Experimental Study on Square Footing Resting on Sand With and Without Confinement

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Abstract - *This paper presents the experimental results obtained from a series of investigations carried out to determine the vertical load carrying capacity of the skirted foundation at different skirt/confining cell length and for different conditions such as confining cell placed at different depth (U) from sand surface and for footing embedded depth. A total 25 model tests are carried out by utilizing 50 mm square footing on the sand which is maintained at relative density of 47% and confining cells of varying length (50 mm, 75 mm, 100 mm, 125 mm & 150 mm) are used. Based on the obtained results, load-settlement plot was prepared and results indicates that load carrying capacity of footing increases as the length of confinement increases. The Laterally confining cell was made to provide vertical confinement, by placing 3 mm thick plate. Load carrying capacity of footing placed on the confining cells which resist only lateral movement of sand is slightly more than the load carrying capacity of footing which resists both lateral & vertical movement of sand.*

***Key Words*: Square footing, Confining cells, Lateral confinement, Vertical confinement, Load carrying capacity, Depth (U), embedded footing.**

1. INTRODUCTION

There always has been search for alternative methods of improving the load carrying capacity and settlement reduction of footing. Although there are variety of methods of soil stabilization which are well known and developed. Some of them might be expensive and restricted by the site conditions. There might be difficulties in executing them on site due to harsh conditions. So, structural skirts are good alternative for improving the load carrying capacity and settlement reduction of footing on soil. Skirted foundations are used widely for various offshore applications. Skirted foundations are gradually gaining over pile foundations. In comparison to a surface foundation, the skirted foundation transfers the load to deeper, thus mobilizing higher load bearing capacity. Skirted foundations were first used in early 1970's as a supporting unit for floating structures in offshore hydrocarbon projects. Nowadays, skirted foundation is adopted for bridges, marine structures and where water scouring is a major issue. Any shape of confining cell can be used but normally shape of the confining cell is kept same as the footing shape. The effect of skirt length on load carrying capacity were investigated and reported in many literatures. Many researchers have already conducted various vertical loading tests on circular footing and concluded that this type of reinforcement increases the load carrying capacity, reduces the settlement and modifies the load settlement behavior. Ahmed Elzoghby Elsaied et.al., (2014) studied the behavior of circular footing resting on laterally confined granular reinforced soil, they observed the effects of cylinder height, cylinder diameter on load carrying capacity of skirted circular foundation. They also conducted the test on skirted footing by inserting square geo-grid layers at different depths below the bottom edge of the cylinder. There was an increase in bearing capacity by 7.5 times than the unconfined case. Amr Z. EL Wakil (2013) performed eighteen laboratory tests on circular footings of different diameters and different skirt lengths. They found enhancement in bearing capacity of footing with skirt was increased by about 6.25 times than the footing without the skirt. They studied the effect of relative density of sand and skirt length on bearing capacity of shallow footings. They conducted tests on circular footing for three different relative densities of sand at 35%, 65% and 90% and found that bearing capacity ratio increased linearly as ratio of length of skirt to footing diameter increases for relative density equal to 65% and 90%. But at 35% relative density there is nonlinear increase in bearing capacity ratio with length of skirt to footing diameter. Rajeev Gupta and Ashutosh Trivedi (2009) conducted test on model circular footing of 150 mm diameter with different cell height and diameter on clean sand and sand having silt up to 25%. The performance of footing without confinement was first found out and then compared with the footing with confinement. As the percentage of fines increases, bearing capacity of circular footing decreases and settlement increases. But by installing confining cell settlement can be reduced and bearing capacity can be appreciably improved. M. EI Sawwaf and A. Nazer (2005) reviewed the behavior of circular footing resting on restrained granular soil. Circular footing of 75 mm diameter and thickness of 10 mm was used. Granular soil is confined by using circular Un-plasticized Polyvinyl Chloride (UPVC) of various height and dia. They studied the parameters such as cell height, cell diameter, embedded depth of footing and depth to the top of the cell. From the study they came to know that, ultimate capacity was increased by 17 times as that of unreinforced case this is due to confinement, the BCR (bearing capacity ratio) increase as the height of the confining cell increase, the BCR is mainly abased on d/D ratio (cell diameter/footing diameter).When confining cell is situated at a depth of 10% of footing diameter from the sand surface maximum improvement in loading capacity was achieved. M.Y.Al-Aghbari and Y. E-A.Mohamedzein (2004) conducted a series of tests on model foundation to give the modified bearing capacity of strip foundations with structural skirts. They also proposed the modified bearing capacity equation of skirted strip foundation resting on dense sand. They found that bearing capacity of foundation can be enhanced by factor of 1.5 to 3.9 by using skirts. Hisham T. Eid and M. Asce (2013) carried out the numerical analysis on the settlement and bearing capacity behavior of square skirted footing on sand with diverse shear strength properties. Physical model test was also conducted to support numerical analysis results. 70% reduction in settlement is achieved for the ratio of depth of skirt to width of foundation of 2, values of the bearing capacity and settlement of skirted foundation was approximately identical to those of pier foundations of same width and depth. P.K. Jain et. al., (2014) has studied the load carrying capacity of circular footing resting on skirt which in turn rests on loose sand. They conducted tests on four footing of different diameters 40 mm, 60 mm, 80 mm and 100 mm on loose sand. UPVC pipes of different diameters 46 mm, 59 mm, 71 mm and 85 mm were used as skirt. The skirt resists lateral movement of sand thereby increasing the load carrying capacity of circular footing. M. A. Mahmoud and F. M. Abdrabbo (1989) presents in their paper on bearing capacity of strip footing resting on reinforced sand sub grades. They used aluminium strip as a reinforcing element having 20 mm width and 2 mm thickness. They studied the effects on bearing capacity of the soil-footing system such as distance between footing and reinforcing row, reinforcing element inclination, length of reinforcing element, spacing of reinforcing elements. The results indicates that use of non-extensible element as a reinforcement along each side of strip footing was good method for increasing the bearing capacity of soil-footing system and general shear failure is eliminated when the reinforcing element is at a length of 2B from the footing edge. Krishna et.al., (2014) studied the load carrying capacity of model square footing resting on sand. Footing is laterally confined with the help of hollow mild steel box. Tests are conducted for confined, unconfined cases and also for embedded depth of footing. The load carrying capacity of footing increases as the depth of confinement increases and load carrying capacity decreases as the embedded depth of footing within the confinement cell increases.

