

EFFECT OF CONFINEMENT ON CIRCULAR FOOTING

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ABSTRACT: - For sustainable development the world has forced the civil engineers to utilize unsuitable sites or weak soil. In recent year geotechnical professionals have adopted the practice of ground improvement of such soils by grouting, vibro compaction, mixing of fibres, reinforcement, and confinement etc. The soil confinement is one such method of improving load carrying capacity and reducing the settlement of the footing resting on sand. Confinement of soil in shallow depths might have a significant effect in enhancing soil bearing capacity. In this research, 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 . Soil confined by using this method 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. These confinements could be easily manufactured and placed around the individual footings.

Key Words: Circular footing, Confinement, Ultimate bearing Capacity, Load-settlement curve.

1. INTRODUCTION: -

Sand deposits are extensively located along the sea shores, bank of rivers and dessert area. Weak soils like sand having low bearing capacity and large settlement of footing resting on it under relatively lesser loads. For such weak soils with large loading condition raft foundation are generally used which enhance the load bearing capacity of such soils. But there are some problems arise with the raft foundation as the excavation of large area is not economical and also if the construction is adjacent to old structures and the foundation depth is large then the excavation has to be braced during foundation construction. For these problems, one of the solutions is use isolated foundation with three dimension confined sand system. It is having same principle as that of the raft foundation with bracing as the confinements restrain the lateral movement of sand like bracing and the geo-grid layer restrains longitudinal movement of sand like rafts and confines the soil in all dimensions. This three dimensionally confined sand system works as a single unit to transfer the load from the superstructure to the bottom of the confinement system and behaves like a deep foundation (Sawwaf and Nazer, 2005).

In recent year geotechnical professionals have adopted the practice of ground improvement of such soils by grouting, vibro compaction, mixing of fibres, reinforcement, and confinement etc. The soil confinement is one such method of improving load carrying capacity and reducing the settlement of the footing resting on sand. For shallow foundations, confinement of sand has significant effect on load carrying capacity of sand (Gupta *et al.*, 2014).

Confinement of soil in shallow depths might have a significant effect in enhancing soil bearing capacity. Skirted foundations form an enclosure where the soil is strictly confined. This allows the confined soil to work as one unit which transferring the superstructure loads to the soil at the skirt tip level (Elsaied *et al.*, 2015).

2. REVIEW OF LITERATURE: -

Many researchers have carried out various studies to investigate the benefits of different types of soil confinement and reinforcement techniques on a different type of footings, and their effects to enhancing the property of soil.

Chandrawanshi et al. (2001) examined the values of load tests conducted on a circular footing resting on confined sand to study the influence of cylindrical skirts with different heights and diameters in medium dense sand. Model test were conducted on circular footing placed centrally in medium dense sand in model tank without and with skirts in different combinations of height and diameters. The comparison was made between the results of unconfined case and confined case. It is concluded that the pressure corresponding to 5 mm settlement (i.e. 10% S/D ratio), increases appreciably by confining the sand with skirts and it is due to that skirt restricts the lateral displacement of the sand underneath the footing, thus resulting in appreciable improvement. The relative density of sand is kept at 50% to study the phenomenon for medium dense sand. For the case of skirts of small diameters, the effect was small and reaches an optimum value for a specific diameter of skirt with respect to diameter of pile and again as skirt diameter increases appreciable this phenomenon loses its significance.

Punrattanasinet al. (2002) analyzed and investigated the vertical and horizontal capacities of square and circular sheet pile foundations on various Sand densities; 30%,45%,60%,75% and 90%.The sheet pile foundation is a shallow footing that is skirted by sheet piles around the periphery. The skirt of the sheet pile foundation may lead the higher vertical and horizontal capacities: 42,53,59,68 and 81KPA.than that of the shallow foundation. The results of vertical 5 loading test clearly demonstrate that both square and circular sheet pile foundations can substantially increase the vertical capacity of conventional shallow foundation on sand. The vertical capacity from the load-settlement characteristic of both square and circular sheet pile foundations were compared and discussed. Using the zero displacement concept of swipec test, a series of horizontal loading tests were carried out with the aim of investigating the horizontal capacity of the foundation.

