Bearing Capacity of Eccentrically Loaded Circular Footing Supported On Reinforced Sand

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Abstract: In the recent past, Investigators has given less attention on circular foundation. Thus, this research deals with the strength of circular foundation on reinforced sand. There are total 48 number of tests are conducted on model footings of radius 10cm and 5cm, eccentricities varying from 5mm to15mm with an increment of 5mm. Square shape geo net is used as reinforcing material having aperture size of 1.637mm.There is 3 layer of reinforcement is used i.e. from 0 to 2, where the distance between reinforcing layer and base of foundation is 0.35D and distance between two reinforcing layers is 0.25D. The test tank has size of 0.60m×0.60m×0.30m. This test is carried out on dense and medium dense sand. Relative density is 71% for dense sand and 51% for medium dense sand, calculated as per IS code method. Load-settlement curve of each experiment is done from which bearing capacity is calculated by tangent intersection method. The result showed that rise in reinforcing layer increases the bearing capacity, whereas rise in eccentricity has decreased bearing capacity. The results also compared with different existing theories, with unreinforced and reinforced dense and medium dense single entities and bearing capacity ratio (BCR) is calculated.

Keywords: Circular footing, Eccentricity, Reinforcement.

1 Introduction:

Structural foundations are the sub structure elements which transmit the structural load to the earth in such a way that the supporting soil is not overstressed and not undergo deformations that would cause excessive settlement of the structure. Hence the properties of the supporting soil must be expected to affect vitally the choice of the type of structural foundation suitable for a structure. The bearing capacity and settlement of foundations have been proven a function of the shape of the footing, foundation soil parameters and conditions. Footing is subjected to moments and vertical loads (like wind, water, earthquake, earth pressure etc.)[1]. Due to this load eccentricity, the overall stability of foundation decreases along with differential settlement, tilting of foundation, heaving the supporting soil which reduces the bearing capacity[5]. To avoid such scenario, we must reduce the contact pressure using larger dimension of footing, which leads to uneconomical design. This can be achieved by increasing the bearing capacity of soil by appropriate reinforcing techniques[9]. Several theories have been established to calculate the bearing capacity and settlement of strip, square and circular footings. In 1943, Terzagi published the landmark theory for estimation of the ultimate bearing capacity of shallow foundation subjected to vertical centric loading on a c-φ soil. Since than many researchers extended their study on this topic based on theoretical and experimental approach. Sometimes eccentrically inclined loads are encountered in strip foundations, which acts inclined towards the center line of strip foundation and was reefed to as partially compensated. Many model tests are conducted with eccentric inclined load on strip foundation[10, 12]. A comprehensive mathematical formulations to calculate bearing capacity of continuous foundation were developed by Prakash & Saran (1971).Population explosion resulted a huge demands of lands for providing basic needs like road, train, metro, homes etc .Shortage of lands provided an opportunity to use unfavorable lands with proper ground improvement. Thus various soil improvement techniques like soil reinforcement, replacing unfavorable soils, compaction, dewatering etc. procedure got popular. During few decades, researchers emphasized more on the bearing capacity of shallow foundations with multi layered reinforced layers[17]. Small scale laboratory model tests on strip foundation have been a popular area of researchinmostcases[17,18] . Large number of studies on geosynthetic reinforced soil foundations found that it forms a soil failure wedge beneath the soil layer .There is substantial improvement in surface heaving and bearing capacity is found when model tests are performed on granular fill overlaying soft clay beds[20,21]. Circular footing behavior beneath the reinforcement layers of geogrid and geocells improves the bearing capacity[22, 23]. A numerical model approach d to predict footing size effect and bearing capacity ratio values developed by Orneck et.al (2012).It is clear from literature review that most of the studies concentrated on behavior of circular footing on vertical and inclined loading arrangement. Thus objective of this studies is to witness the behavior of eccentrically loaded model footings of eccentricity varying from 0 to 15mm with increment of 5mm, relative density and reinforcement layers and their effect on bearing capacity of soil.

