International Journal of Research in Engineering, Science and Management
Volume-1, Issue-11, November-2018
www.ijresm.com | ISSN (Online): 2581-5792

Performance Study of the Confinement and the Reinforcement on Behavior of Circular Footing Resting Over Sand

Ravindra Budania[1], R. P. Arora[2], Yamini Upadhyay[3], Meharuddin Ahmad[4]
[1,4]Asst. Prof., Dept. of Civil and Environmental Engg., Anand International College of Engg., Jaipur, India
[2]Professor, Department of Civil Engineering, College of Technology and Engineering, Udaipur, India
[3]M. Tech. Scholar, Department of Civil Engineering, College of Technology and Engineering, Udaipur, India

***Abstract*: The world is moving toward urbanization to fulfill the growing demand of growing population. The huge mass migration toward cities has developed the scarcity of land. The engineers are compelled to utilize the undeveloped land consisting of weak soil unable to carry the load of the foundation. There are several methods of soil improvement technique used to gain the strength of the soil. In this research, load tests were performed in two stages on the circular footing of 150mm diameter to determine the significant effect on the ultimate bearing capacity of sand. The parameter that influence are diameter of confinement, height of confinement, placement of confinement under model footing and placement of geo-grid layer beneath the bottom of confinement. In first stage the circular footing is resting over cylindrical confinement of varying diameter ratio d/D = 0.73, 1.06 and 1.33 and height ratio h/D = 0.5, 1 and 1.5. In the second stage, the geo-grid is placed beneath the bottom of the cylindrical confinement to determine the load carrying capacity of circular footing. The geo-grid is placed at distance ratio of x/D = 0.25, 0.5 and 1. Sand confined by using circular footing with cylindrical confinement resting over a geo-grid layer, the ultimate bearing capacity was found to increase by 3.42 times as compared to the unconfined and unreinforced case. The optimum depth for placing a single geo-grid layer under the bottom of the cylinder was found x/D = 0.25 i.e. one-fourth of the footing diameter.**

***Keywords*: Confinement, bearing capacity, reinforcement.**

1. Introduction

Foundation is the lowest part of any structure built on ground which carries and transfers a load of the superstructure to the soil. The Behavior of soil plays important role in the stability of any structure. Soil must have an adequate ultimate bearing capacity to resist the load of foundation and transmit below sub soil. The performance of this sub soil depends upon the strength of the soil. The soil available at seashore, coastal area, river bank are loose soil has the tendency of lateral and longitudinal movement, which ultimately cause failure of foundation build on it. In Indian subcontinent vast deposits of silty sand are present in perennial rivers namely Ganga, Indus, Ghaggar, Barinadi, Yamunas, Chandra wanshi et. al. (2014). Soil with weak bearing capacity needs strength to improve. Strength of soil can be improved by using several methods such as reinforcement, stabilization, grouting, compaction, confinement etc. This soil confinement and reinforcement are promising technique of improving load bearing capacity. In the present study, the circular footing is supported with confined and reinforced sand. UPVC pipes as confinement is used to laterally resist the displacement of sand and a geo-grid layer as reinforcement is used for longitudinally resist the displacement of sand.

2. Materials and methodology

A. *Material*

The various materials that were used in this research work are as following:

1) *Sand*

Kharka river sand was used in this experimental investigation. The air dried sand passing through 600µ IS sieve and retained on 300µ IS sieve was used for research work. The geotechnical properties of sand used are listed in the Table 1.

Table 1
Geotechnical Properties of Sand (As per laboratory tests)

S. No.	Property	Code referred	Value
1.	Specific Gravity	IS 2720 (Part 3/Sec 1) - 1980	2.62
2.	Maximum Dry Density	IS 2720 (Part 7) -1980	15.08 kN/m^3
3	Relative density	IS 2720 (Part 14) – 1983	65%
4.	Test Density of sand	IS 2720 (Part 28) – 1974	14.32 kN/m^3

2) *Geo-grid*

In order to provide horizontal reinforcement material for the test, geo-grid was used. Geo-grids are the materials which provide tensile strength connected by strong bond. Biaxial geo-grid of high strength is used as a reinforcement layer which is provided by Strata Geo-systems (India) Pvt Ltd. Biaxial geo-grid of tensile strength 30 KN/m with grid aperture size 43 is used.

