

# Effect of Soil Confinement on Ultimate Bearing Capacity of Square Footing Under Eccentric–Inclined Load

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## ABSTRACT

This paper presents the results of laboratory model tests on the effect of soil confinement on the behavior of a model footing resting on Ganga sand under eccentric – inclined load. Confining cells with different heights and widths have been used to confine the sand. The ultimate bearing load of a square footing supported on a confined sand bed has been studied. The studied parameters include the cell height, cell width and the depth from base of footing to the top of the confining cell, load eccentricity and load inclination. Initially, the behavior of footing for an unconfined case is studied and then it is compared with that of confined soil. The results are then analyzed to study the effect of each parameter. The ultimate bearing capacity improvement due to the soil confinement is represented using a non-dimensional factor, called the Bearing Capacity Ratio (BCR). The results indicate that the ultimate bearing capacity of square footing can be appreciably increased by soil confinement under axial load as well under eccentric–inclined load. It has been observed that such confinement resists the lateral displacement of soil underneath the footing leading to a significant decrease in the vertical settlement and hence improving the ultimate bearing capacity. For small cell width, the cell–soil footing behaves as one unit (deep foundation), while this pattern of behavior was no longer observed with large cell width. The recommended cell heights, depths, and widths that give the maximum ultimate bearing capacity improvement are presented and discussed.

**Keywords:** Model tests; Cohesionless soils; Square Footings; Eccentric-Inclined load; Ultimate Bearing Capacity; Soil Confinement.

## INTRODUCTION

In recent years Civil Engineering professionals have adopted the practice of improvement of soil by reinforcement, compaction, grouting etc. The decreasing availability of good construction sites has led to increased use of sites with marginal soil properties. In view of this, the requirement for in situ treatment of foundation soil to improve its bearing capacity has risen markedly. The soil confinement is one such method of improving soil capacity. The more recent advancement in this field is to provide confinement to the soil by using metalcell, geocell etc. This novel technique of soil confinement, though successfully applied in some areas of geotechnical engineering, has not received much attention in foundation applications. In the last few decades, great strides in the modification of existing forms of foundations have occurred, along with the development of new and unconventional types of foundation systems through consideration of soil and structure interaction. This results in a system that is more realistic in performance, utilizing the form and material strength. Lateral confinement of cohesionless soil is one of them. Many researchers have studied the effect of lateral confinement on bearing capacity, especially on sandy soil. They have concluded that by confining the soil there is a reduction in the settlement, and hence there is an increase in the bearing capacity of the soil.

**Rea and Mitchell (1978)** conducted a series of model plate loading tests on circular footings supported over sand-filled square-shaped paper grid cells to identify different modes of failure and arrive at optimum dimensions of the cell. **Mahmoud and Abdrabbo (1989)** presented an experimental study concerning a method of improving the bearing capacity of strip footing resting on sand sub-grades utilizing vertical nonextensible reinforcement. The test results indicate that this type of reinforcement increases the bearing capacity of sub-grades and modifies the load–displacement behavior of the footing. **Khing et al. (1993)** investigated the laboratory-model test results for the bearing capacity of a strip foundation supported by a sand layer reinforced with layers of geogrid. **Puri et al. (1993)** studied the ultimate bearing capacity of strip and square foundations supported by sand reinforced with geogrid. **Das and Omar (1993)** presented the ultimate bearing capacity of surface strip foundations on geogrid-reinforced sand and unreinforced sand. **Dash et al. (2001b)** investigated the use of vertical reinforcement along with horizontal reinforcement. The reinforcement consisted of a series of interlocking cells, constructed from polymer geogrids, which contain and confine the soil within its pockets. **Schimizu and Inui (1990)** carried out load tests on a single six-sided cell of geotextile wall buried in the subsurface of the soft ground. **Mandal and Manjunath (1995)** used geogrid and bamboo sticks as vertical reinforcement elements and studied their effect on the bearing capacity of a strip footing. The strength of confined sand has been studied by **Rajagopal, Krishnaswamy and Latha (1999)**. They studied the influence of geocell confinement on the strength and stiffness behavior of granular soils. **Dash et al. (2001a)** performed an experimental study on the bearing capacity of a strip footing supported by a sand bed reinforced with a geocell mattress. Several authors have also studied strip foundations but reinforced with different materials such as steel bars (**Milovic, 1977; Bassett and Last, 1978; Verma and Char, 1986**), steel grids (**Dawson and Lee, 1988; Abdel-Baki et al.1993 ;**), geotextile (**Das,1988**), and geogrids (**Milligan and Love, 1984, 1985; Ismail and Raymond, 1995**). **Sawwaf and Nazer (2005)** studied the behavior of circular footing on

confined sand. They used confining cylinders with different heights and diameters to confine the sand.

