Effect of Confinement of Sand using Skirts on its Bearing Capacity

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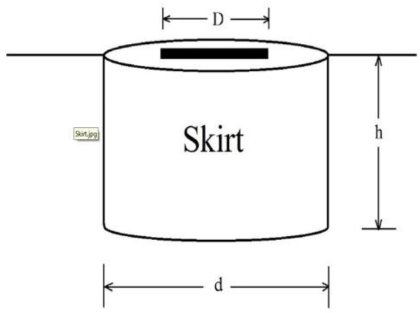
***Abstract* - The problems related with bearing capacity of soil in shallow foundation have been widely elaborated in the field of Geotechnical engineering.The bearing capacity of footings on sandy soil may be improved by using skirts. The skirts are considered to constrain the soil which results in enhancement of the bearing capacity of soil. Skirted footings are used as alternatives to deep foundations in soil with low strength. This paper is concerned with the evaluation of change in bearing capacity of sand after confinement through a set of cylindrical skirts of pvc pipes. Also, the effect of varying moisture content on the confined sand is investigated. The load-settlement relationships were plotted for several tests conducted in the laboratory on various combinations of diameter and height of skirts.**

***keywords* - Bearing capacity, sand, skirt, skirted footing, confinement of sand, moisture content**

I. INTRODUCTION

Bearing capacity of the foundation soil is very much important for the stability of structures. The soil must be capable of carrying the loads from any structure above it without any shear failure and with the tolerable resulting settlements for the structure. For granular soil like sand, a small lateral movement causes its failure. However, if the soil is confined, as in the case of raft foundations surrounded by sheet pile walls, a sufficient increment in the bearing capacity can be achieved.

Here, cylindrical skirts are used as a confinement material for the sand. A skirt may be defined as a surrounding wall or enclosure across a soil mass which can withstand considerable hoop stress which occurs on the application of vertical load on the soil. In unity with the confined soil, the skirt transfers the load coming from the superstructure to the foundation. Figure shows a typical skirt used for the confinement of soil.



Where d = diameter of skirt, h = height of skirt and D = diameter of the footing above the skirt.

The main objectives of this work are as follows:

- To explore the behavior of unconfined sand under different water contents.
- To explore the behavior of confined sand using skirts of varying diameter, keeping the heights same under different water contents.
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- To compare the results for dry, confined sand (w = 0%) from those reported in the literature.
- To plot load-settlement characteristics for the investigation of bearing capacity and settlement behavior of unconfined and confined cases at varying water contents of the sandy soil.

II. PREVIOUS STUDIES ON CONFINEMENT OF SOIL

Binquet and Lee (1975) [3] proposed a method of confining the granular soil. They placed geo-grids in horizontal direction and some improvement in bearing capacity of the compressible sand was seen. They presented possible modes of failure for checking the effectiveness of the foundation due to presence of non-corroding polymeric reinforcement.

Mandal and Manjunath (1995) [12] proposed a method for improving the bearing capacity of strip footing resting on sandy soil by using geo-grids and bamboo as vertical reinforcement. By using dry Mumbra sand of grain size 0.2 mm and uniformity coefficient 4.6, sand beds were prepared. Netlon geogrid strips 3 mm thick and 100 mm wide and bamboo sticks of 6 mm diameter were used as reinforcing element.

The relation between the pressure and settlement of the sand subgrades reinforced with geo-grids and bamboo sticks are shown in the graphs. The results showed that increment in bearing capacity and stiffness of the sand subgrades can be achieved by provision of vertical reinforcement.

Yun and Bransby (2003) [20] performed model tests to explore the response of skirted foundation on loose sand under combined horizontal, vertical and flexural loading. The investigation showed that that the horizontal capacity of the skirted foundation can be improved to 3-4 times that of plane foundation. It was also suggested that the failure mechanism of foundation changed to a rotational mode from a sliding mode.

Al-aghbari and Mohamedzein (2004) [1] proposed a modified equation for bearing capacity of skirted strip footing on dense sand. They used metal skirts for the confinement of soil and a series of tests was carried out. Various factors which affect the bearing capacity of skirted foundation were studied. The factors include depth of skirt, roughness and stiffness of skirt, foundation base friction and compressibility of the sand.