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www.ijresm.com | ISSN (Online): 2581-5792

3) Confining element or skirt

The rigid UPVC pipes (Plasticized polyvinyl chloride pipes as per IS 4985:2000) of different outer diameters 110 mm, 160 mm and 200 mm and lengths of 38mm, 75mm, 150mm, 188mm and 225mm were used as confining element.

4) Footing

Mild steel circular footing model of 150 mm diameter with 20 mm thickness was used. This footing has a little groove of 5 mm at the center to facilitate the application of load. Dimension of the footings were so selected that it can freely develop full failure zone without any interference.

B. Methodology

The tank was fill with the air dried sand at the constant relative density and bulk density throughout the bed. The surface of sand was levelled and geo-grid layer was placed over it at the center of tank, then again the sand at same density was filled into tank in remaining depth and then cylindrical confinement was pushed vertically into the sand at the design depth. The footing was placed above the center of cylindrical confinements. A geo-grid sheet was placed at varying depth of x/D = 0.25, 0.5 and 1 under the cylindrical confinement. After that footing was loaded by a jack, supported against a reaction frame. A pre-calibrated proving ring was used to measure the load transferred to the footing. Loads were applied in small increments. Each load increment was maintained constant until the footing settlement was stabilized. The footing settlements and surface deformations were measured with the help of dial gauges. Settlement corresponding to each load increment was noted and the test result was plotted in term of load-settlement curve. Ultimate bearing capacity for each test was determined from load-settlement curve using tangent intersection method. The tangent intersection method can be done as shown in Fig 2.3

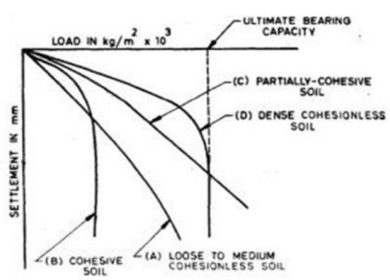

Fig. 1. Tangent intersection method (IS: 1888-1982)

3. Results

Load tests were performed on the circular footing (Diameter 150mm), resting over different height and diameter of cylindrical confinement and confined circular footing reinforced with geo-grid. To fulfill first objective sand bed were prepared introducing different height (h/D = 0.5, 1, and 1.5) and diameter (d/D = 0.25, 0.5 and 1) of confinement, then load test were performed on confined circular footing. For second objective, optimum result of first objective is determined, then sand bed was prepared by introducing optimum diameter of cylindrical confinement and height h/D = 0.5, 1, and 1.5 with geo-grid placed underneath the bottom of cylindrical confinement at varying distant of x/D ratio 0.25, 0.5 and 1 under the circular footing.

A. Circular footing resting supported with cylindrical confinement

Load tests were performed on the circular footing of 150mm diameter, resting over cylindrical confinement of varying diameter ratio d/D = 0.73, 1.06 and 1.33 and height ratio h/D = 0.5, 1, and 1.5.

1) Result of confined circular footing at d/D = 0.73 and h/D = 0.5, 1 and 1.5.

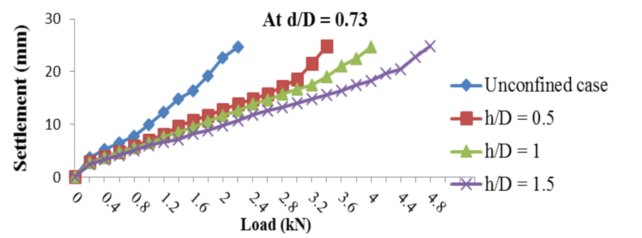

Fig. 2. Load settlement curve of confined circular footing at d/D =0.73 and h/D = 0.5, 1, and 1.5.

From the load-settlement curve shown in Fig. 2, ultimate bearing capacity of unconfined sand was 96.04 kN/m^2 at ultimate load of 1.7 kN whereas the ultimate bearing capacity of sand when circular footing resting on cylindrical confinement at ratios d/D = 0.73 and h/D = 1.5 is calculated as 249.12 kN/m^2 at ultimate load 4.2 kN.