2 Materials and equipment:

Dry sand of dense (I_D=71%) and medium dense (ID = 51%) sand layer is used as the geomaterial, and biaxial geonet is used as the reinforcement material. The tests are performed on circular model footings of mild steel, sizes of 100mm and 50 mm, with varying eccentricities from 0.05cm to 0.15cm with an increment of 0.05mm. The thickness of footing was 4mm. The detail about biaxaial geonet is given in table-2. The bearing capacity and settlement was interpreted from each test and analyzed. All the model tests were performed in a cement concrete tank measuring 0.60m x 0.60m x 0.30m.

Table 1. Geotechnical parameters of sand

Geotechnial parameters	Value
Sp. Gravity (G)	2.60
Eff. Particle size (D_{10})	320micron

Partical size (D_{30})	480micron
Mean particle size (D_{60})	780micron
Uniformity coefficient (C_u)	2.43
Working dry density (γ_d)	13.82kN/m^3
Maximum unit weight (γ_{dmax})	14.10 kN/m^3
Minimum unit weight (γ_{dmin})	13.10 kN/m^3
Relative Density (Dr)	71%(Dense sand) , 51%(Medium dense sand)
Internal angle of friction (φ)	42.3°(Dense sand), 39.8°(Medium dense sand)

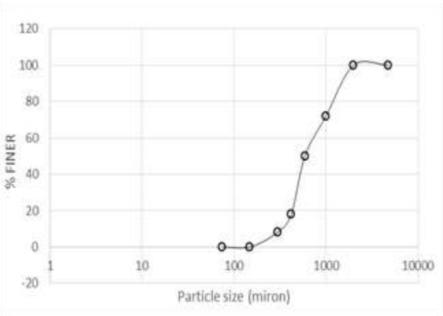


Fig. 1. Grain Size Distribution of Sand

Table 2. Physical parameters of reinforcing material

Material type	Synthetic fabrics
Aperture shape	Square
Aperture size	1.6 X 1.6
Mesh size	1.243mm
Ultimate tensile strength (kN/m)	7.6
Failure strain (%)	2.5
/Mass per unit area (g/m^2)	139

Geonet, as is a reinforcing material, placed horizontally after levelling the surface at preferred depth, keeping (u/D) =0.35 and (h/D) = 0.25 as shown in figure-5. Total 48 number of model tests are carried out on Model footings model test series summarized in table-3

Table 3. Model test series

Number of Test	Diameter of footing (cm)	Density of sand	Unit weight (kN/m^3)	Relative density (I_D)	Shearing Angel (*φ*)	Reinforced layers	Eccentricity (mm)
1-12	10	Dense	13.80	71%	42.3°	0, 1, 2	0, 5, 10, 15
12-24	5	Dense	13.80	71%	42.3°	0, 1, 2	0, 5, 10, 15

24-36	10	Medium dense	11.36	51%	39.8°	0, 1, 2	0, 5, 10, 15
36-48	5	Medium dense	11.36	51%	39.8°	0,1,2	0,5,10,15

Fig. 2. Typical Geonet material

Fig. 3. Model Circular footing

Fig. 4. Model Test Tank

Fig. 5. . Placement of Reinforcing layer

3 Experimental result and analysis:

The loading arrangement is shown in fig-6 where the loading on eccentrically loaded footing is defined. It seen from figure clearly that load on footing deflects according to the eccentricity of footing from centre. The laying of reinforced layer is clear from figure-5. After the all the arrangements i.e. reinforcement layer and loading pattern is done load-settlement data is noted which is penned according to the figure-7. The Bearing capacity of each footing on different condition is calculated as per Tangent intersection method, here two straight lines are drawn from two opposite corner of graph and their intersection point on loading directions gives us the required bearing capacity of respective condition.

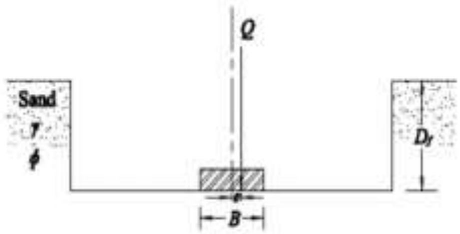


Fig. 6. Eccentrically loaded circular footing (B=Diameter of footing)

From figure 8-13, the load deformation curve of eccentrically loaded footing with varying eccentricity is compared, where as in figure 14-17 compared eccentrically loaded footing in accordance to reinforcing layer. In figure 18- 19, bearing capacity ratio at different condition is shown. Where bearing capacity ratio is given by,

$$\text{Bearing Capacity Ratio} = BCR = Q_{u\,(Reinforced)} / Qu_{\,(un\text{-}Reinforced)} \quad (1)$$