Sawwaf and Nazer (2005) [15] conducted laboratory model testing on the influence of behavior of circular footing on confined granular soil. They used confining cylinders of different heights and diameters for the confinement of sand. The cylinders were made of un-plasticized polyvinyl chloride. First, the behavior of soil in unconfined case was seen and then the study of confinement of soil was done at various parameters including cell diameter and cell height.

The ultimate bearing capacity of the confined soil was found to be 17 times the bearing capacity of the unconfined sand. The BCR (bearing capacity ratio) is highly dependent upon d/D ratio. The optimum value is about 1.40 beyond which there occurs decrement in the bearing capacity.

Al-aghbari and Mohamedzein (2006) [2] again worked on skirted foundation on circular footing resting on sand. It was found that the bearing capacity was increased by a factor of 3. Also at a working stress equal to half of the ultimate bearing capacity, the settlement of the footing can be decreased to 11% of that of the footing without skirt.

R. Gupta and A. Trivedi (2009) [6] performed experimental study for elaborating the effect of cell confinement on the bearing capacity and settlement of circular foundation resting on silty sand. Laboratory tests were performed on clean sand having silt content up to 25%. A model circular footing of diameter 15 cm was used in the experiments. The influence of cell diameter, cell height and amount of fines was investigated.

From the results, it is found that the bearing capacity of the confined sand is increased 3.94 times the bearing capacity of unconfined sand. The improvement factor (If) is highly dependent on d/D ratio. The optimum ratio is about 1.5 beyond which the improvement decreases when the ratio is increased. Also for all ratios of d/D and h/D, with increment of proportions on fines, the bearing capacity of the circular footing is found to be decreased.

Singh, Prasad and Agrawal (2011) [16] conducted laboratory model testing for checking the influence of square model footing resting on Ganga-sand under eccentric- inclined load. The results show that the ultimate bearing capacity of confined sand was found to be 6.75 times that of unconfined sand. The confinement of the soil can be used to reduce the vertical settlements of the footing.

T. Eid (2012) [5] presented the behavior of axially loaded skirted shallow foundation resting on sand. He used deep numerical analysis and physical modeling and utilized surface, pier and skirted square footings of different shear strength properties in his analysis. The results revealed that the bearing capacity of shallow foundation increases with skirt depth and decreases with relative density. Also the values of the bearing capacity and settlement are close to those of pier foundation of same depth and width.

III. METHODOLOGY

The overall methodology performed in the laboratory is described under following points:

1. Testing materials and their properties

In the whole experimental investigation, basically two materials were used: Sandy soil and Cylindrical skirt. The sandy soil used in the work was collected from the Narmada River near Hoshangabad which is situated about 70 km far from the laboratory. The properties of the sandy soil found by performing various engineering tests are given in the following table.

Table 1: Properties of the Sandy soil

Properties	Values
Natural water content, w	0.28 %
Specific gravity, G	2.67
Gravel content	1.48%
Sand content	98.04%
Silt and clay content	0.48%
Fineness modulus	Less than 5%
D_{60}	1.49
D_{30}	0.82
D_{10}	0.45
Cu	3.311
Cc	1.002
Soil classification	Poorly graded, SP

The cylindrical skirt used for the confinement of the sandy soil is made of polyvinyl chloride pipe. The pipes of different diameters and heights were cut and applied in the tests for the investigation. Kasta pipes were used as the skirt material. They are class 2 pipes, blue in colour, ISI marked with bearing pressure 4 kg/cm2 (or 0.4 MPa). Pipes of diameters 6.3 cm, 7.5 cm, 9 cm and 11 cm were used for the investigation. They are cut into lengths of 3 cm, 6 cm, 9 cm and 12 cm to form hollow cylindrical skirts. Hence a total number of 16 pipes (4×4) were used in the investigation.

2. Experimental Details

The entire testing program was divided into 5 series namely I, II, III, IV, and V. In series I, three tests were performed on unconfined soil (i.e. soil with no skirt) at three different water contents (w) namely 0%, 2.5% and 5%. This percentage of water content was taken by weight of the sandy soil taken into the mould. The remaining series contain 12 tests, each for fix height but varying diameters. The entire test program is given in the following table.