Sawwaf andNazer (2005) have conducted laboratory experiments to show the effect of soil confinement on the bearing capacity of circular footing on sandy soil and have found that the bearing capacity is increased 17 times of that without confinement.

Basudharet al. (2007) investigated on the Effect of the footing size, a number of reinforcing layers, reinforcement placement pattern and bond length and the relative density of the soil on the load settlement characteristics of the circular footing over the sand bed with geotextile. By the increase in a number of reinforcement layers, settlement values are decreases. There is substantially increment of BCR values for each increment in the number of reinforcement layers.

Gupta and Trivedi (2009) performed laboratory experiments on clean sand and sand containing silt up to 25%. Initially, the response of a footing without confinement was determined and then compared with that of footing with confinement. The bearing capacity increased by a factor of 3.94 and bearing capacity decreases and settlement increases with fines content.

Sireeshet al. (2009) examined the effect of various parameters such as, thickness of unreinforced sand layer above clay bed, width and height of geo-cell mattress, influence of an additional layer of planar geo-grid placed at the base of the geo-cell mattress, relative density of the sand fill in the geo-cell varies in the test. If the height of geo-cell mattress is greater than 1.8 times the diameter of footing, the effect of voids on the performance of footing reduces. With geo-cells filled with dense soil better improvement in performance can be achieved.

Ebrahimiet al. (2013) investigated the suitability of using structural skirts have been used underneath shallow foundations of marine structures for many years, due to their stability advantages. However, limited knowledge is available on the performance of the skirted foundations when it comes to their usage as conventional shallow foundations. In this research study the bearing capacity of such foundation was 56.8KN/m² evaluated through laboratory testing. In this context the effects of skirt stiffness ratio 1.2 and depth 5.6m on the bearing capacity of skirted footing models were investigated. The test results were then compared with various bearing capacity equations. It was found that using structural skirts may improve the footing bearing capacity up to 3.68 times depending on the geometry and structural 6 specifications of the skirts and footings, soil characteristics and conditions of both soil-skirt and soil-footing interfaces.

Tripathy et al. (2013) carried out an experimental study of shallow foundations for offshore structures include skirts to satisfy bearing capacity requirement and to provide the additional horizontal resistance required by offshore environmental loading. In comparison to a surface foundation, the skirt transfers the load to deeper up to 4.4m, typically stronger, soil, thus mobilizing higher bearing capacity of 79.6KN/m². Skirted foundation has been used as support for large fixed substructures or anchors for floating structures in offshore hydrocarbon development projects. In recent years, skirt suction foundations are applicable to bridge substructures installed in waters. Although a number of theories are available to predict the bearing capacity of shallow footings with reasonable accuracy and it seems there is a convergent prediction of bearing capacity. Unlike this till date the estimation of bearing capacity of skirted foundations are best semi empirical formulations.

Elzaied et al. (2014) studied the effect of three dimensional confinement of sand. They used the plastic hollow cylinder as confinement of sand and square geogrid layers were placed at different depths beneath the bottom edge of the cylinder. They concluded that placing geogrid layers underneath the cylinders improves the bearing capacity up to 7.5 times that of the unconfined case.

Gupta et al. (2014) studied the behavior of circular footing on three dimension confined sand. For confining sand three dimensionally they used skirts of different heights and diameters with a layer of geo-grid below it. They concluded that the bearing capacity increase by a factor of 36.18 as compared to the unconfined case.