2) Result of confined circular footing at d/D = 1.06 and h/D = 0.5, 1, and 1.5

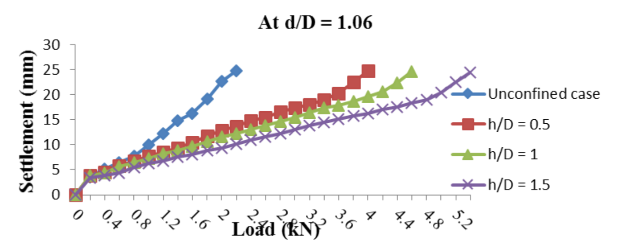

Fig. 3. Load settlement curve of confined circular footing at d/D =1.06 and h/D = 0.5, 1, and 1.5

From the load-settlement curve ultimate bearing capacity of unconfined sand was 96.04 kN/m^2 at ultimate load of 1.7 kN whereas the ultimate bearing capacity of sand when circular footing resting on cylindrical confinement at ratios d/D = 1.06 and h/D = 1.5 is calculated as 283.08 kN/m^2 at ultimate load 5 kN. From the Fig. 3, it is observed that the Ultimate bearing capacity of sand is increased by 2.95 times of unconfined sand's ultimate bearing capacity.

B. Result of confined circular footing at d/D = 1.33 and h/D =0.5, 1 and 1.5

The ultimate bearing capacity of unconfined sand was 96.04

kN/m^2 at ultimate load of 1.7 kN, whereas the ultimate bearing capacity of sand when circular footing resting on cylindrical confinement at ratios d/D = 1.33 and h/D = 1.5 is calculated as 226.47 kN/m^2 at ultimate load 4 kN.

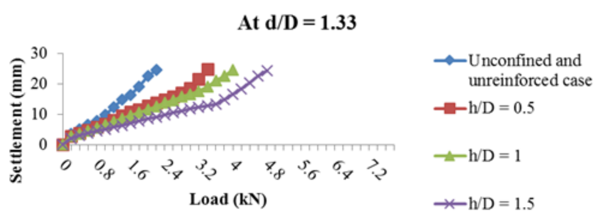

Fig. 4. From the load-settlement curve

C. Effect of confined circular footing resting over a geo-grid layer

From the above test performed on circular model footing with cylindrical confinement, it was found that d/D ratio at 1.06 shows the optimum result in compare to d/D ratios at 0.73 and 1.33. A square geo-grid layer of width ratio l/D = 3 is placed at the bottom of the cylindrical confinement at three different locations, x/D = 0.25, 0.5 and 1. This test was conducted to determine the optimal position of geo-grid layer by keeping d/D ratio i.e. 1.06 constant, as it was found as optimal diameter in former load tests performed on circular model footing with cylindrical confinement. The height of cylindrical confinement i.e. h/D = 0.5, 1, and 1.5 and geo-grid layer placed underneath the bottom of the cylindrical at locations x/D = 0.25, 0.5 and 1.

1) Result of confinement of d/d ratio 1.06 and geogrid at x/D ratio 0.25 under the circular footing

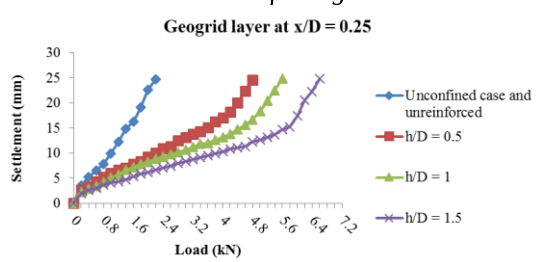

Fig. 5. From the load-settlement curve

The ultimate bearing capacity of unconfined and unreinforced case sand was 96.04 kN/m^2 at ultimate load of 1.7 kN, whereas the ultimate bearing capacity of sand when confined circular model footing resting over a geo-grid layer at ratios x/D = 0.25 and h/D = 1.5 is calculated as 328.4 kN/m^2 at ultimate load 5.8 kN.