Table 2: Details of Test Program

Series	Constant Parameters	Varying parameters		Number of tests
		Diameter (d)	Water content (w)	
I	Unconfined sand	-	0%, 2.5% and 5%	1×3 = 3
II	Height of skirt = 3 cm	6.3 cm, 7.5 cm, 9 cm and 11 cm	0%, 2.5% and 5%	4×3 = 12
III	Height of skirt = 6 cm	6.3 cm, 7.5 cm, 9 cm and 11 cm	0%, 2.5% and 5%	4×3 = 12
IV	Height of skirt = 9 cm	6.3 cm, 7.5 cm, 9 cm and 11 cm	0%, 2.5% and 5%	4×3 = 12
V	Height of skirt = 12 cm	6.3 cm, 7.5 cm, 9 cm and 11 cm	0%, 2.5% and 5%	4×3 = 12
Total number of tests performed				51

3. Testing procedure

Determination of bearing capacity of unconfined and confined sandy soil (for both dry and wet cases) was done using the CBR apparatus setup. The following procedure was adopted:

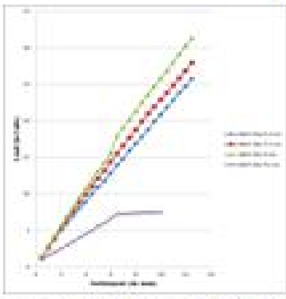
1) The skirt was pressed gently into the sandy soil. The soil was given some blows by a rammer before placing the skirt, so that the soil might set into the mould properly.
2) Afterwards the loading procedure was carried out. Load is applied to the soil (unconfined or confined) till the settlement reaches to 12.5 mm in each case. The rate of loading was set to 1.25 mm/min in each case of testing.
3) Initially loading was done on dry (w = 0%) and unconfined sand. Bearing capacity in units was calculated till the settlement reaches to 12.5 mm or failure of the soil occurs.
4) Then loading was done for confined sand using skirts of various combinations of diameter and height. Bearing capacity in units was calculated similar to the above.
5) When testing for dry soil was completed, water content of the soil was increased to the 2.5 % by weight of the soil and the test was repeated for the unconfined and confined sand.
6) After completion of the above, the water content was increased to 5% by weight of the soil and the testing was again repeated for the same.

Thus, for different sizes of the skirt and at different water contents of the sandy soil, the tests were performed and their corresponding load settlement values were recorded.

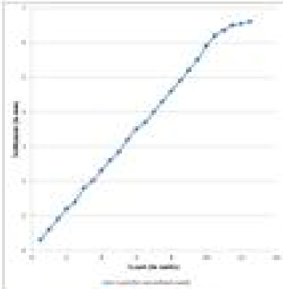
IV. IMPLEMENTATION

The load and settlement values were found for finding the ultimate bearing capacity of the sandy soil for un-skirted as well as skirted case. The load-settlement curves of all the tests performed in the laboratory are shown as following.

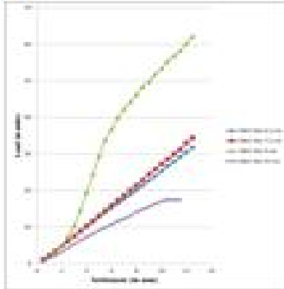
Load-Settlement Curves (w = 0%)



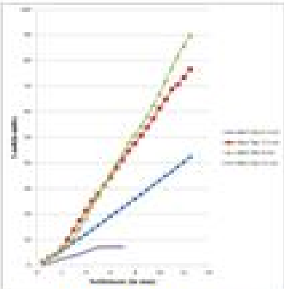
Confined Sand for h = 3 cm (w= 0%)



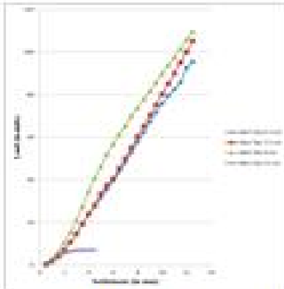
Unconfined Sand (w= 0%)



Confined Sand for h = 6 cm (w= 0%)