A. Krishna et al. (2014) the load carrying capacity of a model square footing resting on sand has been studied. Footing is confined laterally with the help of mild steel plates welded to form a hollow box of different depths. The effect of embedment depth of footing on the load carrying capacity and settlement values has been studied. Varying depth of confinement, relative density, embedment depth of footing ratio was utilized. Based on the results obtained, load versus settlement curves are plotted and it is observed that, as the depth of confinement increases, the load carrying capacity of the footing also increases.

Vishwanath et al. (2014) carried out an experimental investigation of load carrying capacity of a model square footing resting on sand has been studied. Footing is confined laterally with the help of mild steel plates welded to form a hollow box of different depths. The effect of embedded depth of footing on the load carrying capacity and settlement values has been studied. Varying depth of confinement, relative density, embedded depth of footing ratio 1.6 was utilized. Based on the results obtained, load versus settlement curves are plotted and it is observed that, as the depth of confinement increases about 3-4m, the load carrying capacity of footing also increased around 65%.

Azzam and Nasr (2015) found out the ultimate load capacities of shell foundations on unreinforced and reinforced sand by laboratory tests. A series of loading tests were carried out on shell footing with and without a single layer of reinforcement. The tests were done for shell foundation at different shell embedment depth and subgrade density. The experimental studies indicated that the ultimate load capacity of shell footing on reinforced subgrade is higher than those on unreinforced cases. The shell foundation over reinforced subgrade can be considered a good method to increase the effective depth of the foundation and decrease the resulting settlement.

3. MATERIAL AND METHODOLOGY: -

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

Sand: - Kharka river sand is used in this experimental investigation. The air dried sand passing through 600 μ IS sieve and retained on 300 μ IS sieve is used for research work.

Confining element or skirt: -The rigid uPVC pipes (Unplasticized polyvinyl chloride pipes as per IS 4985:2000) of different outer diameters 110 mm, 160 mm and 200 mm and lengths of 100 mm, 150 mm and 200 mm are used as confining element.

Footing: -Mild steel circular footing of 150mm diameter with 20mm thickness is used. Model footing has a little groove at the centre to facilitate the application of load.

Laboratory Set-up:- Laboratory set-up (**Geo-technical Engineering Lab, College of Technology and Engineering, Udaipur**) consists of a tank, a reaction frame, a model footing, proving ring, dial gauges. Tank size is decided on the basis of IS code and from the result of some literature. IS 1888-1962 says that minimum size should be at least 5 times the width of test plate to develop the full failure zone without any interference of side. For cohesionless soil, Chummar (1973) suggested that the maximum extension of failure zone will be 2.5 times of the footing width along the side and 3 times the width of footing below the footing. Keeping the above criteria in mind, 1 m long tank with 0.504 m width and 0.655 m height is chosen.

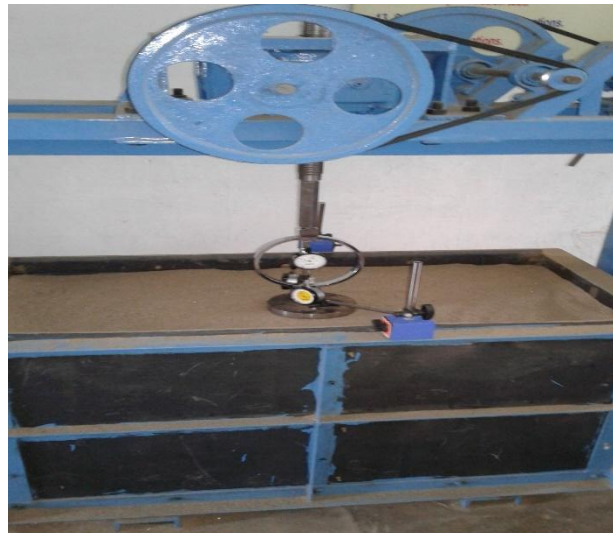


Fig. 3.1 Laboratory setup (Geo-technical Engineering Lab, College of Technology and Engineering, Udaipur)

Laboratory Tests: -The various laboratory tests are performed to decide the different geotechnical and engineering properties of sand such as grade of sand, specific gravity, the density of sand, relative density, the height of fall and angle of internal friction of sand. After that sieve analysis were performed on the sand in accordance with IS: 2720- part IV-1985. The relative density test is also conducted as per IS: 2720- part XIV. The specific gravity of the soil sample is determined by pycnometer method as per IS: 2720 part III-1964.