2. OBJECTIVE OF THE WORK

The objective is to study load-settlement behaviour of sand in unconfined condition, to study the load carrying capacity the footing resting on the confining cells which resist lateral movement of sand & the cell which resist both lateral & vertical movement of sand. To study the effect of confining cell depth (U) on load carrying capacity of footing and to study the outcome of embedded depth of footing within confining cell on load carrying capacity of footing.

3. MATERIALS

The materials used for the test programme consist of sand confining cells (square shaped) and 50 mm square footing. The relevant properties of the materials are as follows.

3.1 Sand

The sand used in the study was collected from Tungabhadra River passing through a nearby village Rajanahalli (vil), Harihara (Tq), Davangere (dist), Karnataka (India). The collected sample is made to pass through 2.36 mm IS sieve and some basic tests were conducted as per Indian standards to know the properties of sand.

Table -1: Properties of Sand

PROPERTY	VALUE
Specific Gravity (G)	2.64
D_{10}, mm	0.28
D_{30}, mm	0.45
D_{60}, mm	0.8
Coefficient of curvature, C_C	0.9
Coefficient of uniformity, C_u	2.86
Maximum void ratio, e_{max}	0.512
Minimum void ratio, e_{min}	0.355
Max.dry density, γ_{max} kN/m^3	19.1
Min.dry density, γ_{min} kN/m^3	17.12
Angle of internal friction (Φ)	39º

The sand used is classified as SP i.e. poorly graded sand. The particle size distribution curve for the sand used in the present work is shown in below figure.

