforced Sand Slopes Loaded with A Footing", Canadian Geotechnical Journal, Vol. 37, pp. 828–842, 2000.
- [3] El Sawwaf, M., "Behavior of Strip Footing on Geogrid-Reinforced Sand Over A Soft Clay Slope", Geotextiles and Geomembranes, Vol. 25, pp. 50–60, 2007.
- [4] Turker, E., Sadoglu, E., Cure, E., and Uzuner, B. A., "Bearing Capacity of Eccentrically Loaded Strip Footings Close to Geotextile-Reinforced Sand Slope", Can. Geotech. J., Vol.51, pp. 884–895, 2014.
- [5] Patil, D. D., and Pusadkar, S. S., "Performance of Strip Footing on Geogrid Reinforced Slope", Proceedings of the Sixth National Conference on Recent Advancements in Geotechnical Engineering (NCRAG), ISBN 978-81-931273-7-7 (Print), pp. 121-124, 2017.