Table 3.1 Geotechnical Properties of Sand (As per laboratory tests at CTAE, Udaipur): -

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

The tank was filled with the dry sand at the constant relative density and bulk density throughout the bed. The cylinder was pushed vertically into the deposits at the desired location after filling the model. The model footing was placed, centrally with the cylinder, on the top surface of the sand and the two dial gauge was placed on the footing. The verticality of the hydraulic jack and horizontality of the footing model was set up with the help of plumb bob. After going through several literatures, the confining hollow cylinders that was used in the tests had different diameters of 110, 160 and 200 i.e. ($d/D = 0.73, 1.06$ and 1.33) and with variant heights of 100, 150 and 200 mm i.e. ($h/D = 0.67, 1$ and 1.33). The inner and outer surface of the cylinder was kept smooth to prevent the effect of the interface friction between the soil particles and the cylinder. A pre-calibrated proving ring was used to measure the load transferred to the footing. Load was 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.



Fig. 3.2 Laboratory test arrangement of confinement and model specimen

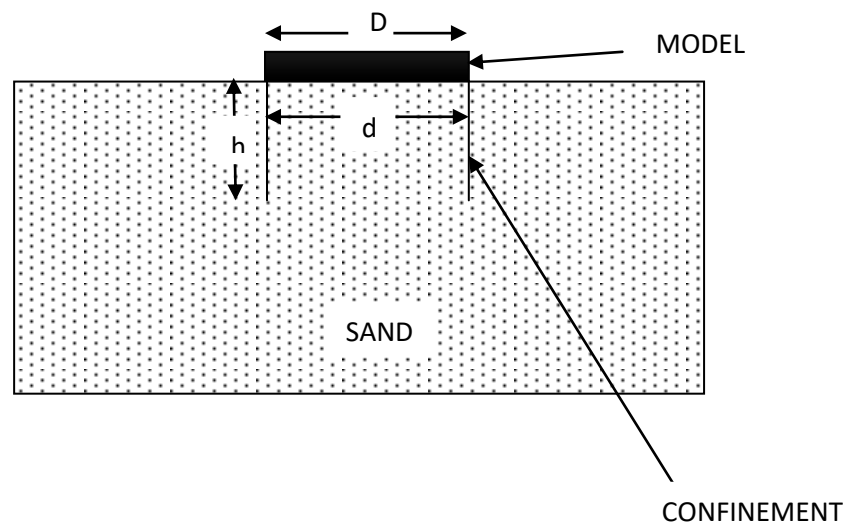


Fig. 3.3 Cross-section area of circular footing with confinement.

Where, D = diameter of model footing (constant)

h = height of confinement

d = diameter of confinement

Ultimate bearing capacity for each test will be determined from load-settlement curve using tangent intersection method. The tangent intersection method can be done as shown in Fig 3.4.

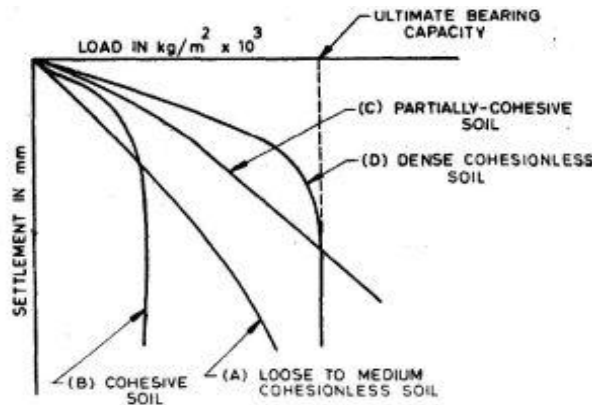


Fig. 3.4 Tangent intersection method (IS: 1888-1982)