Study of bearing capacity of footing under eccentric or eccentric – inclined load has been carried out by many researchers in the past but without reinforcement (**Meyerhof, 1953; Meyerhof, 1963; Meyerhof, 1965; Prakash and Saran, 1971; Prakash and Saran, 1977**)

This laboratory-testing program attempts to provide a better understanding of the behavior of square footing resting on confined Ganga sand under eccentric – inclined load.

## LABORATORY MODEL TESTS

### Footing

A square model footing of size 150 x 150 mm and 10mm thick made of mild steel with grooves at top was used. The footing had a groove at the centre and along a line such that the eccentricity-width ratio becomes 0.1, 0.2 and 0.3. The base was made rough by fixing a thin layer of sand onto the base of the model footing. The footing was placed on the surface of the sand bed and load was applied on it by a hand-operated mechanical jack. The load transferred to the footing was measured by a pre-calibrated proving ring. The load was applied as per IS: 1888-1982. Each load increment was maintained constant till the footing settlement had stabilized. The settlement of the footing was measured by dial gauges placed on the footing.

### Model test tank

Model tests were conducted in a test tank, having inside dimensions of 1500 x 1500 mm in plan and 1000 mm deep. The size of the tank was decided by the size of the footing and the zone of influence. The test tank is made of steel and has arrangement to fix the proving ring with specially fabricated inclined load device for applying the axial as well as inclined load to the footing as shown in Fig.1

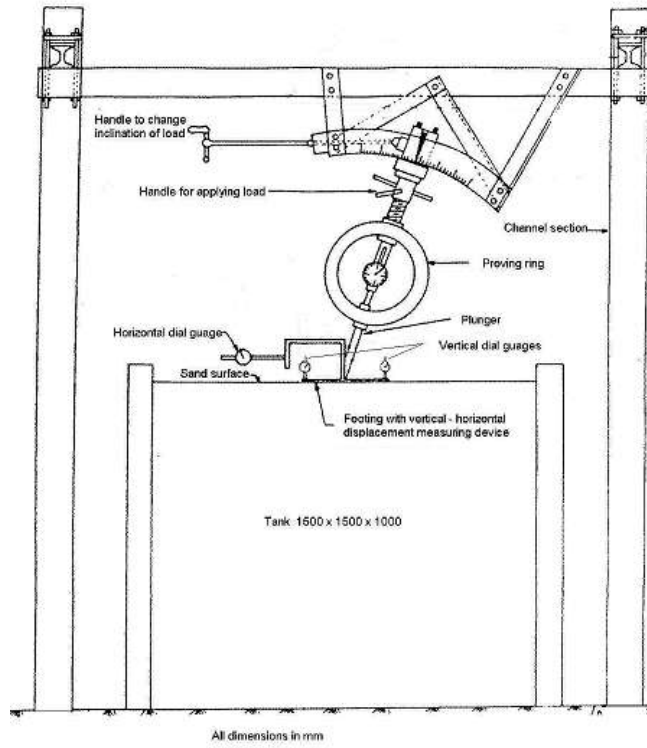
## TEST MATERIAL

### Ganga sand

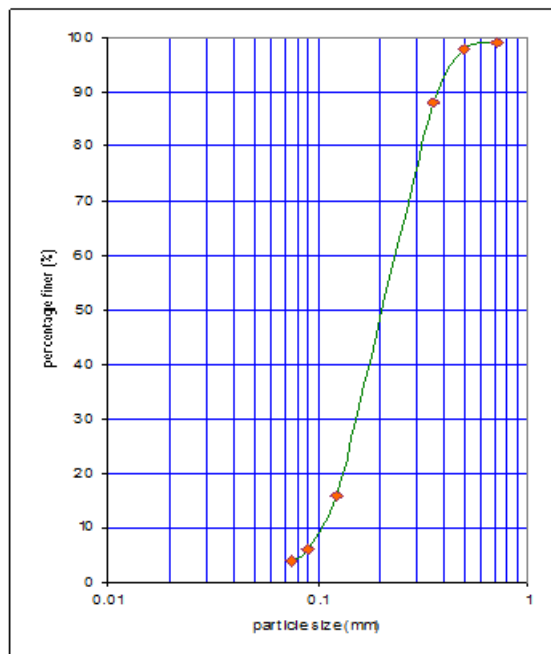
Locally available Ganga sand is used as the foundation bed. The physical properties of Ganga sand is presented in Table 1. The grain size distribution curve of Ganga sand is shown in Fig. 2 and is classified as SP.