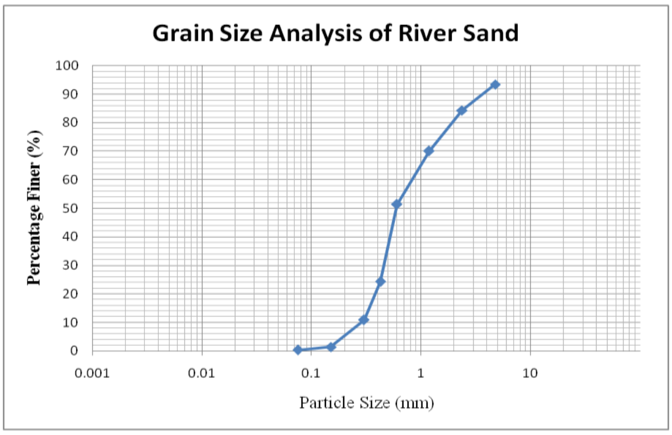

Fig.3.1: Grain Size Distribution Curve.

3.2 Confining Cells/Skirts

The square hollow pipes made of mild steel were used as skirts or confining cells. These confining cells or skirts were used for lateral confinement of sand. The dimension of the confining cell is 58 mm × 58 mm × 3 mm and the length of the confining cell is 50 mm, 75 mm, 100 mm, 125 mm and 150 mm. The cells which resist the lateral movement of the sand are made to resist the vertical movement of the sand by providing the base plate of 3 mm thick having the square size of 62 mm.

Fig.3.2: Confining Cells/Skirts

4. Experimental Programme

4.1 Test Setup and Load test

The experimental work was carried out in tri-axial compression machine. Tri-axial compression machine is basically used to find the shear strength of soil. The whole experiment was carried out in a model tank of size five times the width of footing i.e, 250 mm × 250 mm ×250 mm. The model tank was made up of mild steel plate of 3 mm thickness. The size of the tank was decided by the size of the footing and the zone of influence by keeping the view of various researchers as Gupta and Trivedi (2009) adopted tank dimensions as 4 times the diameter of footing.

Twenty five tests were conducted. First test on unconfined footing condition, five tests on laterally confined footing condition, next five tests on laterally and vertically confined footing condition, nine tests were carried out on the 75 mm confining cell placed at different depth (U) from the sand surface as shown in fig.4.1 (a) and last five tests were carried out on the embedded footing, fig.4.1 (b) represents the footing embedment within the confining cell. The sand was filled into the tank in five layers. To avoid the eccentricity in applying the load, confining cells were inserted exactly at centre. The compressive vertical load was applied on footing by choosing constant strain rate of 1.25 mm/minute. Corresponding to dial gauge reading, proving ring readings were recorded up to maximum settlement of 25 mm and load at 25 mm settlement was considered as ultimate load. Dial gauge was fixed over the edge of test tank to note down the settlement. Fig. 4.1 (c) shows the typical test set up arrangements.