2) Result of confined circular footing resting over geogrid at x/D ratio 0.5

Ultimate bearing capacity of unconfined and unreinforced case sand was 96.04 kN/m^2 at ultimate load of 1.7 kN, whereas the ultimate bearing capacity of sand when confined circular model footing resting over a geo-grid layer at ratios x/D = 0.5 and h/D = 1.5 is calculated as 305.7 kN/m^2 at ultimate load 5.4 kN. The ultimate bearing capacity of sand at height of cylindrical confinement h/D ratio 0.5, 1 and 1.5 is observed as 226.5 kN/m^2, 260.4 kN/m^2 and 305.7 kN/m^2 at ultimate load 4 kN, 4.6 kN and 5.4 kN respectively, which is 2.35, 2.7and 3.18 times of unconfined and unreinforced ultimate bearing capacity respectively. From the results, it is observed that ultimate bearing capacity increase as height of cylindrical confinement is increase.

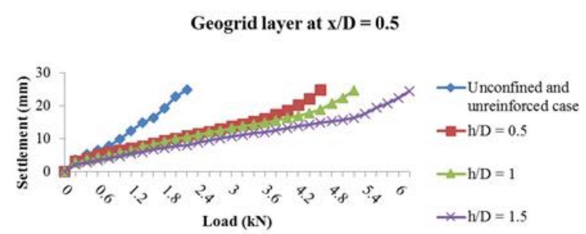

Fig. 6. Load settlement curve of model footing resting over cylindrical confinement d/D = 1.06 and h/D = 0.5, 1 and 1.5 with a geo-grid layer at x/D = 0.5

3) Result of confined circular footing resting over geogrid at x/D ratio

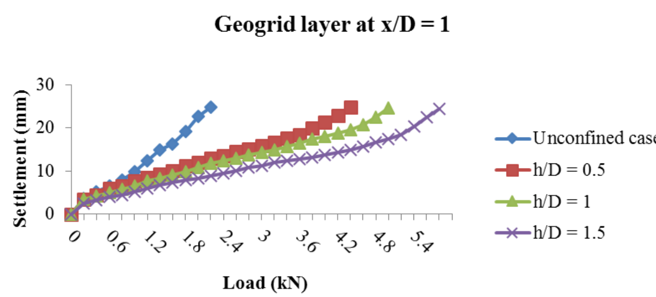

Fig. 7. Load settlement curve of model footing resting over cylindrical confinement d/D = 1.06 and h/D = 0.5, 1 and 1.5 with a geo-grid layer at x/D = 1

Ultimate bearing capacity of unconfined and unreinforced case sand was 96.04 kN/m^2 at ultimate load of 1.7 kN, whereas the ultimate bearing capacity of sand when confined circular model footing resting over a geo-grid layer at ratios x/D = 1 and h/D = 1.5 is calculated as is 288.7 kN/m^2 at ultimate load 5.1 kN. As shows in the ultimate bearing capacity of sand at height of cylindrical confinement h/D ratio 0.5, 1 and 1.5 is observed as 220.8 kN/m^2, 249.1 kN/m^2 and 288.7 kN/m^2 at ultimate load 3.9 kN, 4.4 kN and 5.1 kN, which is 2.35, 2.7 and 3 times of unconfined and unreinforced ultimate bearing capacity respectively. From the results, it is observed that ultimate bearing capacity increase as height of cylindrical confinement is increase. Elsaied et al (2015) had determined the optimum position of geo-grid layer that gives maximum improvement in the load settlement behaviour by placing single geo-grid layer at three different location x/D ranges from 0.25 to 1. The height and diameter of the cylinder in these test is d/D = 1.02 and h/D = 0.25. The optimum depth for placing a single geo-grid layer under the bottom of cylinder was found equal to quarter of the footing width. Thus the existence of geo-grid layer at ratio x/D = 1 fails to cut the failure wedge which reduces the shear strength. The improvement in ultimate bearing capacity found due to the combine effect of both cylindrical confinement and reinforced geo-grid layer under confinement was found 3 time of unconfined and unreinforced case. Here the cylindrical confinement provides the lateral support and reinforced geo-grid layer under the bottom edge of cylindrical confinement placed at ratio x/D = 1 provides longitudinal support at certain point. As the load increase on model footing, it fails to resist the escape of sand. When the model footing is loaded plastic state is developed initially around the bottom edges of the cylindrical confinement. On further increase of pressure on model footing sand start escaping and cause shear failure. Thus geo-grid placed at x/D = 1 is not capable to support longitudinally due to shear failure. Therefore cylindrical confinement, model footing and geo-grid all together do not act as one unit.