4. RESULT AND DISCUSSION: -

Load tests were performed on the circular footing (diameter 150mm), resting over different height and diameter of confinement. To fulfil objective of research sand bed were prepared introducing different height and diameter of confinement. Settlement (up to 25mm as per IS: 1888-1982) corresponding to each load increment is noted and the test result is plotted in term of the load-settlement curve. Bearing capacity for each test is determined from load-settlement curve using tangent intersection method

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 .

4.1 RESULT OF CONFINED CIRCULAR FOOTING AT $d/D = 0.73$ AND $h/D = 0.5, 1$ AND 1.5

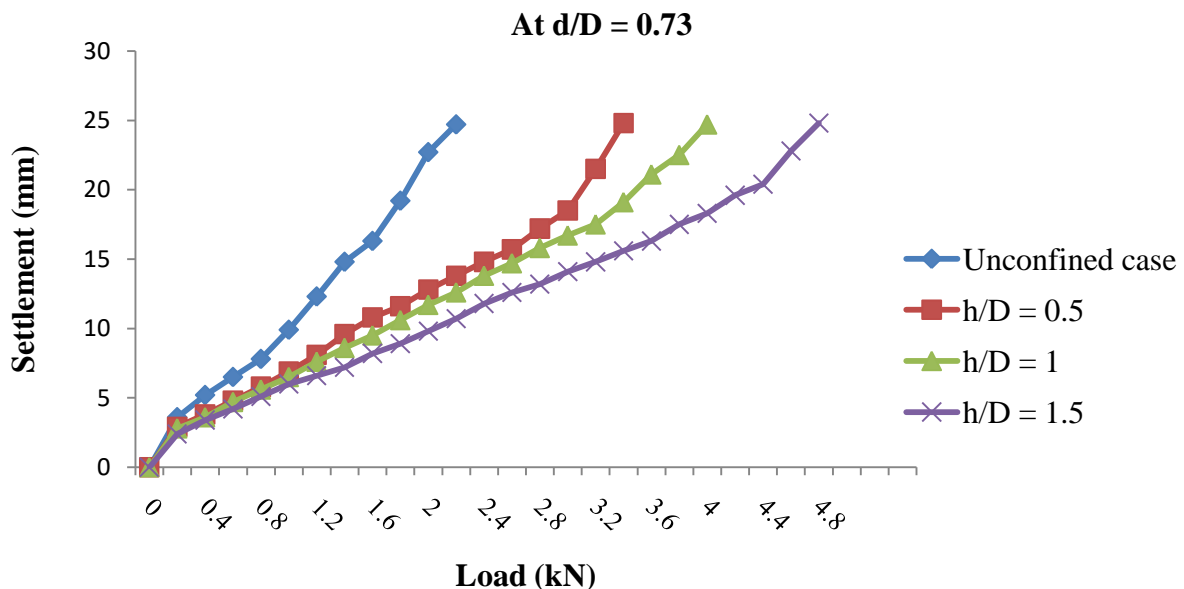


Fig 4.1. Load settlement curve of confined circular footing at $d/D = 0.73$ and $h/D = 0.5, 1$ and 1.5

From the load-settlement curve shown in Figure 4.1, the ultimate bearing capacity of sand at d/D ratio 0.73 and h/D ratio i.e. 0.5, 1, and 1.5 are calculated.

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 .

From the figure 4.1, it is observed that the Ultimate bearing capacity of sand is increased by 2.59 times of unconfined sand's ultimate bearing capacity. From the results, it is observed that introduction of confinement below the circular footing improves the ultimate bearing capacity of sand and also the settlement at failure load decreases.