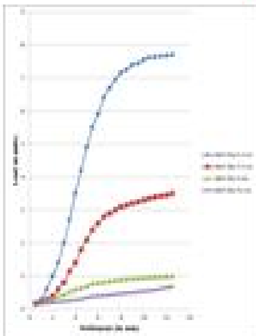


Confined Sand for h = 9 cm (w= 0%)

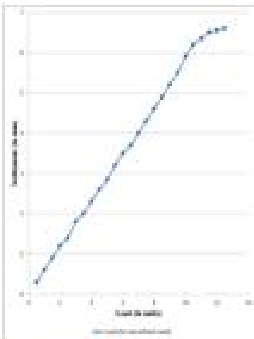


Confined Sand for h = 12 cm (w= 0%)

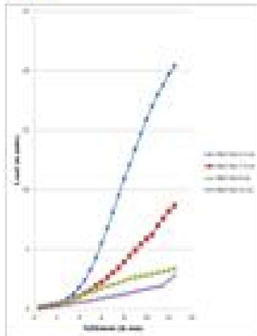
Load-Settlement Curves (w = 2.5%)



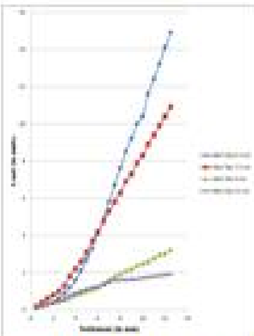
Confined Sand for h = 3 cm (w= 2.5%)



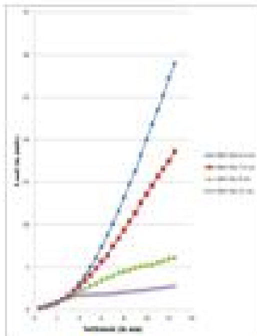
Unconfined Sand (w= 2.5%)



Confined Sand for h = 6 cm (w= 2.5%)

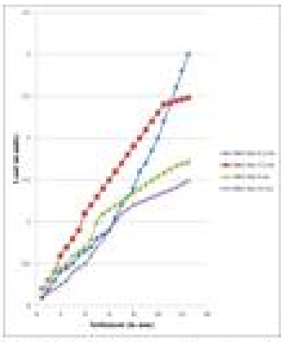


Confined Sand for h = 9 cm (w= 2.5%)

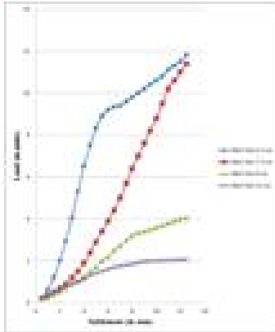


Confined Sand for h = 12 cm (w= 2.5%)

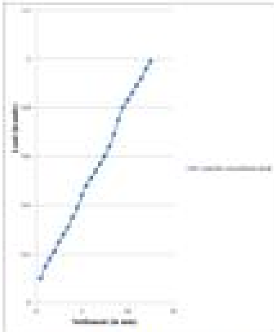
Load-Settlement Curves (w = 5%)



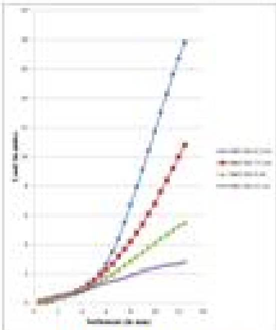
Confined Sand for h = 3 cm (w= 5%)



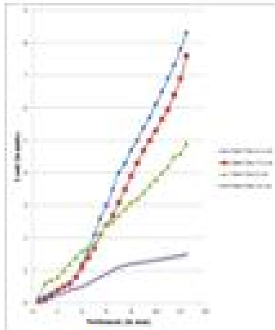
Confined Sand for h = 6 cm (w= 5%)



Unconfined Sand (w= 5%)



Confined Sand for h = 9 cm (w= 5%)



Confined Sand for h = 12 cm (w= 5%)

V. RESULT ANALYSIS

The values of bearing capacity (in units) of the sandy soil taken in the investigation for the above combinations are shown in the following tables.