Fig.4.1 (a): Confining cell placed at different depth (U) from the sand surface

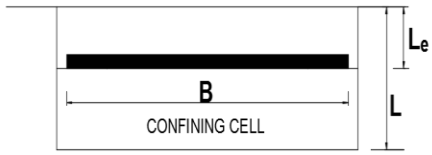

Fig. 4.1 (b): footing embedded within the confining cell

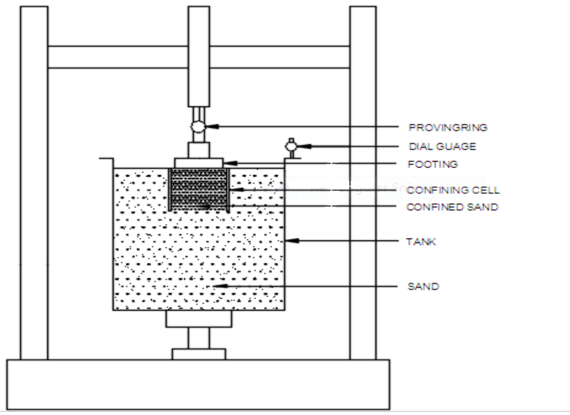

Fig. 4.1 (C): Test Setup

4.2 Preparation of the confined Sand bed

The poorly graded river sand was used as the foundation soil. The sand is filled into the tank in five equal layers of each 50 mm height except for last layer. During compacting last layer spilling of sand takes place. So to avoid this, a clearance of 30 mm was given. Each layer is properly compacted so that sand in the tank is filled at 47% relative density (i.e. $\gamma_{47\%} = 18\ kN/m^3$). After filling the sand in model test tank at required density, confining cells are inserted into sand exactly at centre to avoid the eccentricity in loading. The footing is placed above the cells. To study the behaviour of the embedded footing within the confining cell in that case sand within the inserted confining cell is removed upto the required depth.

5. Results and Discussion

Fig 5 shows the load-settlement graph of the footing on unconfined cell condition. The measured or experimental ultimate load was 78.3 N and the theoretical ultimate load was 79.97 N, this indicates that there is a close relation b/w theoretical an experimental results. The theoretical ultimate load carrying capacity of footing was calculated from Terzaghi's equation

$$q_f = 0.4\gamma B N_\gamma$$

Bearing capacity factor N_γ taken from Terzaghi's (1943) i.e, $N_\gamma = 88.8$

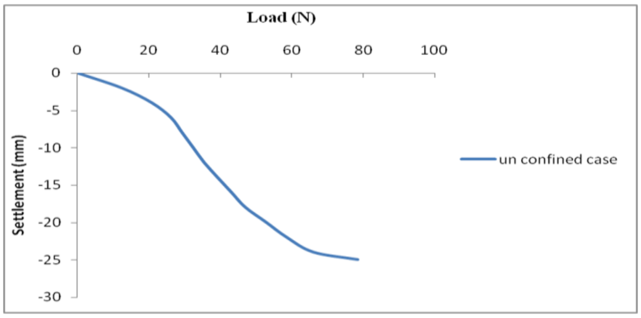

Fig. 5: Load - Settlement curve for uncased footing condition

5.1 Footing resting on laterally confined cell

Fig 5.1 (a) shows the load-settlement plot of the footing resting on the different lengths laterally confined cell and the fig 5.1 (b) indicates that as the length of the confining cell increases ultimate load carrying capacity of the footing also increases.