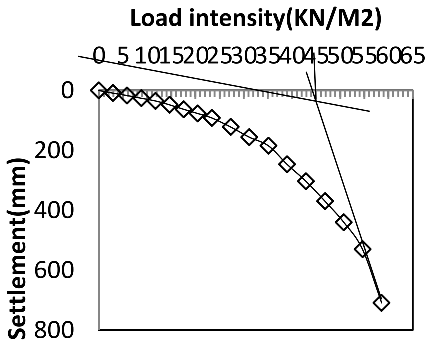
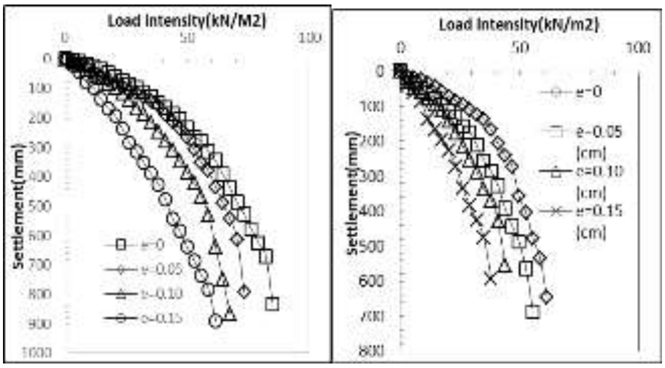


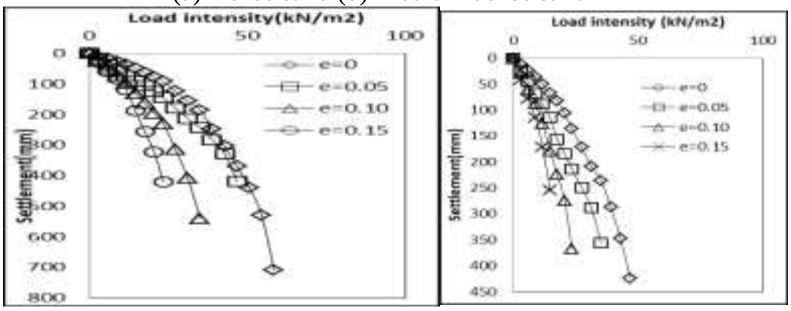
Fig. 7. Interpretation of ultimate bearing capacity of 5cm diameter footing on dense unreinforced sand bed by tangent intersection method at e=0

It is seen from the graph that in dense sand there is greater bearing capacity is observed as compared to medium dense sand. But if we discuss the other side of it, we can say that the settlement is more in case of medium dense sand and the load bearing capacity of dense sand is higher. Hence it can be clear that the variation of relative densities or denseness aspect of the soil has great influence on the bearing pressure. From the discussed graphs with varying densities of sand there is no clear evidence found that the reinforcement is the sole reason behind the increase of the ultimate bearing capacity. To know more about the outcome of reinforcement on the bearing capacity of circular footing, with various eccentricities and varying reinforcement layer (N) comparison is done from figure. In this we will discuss how the load-settlement curve changes according to change in relative densities of soil. The change in relative densities with variation of reinforcement layer gives a clear indication of how the circular footings behaves in this case.



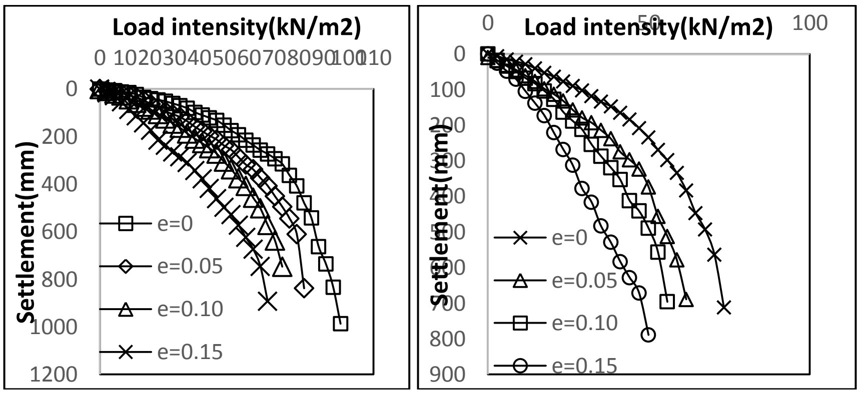
(a) (b)