As shows in Fig 4.1, the ultimate bearing capacity of sand at height of cylindrical confinement h/D ratio 0.5, 1, and 1.5 is observed as 147.2 kN/m², 181.17 kN/m² and 249.12 kN/m² at ultimate load 2.6 kN, 3.2 kN and 4.2 kN respectively for d/D ratio 0.73. From the results, it is observed that ultimate bearing capacity increase as height of cylindrical confinement increases.

For smaller cylinder diameter, as the pressure increases, the plastic state is developed initially around the edge of the footing, then spread downward and outward. The friction between the sand and the inside wall of cylinder increases with the increase of the active earth pressure until it reach a point when the system (cylinder, sand and footing) start to behave as one unit. The behaviour is similar as deep foundation (piles and caissons) in which load increases due to the shear resistance of cylinder surface. (Gupta and trivedi, 2009).

Smaller diameter of confining cylinder relative to footing size, the failure occurs as a shear failure in the sand around the cylinder and the system (cylinder, sand and footing) settles together.

From the Figure 4.1 it is clear that increasing the cylinder height led to a greater improvement in the load-settlement behaviour due to enlargement in the contact confined sand volume under the footing. The failure plane moves in the downward direction to the bottom edge of the cylinder which leads to an increase in the area of the resisting soil around the cylinder. The deeper locations of the failure wedge increase the surface area of the cylinder-model footing. This enhanced the soil carrying capacity and improved the load-settlement behaviour of the footing (Sawwaf and Nazer, 2005), (Gupta and trivedi, 2009).

Increase of confinement height increases the contact area of sand and confining cylinder and failure zone get shift downward. This delays the creation of failure zone and improves the bearing capacity of sand.

Earlier, (Sawwaf and Nazer, 2005) have reported that load carrying capacity of confined circular footing at d/D = 0.67, h/D = 2 is 3.9 times the unconfined circular footing which is comparative less then ratio at d/D = 1.33, h/D = 2 i.e. 17.

4.2 RESULT OF CYLINDRICALLY CONFINED CIRCULAR FOOTING AT d/D = 1.06 AND h/D = 0.5, 1 AND 1.5

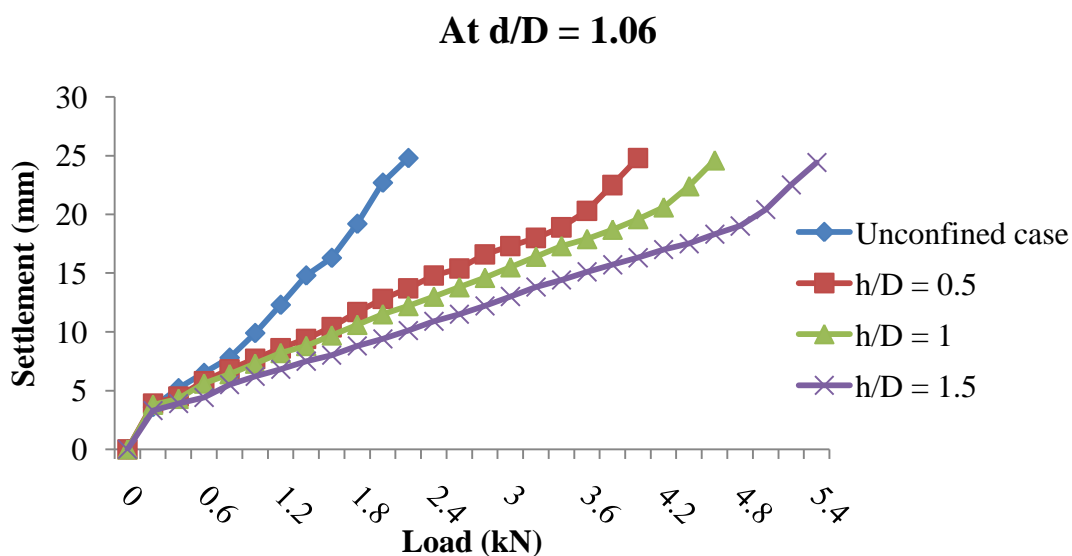


Fig.4.2 Load settlement curve of confined circular footing at d/D = 1.06 and h/D = 0.5, 1 and 1.5

From the load-settlement curve shown in Figure 4.2, the ultimate bearing capacity of sand at d/D ratio 1.06 and h/D ratio i.e. 0.5, 1, and 1.5 were calculated.