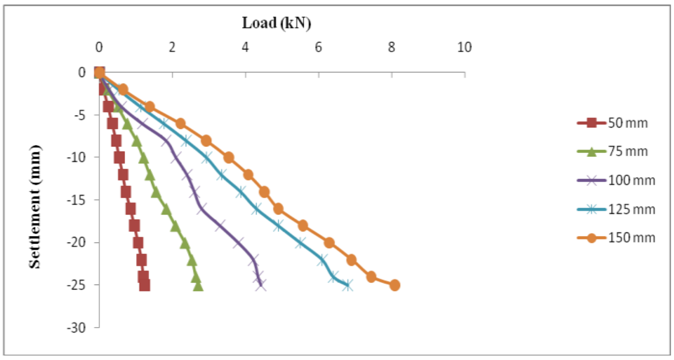

Fig 5.1 (b): Load - Settlement curves for confining cells of varying length

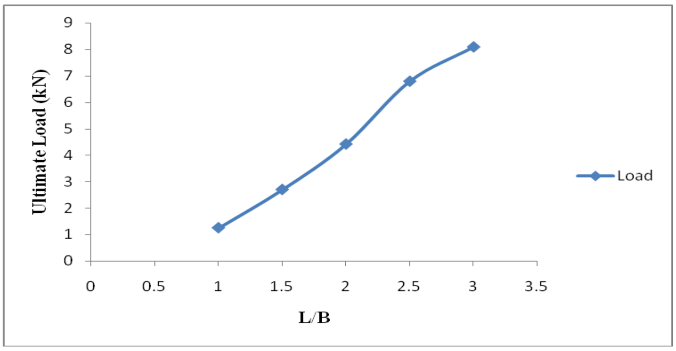

Fig 5.1 (C): Increase in ultimate load carried by footing as increase in L/B ratio

5.2 Footing resting on cell which resists both vertical & lateral movement of sand.

The Laterally confining cell was made to provide vertical confinement, by placing 3 mm thick plate of size 62 mm × 62 mm below the laterally confining cell. Fig 5.2 (a) shows the load-settlement plot of the footing resting on the varying length of the confining cells which are capable of resisting the lateral and vertical movement of the sand, fig 5.2 (b) indicates the comparative plot for the ultimate load carried by the footing which rests on the laterally confining cells and the footing which rests on the cell which resist both lateral & vertical movement of sand.

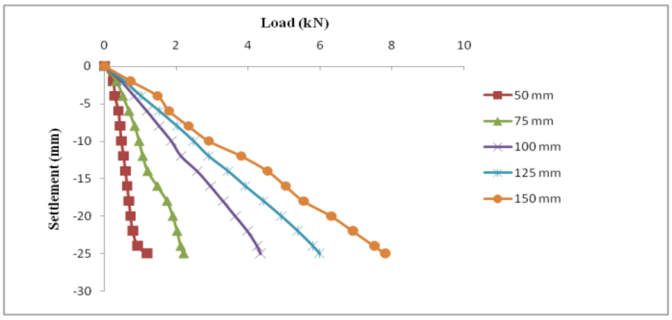

Fig 5.2 (a): Load - Settlement curves for different length of confining cells which resists both lateral and vertical movement of sand

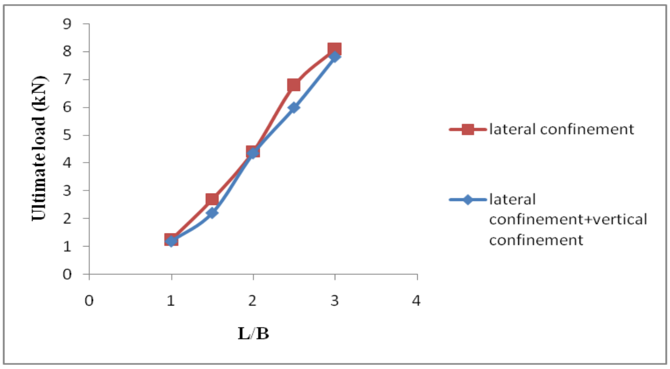

Fig. 5.2 (b): Comparative graph of ultimate load carrying capacity of footing b/w lateral confining cells and vertical and lateral confinement cells

5.3 Footing placed on 75 mm confining cell which is placed at different depth (u) from the sand surface

The schematic representation of the confining cell placed at depth (U) is as shown in fig 4.1 (a). The depth (U) is the distance between the sand surface and the top edge of the confining cell. The depth (U) of the confining cell was varied from the 10 mm to 50 mm. The final depth i.e., 50 mm is equal to width of the footing (U=B). fig 5.3 (a) indicates the load carried by the footing resting on the 75 mm confining cell, which was placed at various pre-defined depth and the fig 5.3 (b) shows the fluctuation in the ultimate load carried by the footing with increase in U/B ratio.