### Confining cells

The confining cells were made of MS plate with different width and heights. The internal sizes of cells used are 150, 225, 300, 375 and 450 mm. The heights of cell used are 150, 225 and 300 mm. The thickness of the all the confining cells is 10 mm. The tests were carried out by placing the confining box initially in position and then the sand bed was prepared by rainfall technique to get the desired relative density of 65%.



**Figure 1:** Experimental setup



**Figure 2:** Particle size distribution curve of Ganga sand

S. No.	Characteristics	Value
1	I. S. Classification	SP
2	D <sub>10</sub>	0.11 mm
3	D <sub>30</sub>	0.15 mm
4	D <sub>60</sub>	0.22 mm
5	Uniformity coefficient (C <sub>u</sub> )	2.0
6	Coefficient of curvature (C <sub>c</sub> )	0.929
7	Minimum void ratio (e <sub>min</sub> )	0.67
8	Maximum void ratio (e <sub>max</sub> )	0.92
9	Void ratio in test (e)	0.75
10	Specific gravity (G)	2.67
11	Minimum dry density	13.62 kN/m <sup>3</sup>
12	Maximum dry density	15.05 kN/m <sup>3</sup>
13	Density of sand in test	14.78 kN/m <sup>3</sup>
14	Relative density of sand during test (D <sub>r</sub> )	65 %
15	Angle of internal friction (φ)	34°
16	Classification of sand based on relative density	Medium dense

**Table 1:** Physical properties of Ganga sand

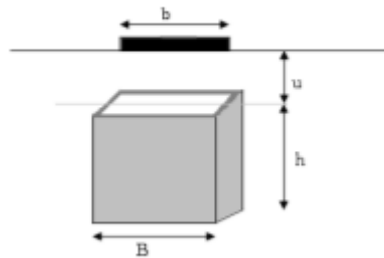
## EXPERIMENTAL SETUP AND TEST PROGRAM

The footing was placed in position and the load was applied to it by the jack through the proving ring. The load was applied in small increments until failure occurred. Each load increment was maintained constant until the footing settlement had stabilized. The settlements of the footing were measured by dial gauges. The geometry of the soil, model footing, and confining box is shown in Fig. 4. The test program consisted of carrying out of ten series of tests (A – J) on square footing to study the effect of soil confinement on the soil-foundation response as shown in Table 2. Initially, the test has been carried out under axial load on the footing resting on the unconfined bed. Then, each series of the tests were carried out under axial load to study the effect of one parameter while the other variables were kept constant. The studied variables are the cell height (h), cell width (B) and the depth from base of footing to the top of confining cell (u) keeping footing width (b) constant for all the cases.

Finally, tests were conducted under eccentric-inclined load for one case of confinement. The confinement condition, for which the BCR is maximum ( $B/b = 1.5$  and  $h/b = 2.0$ ), is chosen for the eccentric-inclined loading. The  $e/B$  ratio for eccentric load is 0.1, 0.2 and 0.3. The load inclination is  $5^\circ$ ,  $10^\circ$ ,  $15^\circ$  and  $20^\circ$ .

**Table 2:** Model Test Program

Test Series	Constant parameters	Variable parameters
	Test on unconfined sand bed	
A	$\frac{h}{b} = 2.0$ and $\frac{u}{b} = 0$	$\frac{B}{b} = 1.0, 1.5, 2.0, 2.5, 3.0$
B	$\frac{h}{b} = 2.0$ and $\frac{u}{b} = 0.5$	$\frac{B}{b} = 1.0, 1.5, 2.0, 2.5, 3.0$
C	$\frac{h}{b} = 2.0$ and $\frac{u}{b} = 1$	$\frac{B}{b} = 1.0, 1.5, 2.0, 2.5, 3.0$
D	$\frac{h}{b} = 1.5$ and $\frac{u}{b} = 0$	$\frac{B}{b} = 1.0, 1.5, 2.0, 2.5, 3.0$
E	$\frac{h}{b} = 1.5$ and $\frac{u}{b} = 0.5$	$\frac{B}{b} = 1.0, 1.5, 2.0, 2.5, 3.0$
F	$\frac{h}{b} = 1.5$ and $\frac{u}{b} = 1$	$\frac{B}{b} = 1.0, 1.5, 2.0, 2.5, 3.0$
G	$\frac{h}{b} = 1.0$ and $\frac{u}{b} = 0$	$\frac{B}{b} = 1.0, 1.5, 2.0, 2.5, 3.0$
H	$\frac{h}{b} = 1.0$ and $\frac{u}{b} = 0.5$	$\frac{B}{b} = 1.0, 1.5, 2.0, 2.5, 3.0$
I	$\frac{h}{b} = 1.0$ and $\frac{u}{b} = 1$	$\frac{B}{b} = 1.0, 1.5, 2.0, 2.5, 3.0$
J	$\frac{h}{b} = 1.0$ and $\frac{u}{b} = 1$	$\frac{B}{b} = 1.0, 1.5, 2.0, 2.5, 3.0$