Fig. 8. Load-settlement curve of eccentrically loaded 10cm footings on unreinforced (a) Dense sand (b) Medium dense sand



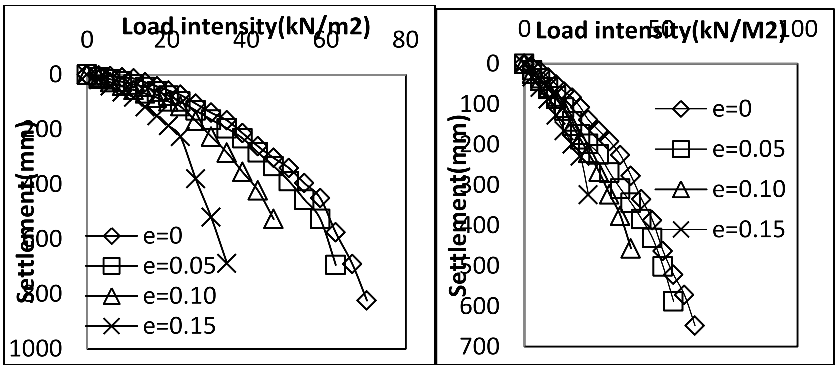
(a) (b)

Fig. 9. Load-settlement curve of eccentrically loaded 5cm footings on unreinforced (a) Dense sand (b)Medium dense sand



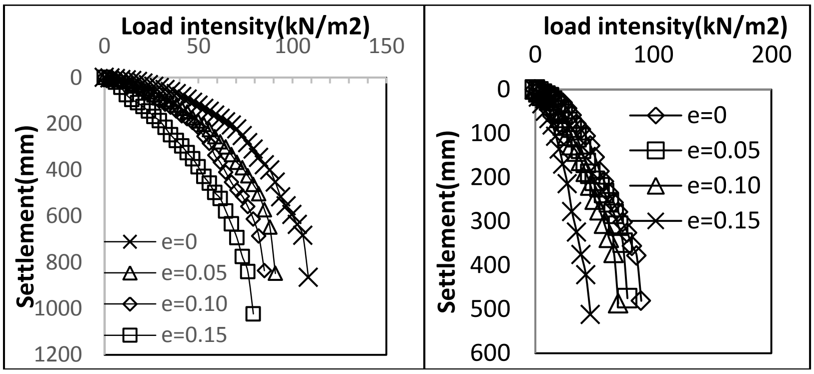
(a) (b)

Fig. 10. Load-settlement curve of eccentrically loaded 10cm footings on (a) Dense sand(b) Medium dense sand at N=1.



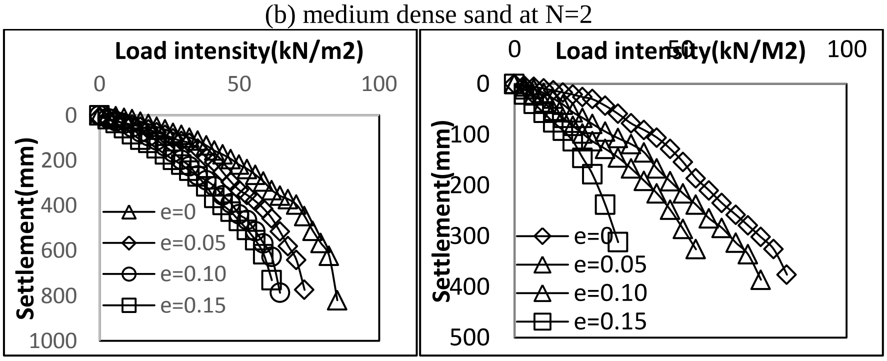
(a) (b)

Fig. 11. . Load-settlement curve of eccentrically loaded 5cm footings on (a) dense sand (b) medium dense sand at N=1