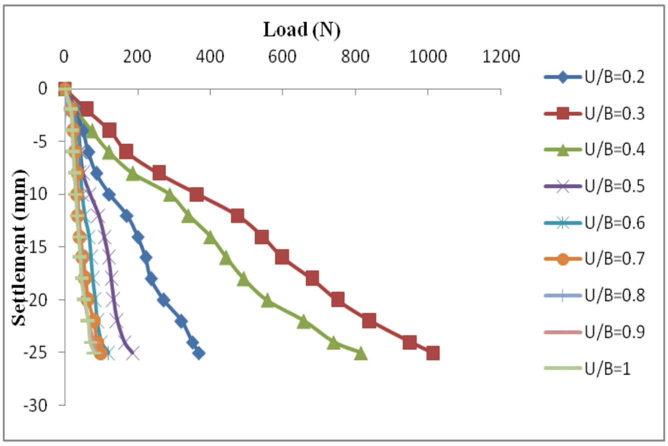

Fig. 5.3 (a): Comparison of Load - Settlement graph for 75mm confining cell situated at different depth (U) from sand surface

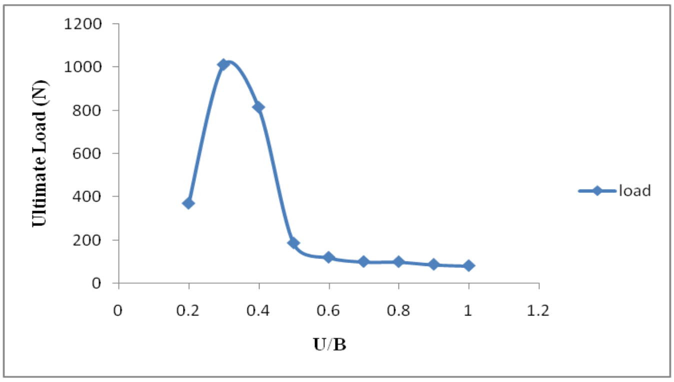

Fig. 5.3 (b): Fluctuation in ultimate load carried by footing with increase in U/B ratio

5.4 Footing embedded within the confining cells

The diagrammatic representation of the footing embedded within the confining cell is as shown in fig 4.1 (b). The footing is embedded depth (L_e) is equal to half of the confining cell length. Therefore L_e/L=0.5. Fig 5.4 (a) represent the load-settlement plot for the different depth of footing embedment, fig 5.4 (b) represent the comparison plot of load-settlement b/w embedded footing within the confining cells and footing placed on the surface of the confining cells and fig 5.4 (c) is the Comparative graph of ultimate load carrying capacity of footing b/w embedded footing within the confining cells and footing placed on the surface of confinement cells