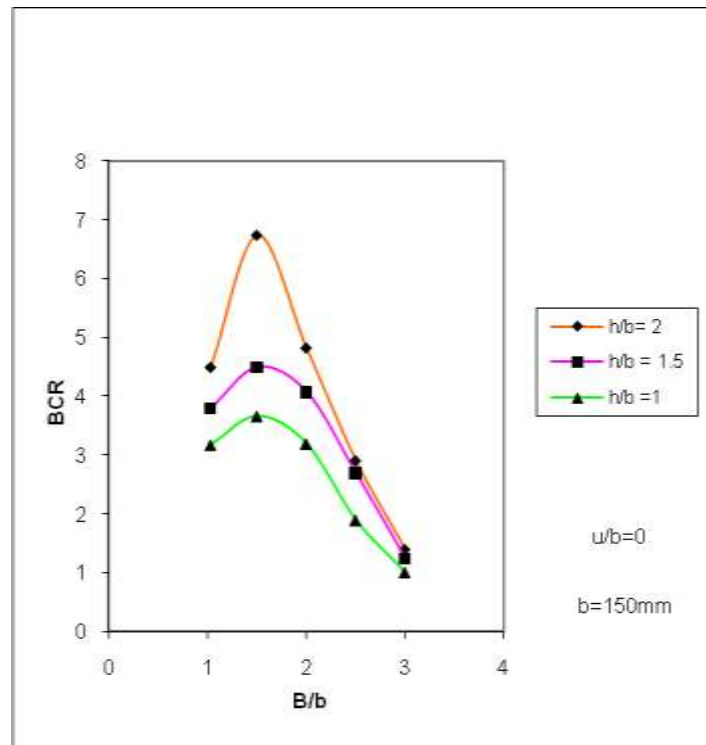
**Figure 4:** Geometric parameters of confined sand-foundation system

## RESULTS AND DISCUSSION

The load–settlement relationship and the ultimate bearing capacity of the footing with and without confinement have been obtained. The bearing capacity improvement due to the soil confinement is represented using a non-dimensional factor, called the Bearing Capacity Ratio (BCR). This factor is defined as the ratio of the ultimate bearing capacity with confinement to the ultimate bearing capacity in tests without confinement.

## Effects of cell width

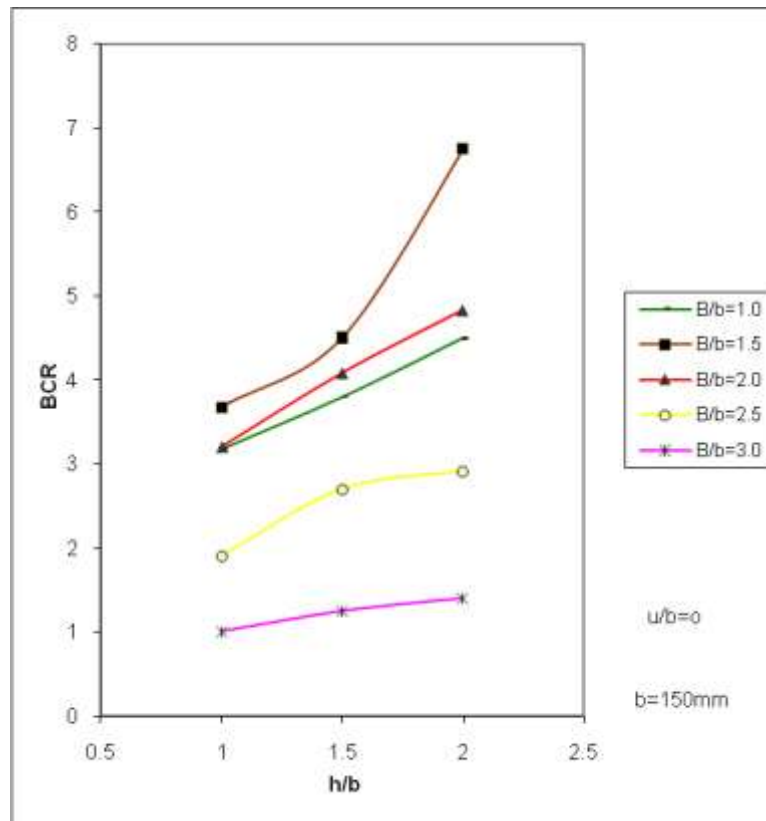
In order to investigate the effect of cell width on the footing behavior, five cells with width of 150, 225, 300, 375 and 450 mm were used. Fig.5 shows the variation of BCR with normalized cell width for different cell heights with a constant footing width of 150 mm. A significant increase in the bearing capacity of the model footing supported on confined sand with the increase of normalized cell width  $B/b$  is observed up to about  $B/b$  ratio of 1.5; after which the BCR decreases with an increase in the  $B/b$  ratio. While conducting the model tests, it was observed that as failure approached in tests carried out with small cell width, the cell and the sand within the cell behaved as one unit. In tests carried out with large cell width, this behavior was noticed initially, but as the load was increased it was no longer observed. Fig.5 also shows that using soil confinement could result in an improvement in bearing capacity as high as 6.75 times more than that without soil confinement. It is clear that the best benefit of soil confinement could be obtained with a  $(B/b)$  ratio between 1.0 to 2.0 with the maximum improvement in the bearing capacity at a  $(B/b)$  ratio of about 1.5 for different heights of confining cells. When the footing is loaded, such confinement resists the lateral displacements of soil particles underneath the footing and confines the soil leading to a significant decrease in the vertical settlement and hence improving the bearing capacity. For small cell widths, as the pressure is increased, the plastic state is developed initially around the edges of the footing and then spreads downward and outward. The mobilized vertical friction between sand and the inside wall of the cell increases with the increase of the acting active earth pressure. This behavior is observed until the point when the system (the cell, sand and footing) starts to behave as one unit. The behavior is similar to that observed in deep foundations (piles and caissons) in which the bearing load increases due to the shear resistance of cell surface. This illustrates the increase of the bearing load with the increase of the cell width and cell height.