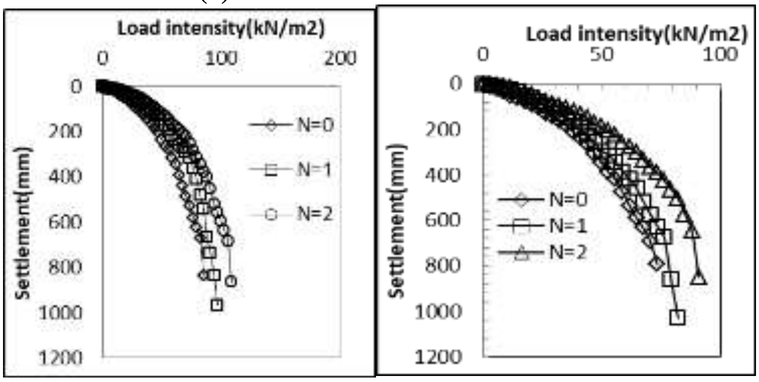
(a) (b)

Fig.12. Load-settlement curve of eccentrically loaded 10cm footings on (a) dense sand (b) medium dense sand at N=2

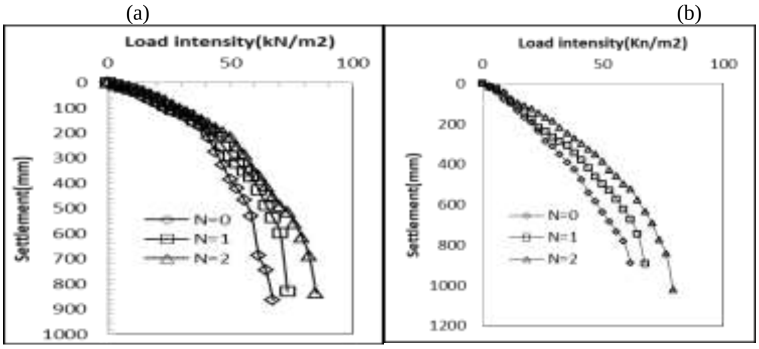


(a) (b)

Fig. 13. Load-settlement curve of eccentrically loaded 5cm footings on (a) Dense sand (b) Medium dense sand at N=2



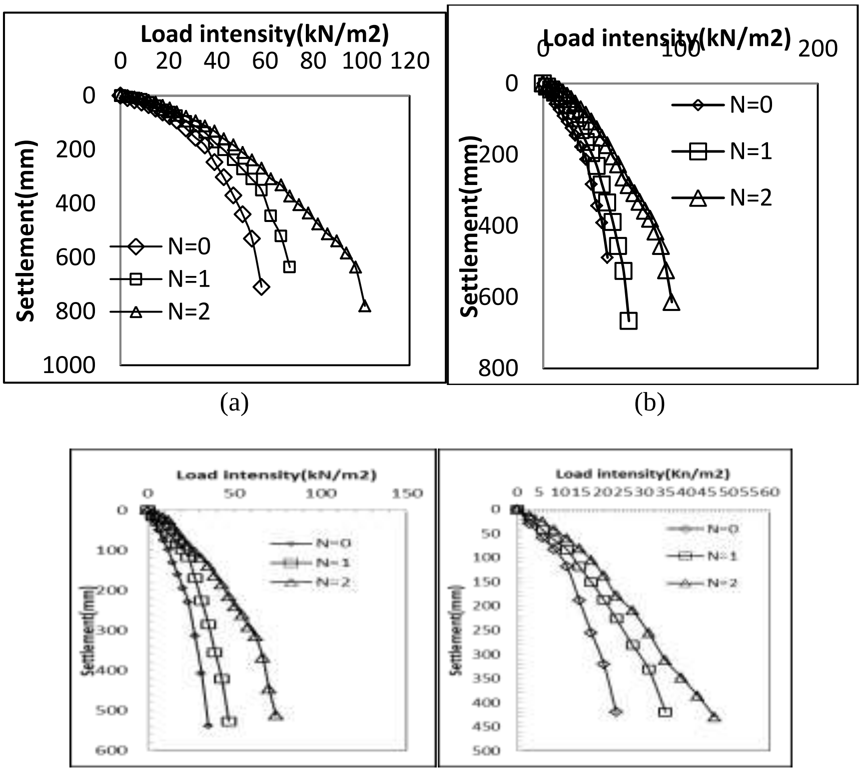
(a) (b)



(c) (d)

Fig. 14. Comparison of load-settlement curve of 10cm footing on Dense sand of (a) e= 0 (b) e= 0.05cm (c) e= 0.10cm (d) e= 0.15cm varying reinforcement layer.