D. Combine effect of cylindrical confinement and geogrid on load carrying capacity of circular footing

Effect of placing a geo-grid layer on load carrying capacity of circular model footing was determined. A geo-grid layer was placed at different position underneath the bottom of cylindrical confinement was determined. A comparison was made for the test results of load-settlement curves where a geo-grid lying at three different position, x/D = 0.25, 0.5 and 1 whereas diameter and height parameter are constant.

1) Effect of geogrid at d/D = 1.06 and h/D = 0.5

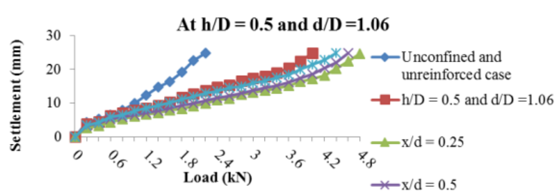

Fig. 8. Load settlement curve of model footing resting over cylindrical confinement d/D = 1.06 and h/D = 0.5 with a geo-grid layer at x/D = 0.25, 0.5 and 1

The Fig. 8, show the result of load test on circular model footing in term of load settlement curve. Here, the diameter and height parameter d/D = 1.06 and h/D = 0.5 respectively are constant. A geo-grid layer placed at different position i.e. x/D = 0.25, 0.5 and 1 underneath the bottom of cylindrical confinement. Moreover, the results for the cases of unconfined and unreinforced sand and confined sand at h/D =0.5 are shown in same Fig. 8, for comparison.

The ultimate bearing capacity of unconfined and unreinforced case, confined case at h/D = 0.25 and confinement with geo-grid placed at x/D = 0.25, 0.5 and 1 are 96.04 kN/m^2, 215.1 kN/m^2, 243.45 kN/m^2, 226.46 kN/m^2 and 220.8 kN/m^2 respectively. The ultimate bearing capacity of confinement with geo-grid at x/D = 0.25, 0.5 and 1 are 2.5, 2.4 and 2.3 times respectively of unconfined and unreinforced case and 1.13, 1.05 and 1.03 times respectively times of confined case.

The introduction of confinement and geo-grid below the model footing improves the ultimate bearing capacity of sand. Earlier, it was reported by Wakil (2013) that BCR = 2.25 at skirt length ratio L/D = 0.5. Ultimate bearing increases as the depth of placing geo-grid underneath the bottom of confinement is reduce. Gupta et al (2014) found the bearing capacity increase by the factor 14.07 of unconfined case and unreinforced case.

2) Effect of Geogrid at d/D = 1.06 and h/D = 1

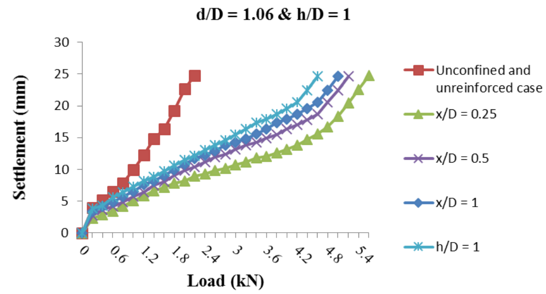

Fig. 9. Load settlement curve of model footing resting over cylindrical confinement d/D = 1.06 and h/D = 1 with a geo-grid layer at x/D = 0.25, 0.5 and 1

The result of load test on circular model footing in term of load settlement curve. Here, the diameter and height parameter d/D = 1.06 and h/D = 1 respectively are constant. A geo-grid layer placed at different position i.e. x/D = 0.25, 0.5 and 1 underneath the bottom of cylindrical confinement. Moreover, the results for the cases of unconfined and unreinforced sand and confined sand at h/D =1 are shown in same figure 4.8 for comparison. The ultimate bearing capacity of unconfined and unreinforced case, confined case at h/D = 0.25 and confinement with geo-grid placed at x/D = 0.25, 0.5 and 1 are 96.04 kN/m^2, 243.4 kN/m^2, 267.8 kN/m^2, 260.4 kN/m^2 and 249.1 kN/m^2 respectively. The ultimate bearing capacity of confinement with geo-grid at x/D = 0.25, 0.5 and 1 are 2.8, 2.7 and 2.5 times of unconfined and unreinforced sand case and 1.1, 1.06 and 1.02 times respectively times of confined case. The improvement of load carrying capacity of model footing after application of confinement and confinement with geo-grid is observed from above results. Earlier, also Wakil (2013) have found that BCR = 3.75 at skirt length ratio L/D = 0.1. The bearing capacity was found to increase by a factor of 12.32 as compared to the three dimensionally unconfined case Gupta et al. (2014).