**Figure 5:** Variation of bearing capacity ratio with normalized cell widths (B/b) for different cell heights at  $u=0$  mm

### Effect of cell height

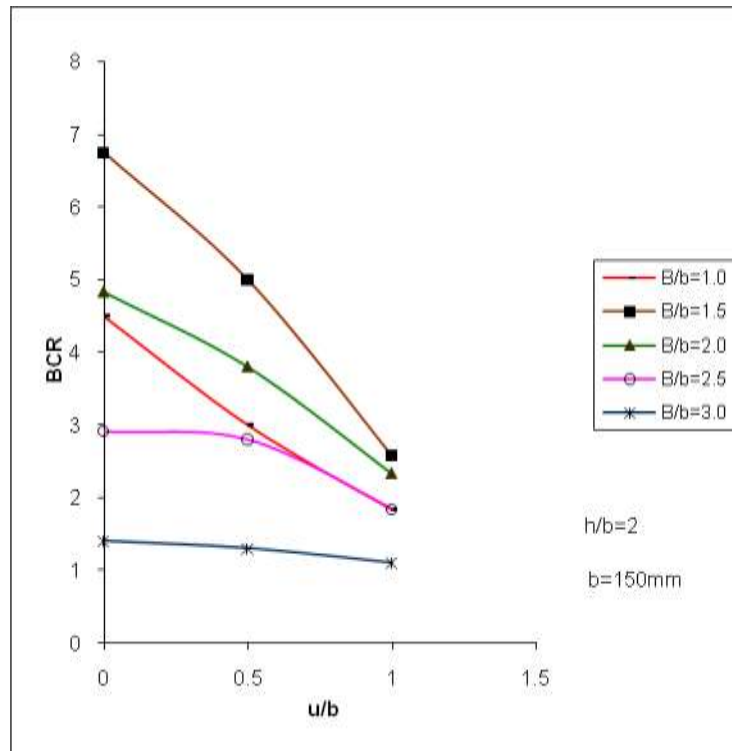
In order to investigate the effect of cell height on the footing response, tests were carried out using three different heights for each cell width. The variation of BCR with normalized cell height ( $h/b$ ) is shown in Figure 6 for different normalized cell widths ( $B/b$ ). The figure shows the same pattern of behavior for the different cell widths. Increasing cell heights results in a greater improvement in the BCR. The increase in cell height results in the enlargement in the surface area of the cell–model footing leading to a higher bearing capacity load. The slope of the BCR versus  $h/b$  curves for  $B/b$  ratios of 1.0 and 2.5 are less than the comparable slopes for  $B/b$  ratios of 1.5 and 2.0. This trend confirms the previous conclusion that the greatest benefit of cell confinement can be obtained at a  $B/b$  ratio of about 1.5.



**Figure 6:** Variation of bearing capacity ratio with normalized cell height ( $h/b$ ) for different cell widths ( $B/b$ ) at  $u=0$  mm

### Effect of cell depth

The variation of the BCR at different normalized depths to the top of the cell ( $u/b$ ) for cells with a different cell widths are shown in Fig.7. It is observed that the BCR decreases with the increase in the depth of the cell. With an increase in the depth of placement, the soil between the footing and the cell top deforms laterally and, therefore, the vertical settlements increase and the BCR decreases. Based on these results, it is observed that the maximum bearing capacity ratio is obtained at  $u/b$  ratio of zero i.e., when the top of cell is placed at the footing level. However, for confined footing the effect of overburden pressure is not significant. When the footing is loaded, it settles and the plastic state is developed until the point at which the system starts to behave as one unit.