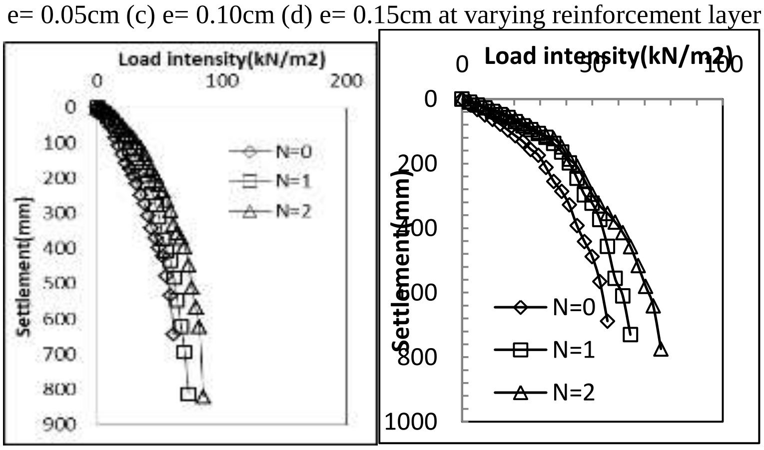
The effect of number of geonet layers and variation of densities of sand on settlement and load bearing pressure clearly visible in this figures. It is observed that with increase in reinforcement bearing pressure increases at any eccentricity of load application for any level of settlement. On the contrary settlement of footings decreases with increase in reinforcing layer for any type of load bearing pressure



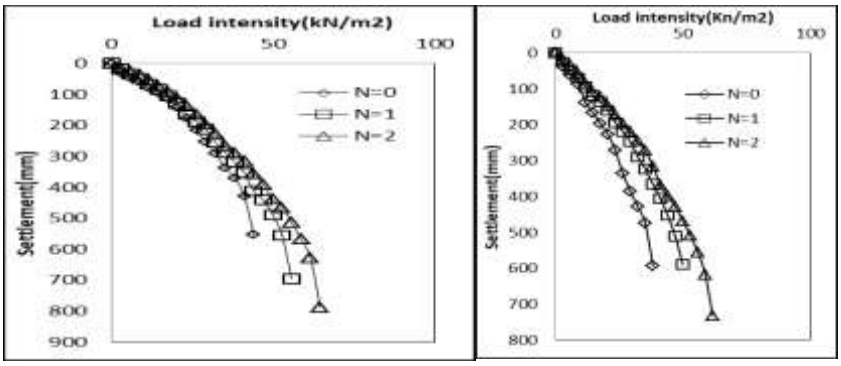
(a) (b)

(c) (d)

Fig.15. Comparison of load-settlement curve of 5cm footing on dense sand bed(a) e= o (b) e= 0.05cm (c) e= 0.10cm (d) e= 0.15cm at varying reinforcement layer