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 figure 4.2, it is observed that the Ultimate bearing capacity of sand is increased by 2.95 times of unconfined sand's ultimate bearing capacity. From the results, it is observed that introduction of confinement below the circular footing improves the ultimate bearing capacity of sand and also the total settlement at failure load decreases.

As shows in Fig 4.2, the ultimate bearing capacity of sand at height of cylindrical confinement h/D ratio 0.5, 1, 1.25 and 1.5 is observed as 215.14 kN/m^2 , 260.44 kN/m^2 and 283.08 kN/m^2 at ultimate load 3.8 kN , 4.6 kN and 5 kN respectively for d/D ratio 1.06. From the results, it is observed that ultimate bearing capacity increase as height of cylindrical confinement increases.

The load settlement relationship for unconfined case is shown in same figure 4.2 as basic case of comparison. The cylinder around the footing resist the lateral displacement of soil particles underneath the footing so the soil get more confined leading to a significant decrease in settlement and therefore improving the load settlement behaviour.

Earlier also, Soil bearing capacity of cylindrically confined circular footing at $h/D = 1$, $d/D = 1.02$ was increased 2.5 times the unconfined case. The improvement increase as cylinder diameter decreases because the soil inside the cylinder and the footing behave as one unit and settle together. (Elasaid *et al*,2015).

Earlier Gupta *et al* (2014) have reported that maximum improvement ratio which is ratio of load carrying capacity of confined sand to load carrying capacity of unconfined sand at skirt height 150mm is 5.72.

From the Figure 4.2 it is clear that increasing the cylinder height led to a greater improvement in the load-settlement behaviour due to enlargement in the contact confined soil volume under the footing. The failure plane moves in the downward direction to the bottom edge of the cylinder which leads to an increase in the area of the resisting soil around the cylinder. The deeper locations of the failure wedge increase the surface area of the cylinder-model footing. This enhanced the soil bearing capacity and improved the load-settlement behaviour of the footing.