**Figure 7:** Variation of bearing capacity ratio with normalized depth to the top of the cell ( $u/b$ ) for different cell widths and constant cell height 300 mm

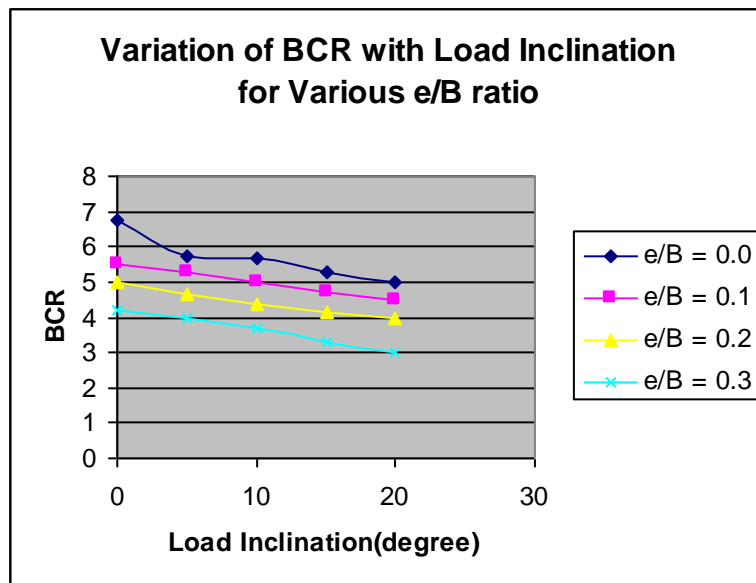
### Effect of eccentric-inclined load

Eccentric-inclined load was applied to the footing for the confined case that showed the maximum benefits of confinement. The ratio of  $B/b = 1.5$  and  $h/b = 2.0$ . Load eccentricity ( $e/B$ ) used is 0.1, 0.2 and 0.3 and load inclination is  $5^\circ$ ,  $10^\circ$ ,  $15^\circ$  and  $20^\circ$ . Ultimate bearing capacity has been found out from the load-settlement curve. Vertical settlement and horizontal displacement of the footing were recorded by dial gauges. It was observed that with the increase in load eccentricity and load inclination, there was a reduction in ultimate bearing capacity. But this ultimate bearing capacity was found to show a remarkable improvement with footing with confinement. The horizontal displacement of the footing also increased with the increase in the load inclination. The results are presented in Table 3. BCR ratio for various load inclination and  $e/B$  ratio is calculated and shown in the Fig.8.

The ultimate load decreased from  $1.35 \text{ kg/cm}^2$  to  $0.45 \text{ kg/cm}^2$  when the load inclination increased from  $0^\circ$  to  $20^\circ$  for  $e/B$  ratio of 0.0. Similarly it decreased from  $0.29 \text{ kg/cm}^2$  to  $0.07 \text{ kg/cm}^2$  when load inclination increased from  $0^\circ$  to  $20^\circ$  for  $e/B$  ratio of 0.3. The vertical settlement and horizontal displacement also showed a reduction due to confinement.

**Table 3:** BCR of Unconfined and Confined Footing for Eccentric-Inclined Load

Sl. No.	e/B	i (degree)	Footing with No Confinement			Footing with Confinement			BCR
			Q <sub>ult</sub> (kg/cm <sup>2</sup> )	V <sub>settl.</sub> (mm)	H <sub>disp.</sub> (mm)	Q <sub>ult</sub> (kg/cm <sup>2</sup> )	V <sub>settl.</sub> (mm)	H <sub>disp.</sub> (mm)	
1	0.0	0	1.35	18.4	--	9.11	17.90	--	6.75
2	0.0	5	1.24	14.04	3.51	7.13	13.90	3.42	5.75
3	0.0	10	1.04	10.42	5.92	5.93	10.30	5.85	5.70
4	0.0	15	0.66	8.83	7.74	3.49	8.70	7.65	5.29
5	0.0	20	0.45	6.26	4.59	2.25	6.15	4.42	5.00
6	0.1	0	0.88	14.35	--	4.84	14010	--	5.50
7	0.1	5	0.71	8.65	5.12	3.76	8.25	5.01	5.29
8	0.1	10	0.59	7.36	5.90	2.95	7.10	5.70	5.00
9	0.1	15	0.45	6.07	6.60	2.12	5.92	6.20	4.71
10	0.1	20	0.34	4.97	4.80	1.53	4.85	4.50	4.50
11	0.2	0	0.57	7.92	--	2.85	7.65	--	5.00
12	0.2	5	0.49	6.44	3.08	2.29	6.40	2.92	4.67
13	0.2	10	0.41	5.15	4.43	1.80	5.02	4.35	4.39
14	0.2	15	0.26	3.31	3.60	1.08	3.17	3.51	4.15
15	0.2	20	0.18	2.21	3.08	0.72	2.00	2.98	4.00
16	0.3	0	0.29	4.42	--	1.22	4.37	--	4.21
17	0.3	5	0.23	3.52	2.82	0.91	3.21	2.73	3.96
18	0.3	10	0.16	2.75	2.63	0.59	2.55	2.55	3.69
19	0.3	15	0.11	2.39	2.85	0.36	2.18	2.12	3.27
20	0.3	20	0.07	1.82	1.94	0.21	1.75	1.88	3.00