Table 3: Bearing capacity of Confined Sand at w = 0%

Water Content, w = 0%				
Skirt-height (h) (in cm)	Bearing Capacity (in units)			
	Skirt-diameter = 6.3 cm	Skirt-diameter = 7.5 cm	Skirt-diameter = 9 cm	Skirt-diameter = 11 cm
3	25.7	27.9	31.25	7.45
6	31.7	34.35	62.1	17.4
9	42.2	76.6	89.9	7.15
12	95.4	105.1	**109.6**	7.1

From the above table, it is noted that the bearing capacity of the confined sand (w= 0%) has been improved due to inclusion of skirts, when compared from that of unconfined sand. The maximum bearing capacity is obtained when skirt-diameter is 9cm and skirt height is 12 cm.

Results of the present research hold good agreement with those reported by other researches. **Sawwaf and Nazer (2005)** reported that the bearing capacity of the confined soil was found to be **17** times the bearing capacity of the unconfined sand. In this research, the bearing capacity is **16.6** times the bearing capacity of the unconfined sand. Hence similar observations are obtained for water content 0%.

Table 4: Bearing capacity of Confined Sand at w = 2.5%

Water Content, w = 2.5%				
Skirt-height (h) (in cm)	Bearing Capacity (in units)			
	Skirt-diameter = 6.3 cm	Skirt-diameter = 7.5 cm	Skirt-diameter = 9 cm	Skirt-diameter = 11 cm
3	7.7	3.5	1	0.68
6	20.4	8.7	3.45	2.8
9	14.9	10.9	3.25	1.92
12	**28.9**	18.6	6.2	2.8

Table 5: Bearing capacity of Confined Sand at w = 5%

Water Content, w = 5%				
Skirt-height (h) (in cm)	**Bearing Capacity (in units)**			
	Skirt-diameter = 6.3 cm	**Skirt-diameter = 7.5 cm**	**Skirt-diameter = 9 cm**	**Skirt-diameter = 11 cm**
3	3	2.48	1.72	1.49
6	11.8	11.4	4.05	2.05
9	**17.8**	10.8	5.5	2.8
12	8.3	7.6	4.9	1.48

VI. CONCLUSION

On the basis of above experimental investigation and analysis of the results, following conclusions can be drawn:

1. Soil confinement can be significantly applied for improving the bearing capacity of circular foundation resting on sandy soil.
2. For dry confined sand (w = 0%), the bearing capacity is found to be increased when the skirt-diameter (d) is increased to a certain extent. When d > 9 cm, the bearing capacity is found to be decreased due to decrease in the effect of the confinement.
3. For dry confined sand (w = 0%), the bearing capacity is found to be increased when the skirt-height (h) is increased due increase in the surface area for the confinement.
4. In case when water content is 0%, the maximum bearing capacity is found at skirt-diameter 9 cm and skirt-height 12 cm and the bearing capacity for the confined sand is found to be 16.6 times the bearing capacity of unconfined sand.
5. The bearing capacity of the confined sand is found to be decreased when water content of the sand is increased.
6. At water contents 2.5% and 5 %, the bearing capacity of the confined sand is found to be increased when the skirt-diameter is decreased. Hence in each case, maximum bearing capacity is reported at d = 6.3 cm, which is the least diameter of all the sections.
7. In case when w = 2.5%, the best section of the skirt at which maximum bearing capacity is achieved is obtained when the skirt-diameter is 6.3 cm and skirt-height is 12 cm.
8. In case when w = 5%, the best section of the skirt at which maximum bearing capacity is achieved is when the skirt-diameter is 6.3 cm and skirt-height is 9 cm.

VII. FUTURE WORK

Based on the above work and its findings, future scope for this topic may be as following:

- Effectiveness of the soil confinement can be explored on different types of soils.
- Study of effect of water content on other soils after the confinement can be done.
- Investigation can be done for checking that the soil confinement can be used as a ground improvement technique or not.
- Study of confinement of soil on varying test tank dimensions may also be done.
- Comparison between different materials of the skirts can be explored so far.
- The shape of the skirts can be modified from cylindrical section to tapered section and the analysis can be done on those modified shapes.
- Finite element analysis and soil modeling can be adopted for obtaining more advanced results.

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