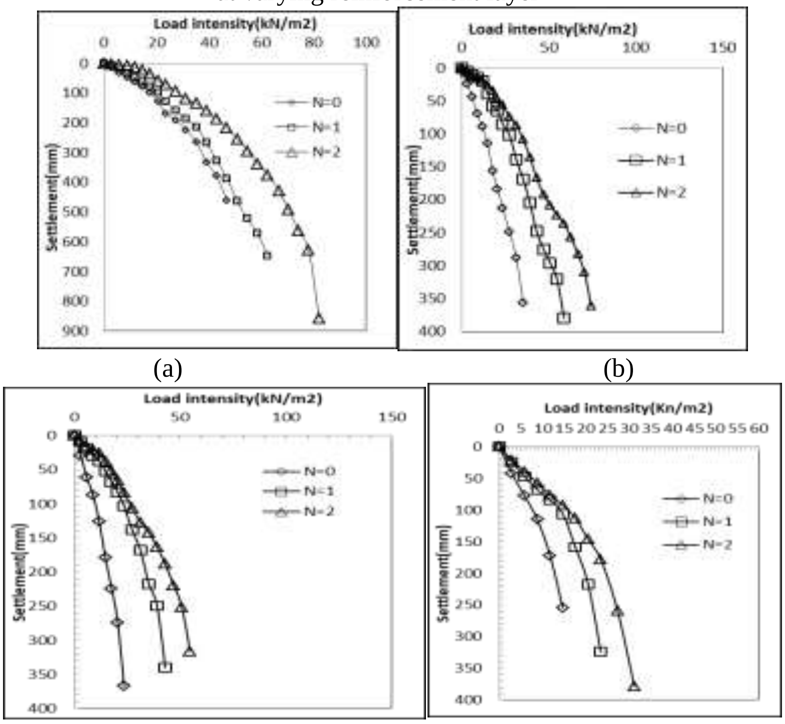


(a) (b)



(c) (d)

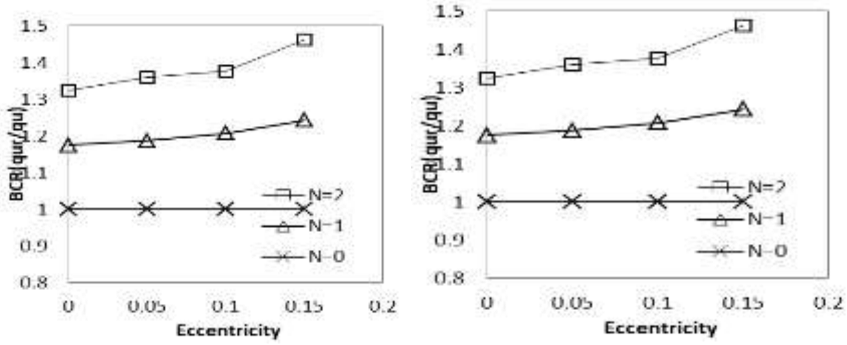
Fig. 16. Comparison of load-settlement curve of 10cm footing on medium dense sand bed (a) e= 0(b) e= 0.05cm (c) e =0.10cm (d) e= 0.15cm at varying reinforcement layer at varying reinforcement layer



(a) (b)

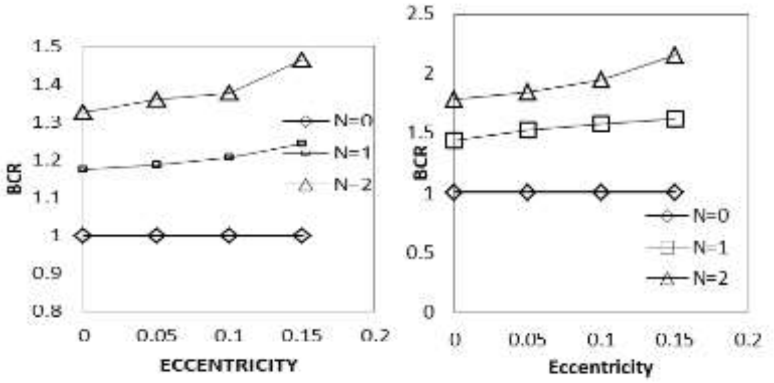
(c) (d)

Fig. 17. Comparison of load-settlement curve of 5cm footing on (a) e =o (b) e= 0.05cm (c) e= 0.10cm (d) e =0.15cm medium dense sand bed at varying reinforcement layer



(a) (b)

Fig. 18. BCR of 10cm footing :(a) on dense sand ,(b) Medium dense sand with varying Reinforcing layer



(a) (b)

Fig. 19. BCR of 10cm footing :(a) on dense sand ,(b) Medium dense sand with varying Reinforcing layer

4 Conclusion:

As per this experimental results and within the range of parameters, following conclusions are made:

- Relative density increased had a positive effect on bearing capacity of soil but final settlement is more or less same.
- Settlement decreases in decreasing rate with increase in reinforcement layer.
- Increasing in reinforcement layer resulted substantial increase in BCR value, although considerable settlement improvement is not observed.
- For reinforced condition it is observed that with increase in footing size bearing capacity ratio decreases, but increases with increase in eccentricity and latter bearing capacity ratio values become steady.

5 Acknowledgments:

This study reported is performed at VSSUT,Burla, Odisha as part of course of studies. Thanks to faculty members of civil engineering department and other official staff for their support. Timely assistance and help of geotechnical engineering laboratory staffs is highly acknowledged.

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