**Figure 8:** Variation of BCR with load inclination for various e/B ratios (B/b= 1.5, h/b = 2.0)

## CONCLUSIONS

Based on the experimental test results, the following conclusions can be drawn.

- Soil confinement has a significant effect on improving the behavior of square footing supported on granular soil. The ultimate bearing capacity was found to increase by a factor of 6.75 as compared to the unconfined case.
- Based on experimental results, soil confinement could be considered as a method to improve the bearing capacity of isolated footings resting on medium to dense sand. This type of cells with different heights, widths and thickness could be easily manufactured and placed around the individual footings leading to a significant improvement in their response.
- In cases where structures are very sensitive to settlement, soil confinement can be used to obtain the same allowable bearing capacity at a much lower settlement
- The BCR is highly dependent on the B/b ratio (cell width/footing width). The optimum ratio is about 1.50 beyond which the improvement decreases as the ratio increase.
- Increasing the height of the confining cells, results in increasing the surface area of the cell-model footing, this transfers the footing load to deeper depth and leads to improving the BCR. Optimum value of h/b ratio is 2.
- To obtain maximum improvement, the top of the confining cell should be situated at top of the foundation bed.
- Soil confinement has a significant effect on improving the behavior of square footing under eccentric-inclined load. The BCR in this case is also 6.75.

## REFERENCES

1. **Abdel-baki,S., G.P. Raymond, and P. Johnson (1993)** "Improvement of the Bearing Capacity of Footing by a Single Layer of Reinforcement," Proceedings, Vol. 2, Geosynthetics 93 Conference, Vancouver, Canada. pp. 407-416
2. **Bassett, R.H., and N.C. Last (1978)** "Reinforcing earth below footing and embankments." Symposium on Earth Reinforcement, ASCE, Pittsburgh. 202-231.
3. **Binquet, J., and K.L. Lee (1975)** "Bearing capacity tests on reinforced earth slabs." Journal of Geotechnical Engineering Division, 101(12), 1241-1255.
4. **Das, B.M. (1988)** "Shallow foundation on sand underlain by soft clay with geotextile interface," "Geosynthetics for Soil Improvement. 112-126.
5. **Das, B.M., and M.T. Omar (1994)** "The effects of foundation width on model tests for the bearing capacity of sand with geogrid reinforcement." Geotechnical and Geological Engineering, 12, 133-141.
6. **Das, B.M., V.K. Puri, M.T. Omar and E. Evigin (1996)** "Bearing capacity of strip foundation on geogrid reinforced sand-scale effects in model tests." Proc., 6<sup>th</sup> International Conference on Offshore and Polar Engineering, Vol.12, 527-530.