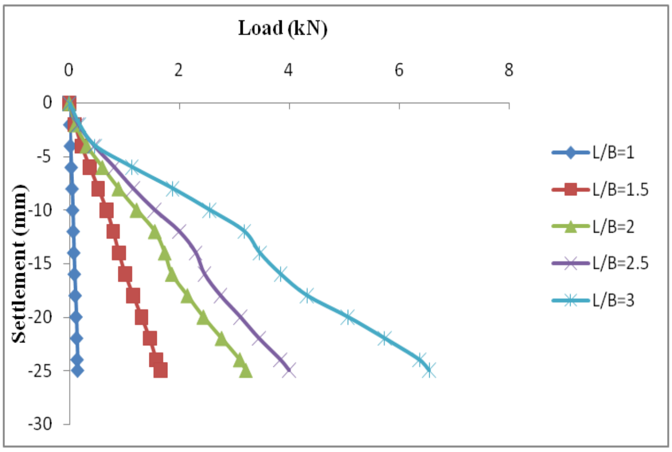

Fig. 5.4 (a): Load - Settlement curves for different depth of footing embedment

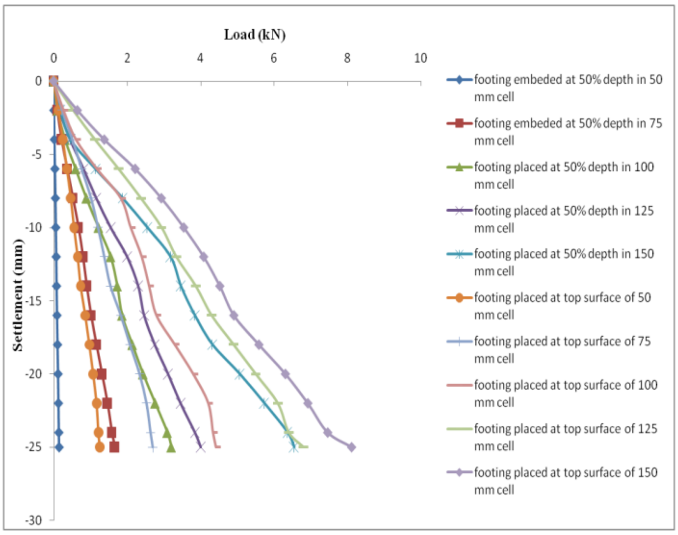

Fig. 5.4 (b): Comparison of Load - Settlement graph b/w embedded footing with in the confining cells and the footing placed on the surface of confining cells

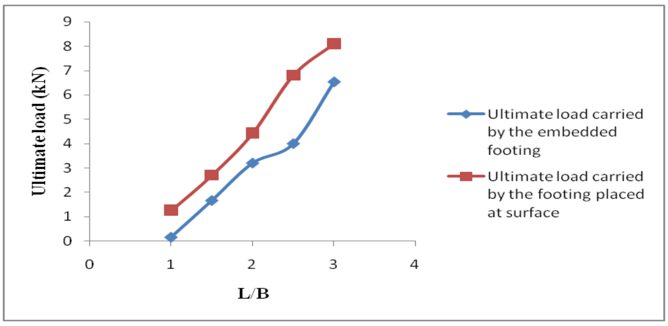

Fig. 5.4 (c): Comparative graph of ultimate load carrying capacity of footing b/w embedded footing within the confining cells and footing placed on the surface of confinement cells

6. CONCLUSIONS

1. From the experimental results, it can be concluded that soil confinement is one of the methods of lowering the settlement of the structure which are very sensitive to settlement.
2. Significant increment in load carrying capacity of footing was observed for confined case when compared to unconfined case.
3. As the length of the confining cell increase load carrying capacity of footing also increases, this is due to as increase in length of the confining cell surface area available to resist the shear failure also increases.
4. Load carrying capacity of footing placed on the confining cells which resist only lateral movement of sand is slightly more than the load carrying capacity of footing which resists both lateral & vertical movement of sand.
5. There is no drastic improvement or decline in ultimate load carried by footing due to installation of base plate.
6. As the depth (U) of the confining cell below the surface of the sand increases load carrying capacity of the footing also increases upto a certain depth (U) below the surface of sand. Thereafter increment in depth (U) of confining cell leads to decrease in load carrying capacity of footing.
7. Decline in load carrying capacity of footing as increase in depth (U) of confining cell is due to lateral deformation of the sand which is in between cell top and footing. Due to this vertical settlement increase and load carrying capacity decreases.
8. The maximum load carrying capacity of the footing was obtained for the cell which was at depth (U) of 0.3 times width of footing.
9. The load carried by the footing which rests on the confining cell placed at depth (U) equal to footing width, which nearly is equal to load carried by footing in uncased condition (ultimate load in uncased condition is 78.37 N and ultimate load carried by footing resting on confining cell placed at depth (U) equal to 50 mm is 80.89 N).
10. The load carrying capacity of footing which was embedded at 50% of the depth of confining cell found to be less than the load carried by footing which was placed on the surface of confining cell.
11. Decline in the load carrying capacity of the footing which is embedded within the confining cell is due to decrease in the depth of the confinement below the footing.

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