3) Effect of geogrid at d/D = 1.06 and h/D = 1.5

The result of load test on circular model footing in term of load settlement curve. Here, the diameter and height parameter d/D = 1.06 and h/D = 1.5 respectively are constant. A geo-grid layer placed at different position i.e. x/D = 0.25, 0.5 and 1 underneath the bottom of cylindrical confinement. The ultimate bearing capacity of unconfined and unreinforced case, confined case at h/D = 0.25 and confinement with geo-grid placed at x/D

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= 0.25, 0.5 and 1 are 96.04 kN/m^2, 271.8 kN/m^2, 328.4 kN/m^2, 305.7 kN/m^2 and 288.7 kN/m^2 respectively. The ultimate bearing capacity of confinement with geo-grid at x/D = 0.25, 0.5 and 1 is 3.4, 3.2 and 3 times of unconfined and unreinforced sand case and 1.2, 1.12 and 1.06 times respectively times of confined case. The improvement of load carrying capacity of model footing after application of confinement and confinement with geo-grid is observed from above results. Earlier Wakil (2013) have found that skirt improve appreciably the sustainability of shallow footing by some up to 6.25. (Elasaid et al. 2015) reported that the optimum depth for placing a single geo-grid layer under the bottom of the cylinder was found equal to the quarter of footing width.

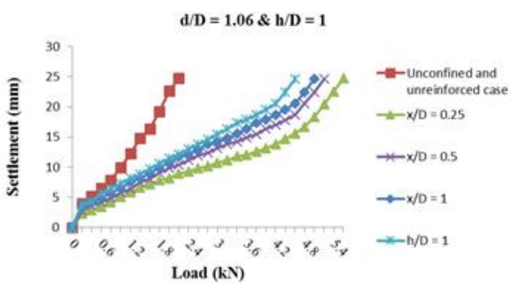

Fig. 10. Load settlement curve of model footing resting over cylindrical confinement d/D = 1.06 and h/D = 1.5 with a geo-grid layer at x/D = 0.25, 0.5 and 1

4. Conclusion

This study has been carried out to understand the effect of circular footing with cylindrical confinement and cylindrical confinement resting over geo-grid layer, on the ultimate bearing capacity of sand. The result of all the experimental work has been discussed in previous chapter. On the basis of discussion of result, following conclusion is made:

- Sand confined by using cylindrical confinement has a significant effect on improving the behavior of circular footing on sands. The ultimate load carrying capacity was found to increase by 2.95 times as compared to the unconfined case.
- The load-settlement behavior depends on the diameter and height of the confinement cylinder relative to the footing diameter.
- For small diameter of confining cylinder relative to footing size, the cylinder-sand-footing system behaves as a deep foundation (the cylinder, sand, and footing settle all together) and the failure occur as a shear failure in the sand surrounding the cylinder
- For large diameter confining cylinder relative to footing size, the cylinder-sand-footing system behave initially as one unit (deep foundation) but as the failure approaches, the footing only settles while the cylinder seems to be unaffected.
- As the height of confining cylinder increase, the surface area contact of cylinder-model footing with sand confined also increase which transfer footing loads to deeper depths and leads to improving ultimate load carrying capacity.
- Circular footing with cylindrical confinement resting over a geo-grid layer resist lateral and longitudinal both displacement of sand underneath the footing while Circular footing with cylindrical confinement resist only lateral displacement of sand underneath the footing.
- Sand confines by using circular footing with cylindrical confinement resting over a geo-grid layer, the ultimate bearing capacity was found to increase by 3.42 times as compared to the unconfined and unreinforced case.
- The optimum depth for placing a single geo-grid layer under the bottom of the cylinder was found x/D = 0.25 i.e. one fourth of the footing diameter.
- The ultimate bearing capacity of confined circular footing with a geo-grid layer is 1.15 times the confine circular footing case.

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