7. **Dash, S., N. Krishnaswamy and K. Rajagopal (2001 a)** "Bearing capacity of strip footing supported on geocell-reinforced sand." *Geotextile and Geomembrane*, 19, 535-256.
8. **Dash, S., K. Rajagopal and N. Krishnaswamy (2001b)** "Strip footing on geocell reinforced sand beds with additional planar reinforcement." *Geotextile and Geomembrane*, 19, 529-538.
9. **Dawson, A. and R. Lee (1988)** "Full scale foundation trials on grid reinforced clay," *Geosynthetics for Soil Improvement*. 127-147.
10. **De Beer, E.E. (1970)** "Experimental determination of the shape factor and the bearing capacity factors of sand." *Geotechnique*, 20, 387-411.
11. **Fragaszy, R.J., and E. Lawton (1984)** "Bearing capacity of reinforced sand subgrades." *Journal of Geotechnical Engineering Division*, 110(10), 1500-1507.
12. **Guid, V.A., D.K. Chang and M.A. Sweeney (1986)** "Comparison of geogrid and geotextile reinforced earth slabs." *Canadian Geotechnical Journal*, 23, 435-440.
13. **Ismail, I., and G.P. Raymond (1995)** "Geosynthetic reinforcement of granular layered soils." *Proceedings*, 1, *Geosynthetics* .95, 317-330.
14. **Khing, K.H., B.M. Das, V.K. Puri, E.E. Cook and S.C. Yen** "The bearing capacity of a strip foundation on geogrid-reinforced sand", *Geotextiles and Geomembranes*, 12, 351-361.
15. **Kumar, A. and B.S. Waliya (2006)** "Bearing capacity of square footing on reinforced layered soil" *Geotechnical and Geological Engineering*, Vol. 24, 1001-1008.
16. **Mahmoud, M.A., and F.M. Abdrabbo (1989)** "Bearing capacity tests on strip footing on reinforced sand subgrade." *Canadian Geotechnical Journal*, 26, 154-159.
17. **Milligan, G.W.E., and J.P. Love (1984)** "Model testing of geogrids under and aggregate layer in soft ground/" *Proceedings, Symposium on polymer Grid Reinforcement in Civil Engineering*, ICI, London, England, 4.2.1-4.2.11.
18. **Mandal, J.M., and V.R. Manjunath (1995)** "Bearing capacity of strip footing resting on reinforced sand subgrades." *Construction and Building Material*, 9 (1), 35-38.
19. **Meyerhof, G.G. (1953)** "The bearing capacity of foundations under eccentric-inclined loads", 3<sup>rd</sup> ICSMFE, Zurich, Vol.1, 1-19.
20. **Meyerhof, G.G. (1963)** "Some recent research on the bearing capacity of foundations." *Canadian Geotechnical Journal*, 1 (1), 16-26.
21. **Meyerhof, G.G. (1965)** "Shallow foundations", *J. of SMFD, ASCE*, Vol. 91, SM2, 21-31.
22. **Milovic, D. (1977)** "Bearing capacity tests on reinforced sand", *Proc. Of the 9<sup>th</sup> International conf. on Soil Mechanics and Foundation Engineering*, Tokyo, Japan, 1, 651-654.
23. **Omar, M.T., B.M. Das, V.K. Puri and S.C. Yen (1993a)** "Ultimate bearing capacity of shallow foundations on sand with geogrid reinforcement." *Canadian Geotechnical Journal*, 30, 545-549.

24. **Omar, M.T., B.M. Das, S.C. Yen, V.K. Puri and E.E. Cook (1993b)** "Ultimate bearing capacity of rectangular foundations on geogrid reinforced sand." *Geotechnical Testing Journal*, 16, 246-252.
25. **Prakash, S. and S. Saran (1971)** "Bearing capacity of eccentrically loaded footings", *J of SMFE div, ASCE*, No. SM1, 95-118.
26. **Prakash, S. and S. Saran (1977)** "Settlement and tilt on eccentrically loaded footings", *J. of structural engineering*, Roorkee, Vol.4, No.4, 176-186
27. **Puri, V.K., K.H. Khing, B.M. Das, E.E. Cook and S.C. Yen (1993)** "The bearing capacity of a strip foundation on geogrid reinforced sand." *Geotextile and Geomembrane*, 12, 351-361.
28. **Rajagopal, K., N. Krishnaswamy and G. Latha (1999)** "Behavior of sand confined with single and multiple geocells", *Geotextile and Geomembrane*, 17, 171-184.
29. **Rea, C. and J.K. Mitchell (1978)** "Sand reinforcement using paper grid cells", *Proc. Symposium on Earth Reinforcement*, Pittsburg, ASCE, 644-663.
30. **Sawwaf, M.E., and A. Nazer (2005)** "Behavior of circular footing resting on confined granular soil." *Journal of Geotechnical and Geoenvironmental Engineering*, 131(3), 359-366.
31. **Schimizu, M., and T. Inui (1990)** "Increase in bearing capacity of ground with geotextile wall frame." *Proc., 4<sup>th</sup> International Conference on Geotextiles, Geomembranes and Related Products*, Vol. 1, 254.
32. **Steenfelt, J.S. (1977)**. "Scale effect capacity factor  $N_\gamma$ ." *Proc., 9<sup>th</sup> International Conference on Soil Mechanics and Foundation Engineering*, Vol. 1, 749-752.
33. **Verma, B.P., and A.N.R. Char (1986)** "Bearing capacity tests on reinforced sand subgrades," *Journal of Geotechnical Engineering*. 112(7), 701-706.
34. **Vesic, A.S. (1973)** "Analysis of ultimate loads of Shallow foundations." *Journal of Soil Mechanics and Foundation Division*, Vol. 99(1), 45-73.