4.3 RESULT OF CYLINDRICALLY CONFINED CIRCULAR FOOTING AT $d/D = 1.33$ AND $h/D = 0.5, 1$ AND 1.5

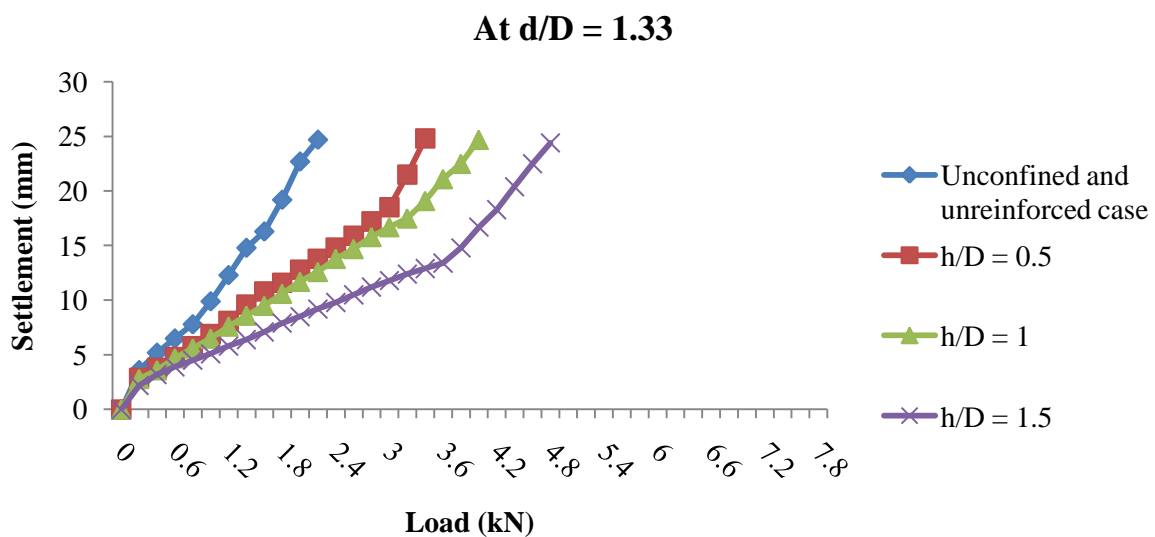


Fig. 4.3 Load settlement curve of confined circular footing at $d/D = 1.33$ and $h/D = 0.5, 1$ and 1.5

Figure 4.3 show the results of load test on circular model footing on cylindrical confinement of 200mm diameter and different heights ($h = 75\text{mm}, 150\text{mm}$ and 225mm) are plotted in term of the load-settlement curve.

From the load-settlement curve shown in Figure 4.2, the ultimate bearing capacity of sand at ratios $d/D = 1.33$ and $h/D = 0.5, 1$ and 1.5 are calculated.

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 .

From the figure 4.3, it is observed that the Ultimate bearing capacity of sand is increased by 2.35 times of unconfined sand's ultimate bearing capacity. From the results, it is observed that introduction of confinement below the circular footing improves the ultimate bearing capacity of sand.

As shows in Fig 4.3, the ultimate bearing capacity of sand at height of cylindrical confinement h/D ratio 0.5, 1 and 1.5 is observed as 135.8 kN/m^2 , 158.5 kN/m^2 and 260.43 kN/m^2 at ultimate load 3.2 kN , 3.6 kN and 4.6 kN respectively for d/D ratio 1.33. From the results, it is observed that ultimate bearing capacity increase as height of cylindrical confinement increases.

Earlier Chandrawanshi *et al*, (2014) have reported load carrying capacity of confined circular footing at $d/D = 2.08$ and $h/D = 3.5$ is 4.71 times the unconfined circular footing which is lesser than 21.14 at $d/D = 1.42$ and $h/D = 3.5$.

Gupta and trivedi (2009) had also observed through various tests that for large cell diameters, the cell and the soil within cell act as one unit initially, but as the load was increased it was no longer observed.

For larger cylinder diameter the increase of load on the footing remain unaffected by cylinder and footing settles down. Here, the cylindrical confinement place below the circular model footing is not capable to confine the sand below the model footing. Circular model footing and cylindrical confinement together does not act as one unit and model footing settles individually.

From the Figure 4.3 it is clear that increasing the cylinder height led to a greater improvement in the load-settlement behaviour due to enlargement in the contact confined soil volume under the footing. The failure plane moves in the downward direction to the bottom edge of the cylinder which leads to an increase in the area of the resisting soil around the cylinder. The deeper locations of the failure wedge increase the surface area of the cylinder-model footing. This enhanced the bearing capacity and improved the load-settlement behaviour of the footing.

5. SUMMARY AND CONCLUSIONS

In this work, the performance of confined circular footing has been studied based on a series of experimental tests. Hollow cylinder with various height and diameter were installed around the footing model for soil confinement purpose. This study has been carried out to understand the effect of circular footing with cylindrical confinement, on the load carrying 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:

- Soil confined by using this method 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. These confinements could be easily manufactured and placed around the individual footings.
- 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.
- Increasing the height of confining cylinder, results in increasing the surface area of cylinder-model footing, which transfer footing loads to deeper depths and leads to improving ultimate load carrying capacity.

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