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EFFECT OF SKIRT SIZE AND PILE SPACING ON BEARING CAPACITY OF SKRITED FOUNDATION IN GRANULAR SOIL

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ABSTRACT: This paper presents the results of laboratory model tests on the benefit of providing confinement to the footing on loose sand deposits using small diameter steel piles driven around the footing is explored. The provision of piles skirt around the footing is known to be enhancing bearing capacity and reduced the settlements. The provision of piles skirt also minimizes the practical difficulties of installing a continuous skirt of skirted foundation. An experimental investigation on pile confined model footing is undertaken and the response of such footing compared with unconfined footing. The effects of varying skirt size and center to center spacing of piles at constant depth of 2b are studied. The experimental investigation revealed that the confining piles can be successfully used to improve the bearing capacity and reduced the settlement. The method can be economically used to improve the bearing capacity and reduced the excavation required for the placing of continuous wall skirt.

Key Words: Footing, Pile Skirt, Load Bearing Capacity, Granular Soil

I. INTRODUCTION

India has a wide coastal region in south and also has a big network of rivers which has vast sand deposit along the banks. Besides this there is also ample sand deposit in west-north India (Rajasthan). These sands deposit result due to either water or wind. These areas are characterized by loose and uniformly graded medium to fine sand. These sand deposits have very low shear strength and low bearing capacity. Especially in case of loose sand deposits, poses a challenge because a small lateral movement leads its shear failure. The probable settlements, differential as well as total, of the foundation must be limited to safe limited to safe and within permissible limit. Bearing capacity and settlement are important criterion which affects the performance and stability of any structure. Many investigators in the past studied the concept of soil confinement by providing horizontal and vertical confinement (Binquet and Lee 1975; Fragaszy and Lawton 1984; Mahmoud and Abdrabbo 1989; Mandal and Manjunath 1995; Das et al. 1996 etc.). A few of them studied the technique of skirted foundation on loose sand deposits. But the provision of a continuous box skirt has some practical difficulties of installation around the footing. Hence, there is a need for a technique that is economical and feasible for small residential buildings. Though the loose sands deposits can be compacted by various techniques, but many of them have limited application in case of small and medium residential buildings. The technique of ground improvement such as vibratory compaction, vobro-float, sand piling cannot be applicable to existing foundations. The technique such as grouting may prove to be expansive for light residential buildings. Hence there is a need for a cost effective technique to improve the performance of foundation in loose sand deposits.

II. CONFINED FOUNDATIONS

The structural measures for footings are widely used in weak loose sand deposits to support the column loads. Sometimes, during the construction the excavation needs to be braced. In such circumstances one of the available solutions is to use side support to the excavation during construction. The removal of these supports is very cumbersome; hence they are act as part of permanent foundation. The structural foundation result in such condition is known as the confined footing. The side supports provided around the footing is known as the skirt. Such skirt provides additional confinement to the soil supporting the footing.

However, if this loose soil deposit is confined by providing a continuous box skirt, the bearing capacity is enhanced enormously as well as reduction in settlement are reported from the experimental investigation on footings with mild steel box skirt (Kurian & Nirmala Devi 1997). Various investigations are reported on the application of continuous skirt supported foundations elsewhere (Al-aghbari and Mohamedzein (2004); Sawwaf and Nazer (2005); Al-aghbari and Mohamedzein (2006); Al-Aghbari and dutta (2008); Gupta and Trivedi (2009); Prasad and Singh (2011), Eid (2012); Sareesh Chandrawanshi (2013))

Footing with integrated skirts is also used as solution for the various types of offshore platforms, and sub-sea systems (Andersen et al. 2008; Hu et al. 1999). Internal skirts in addition to peripheral skirts have more benefit (Bransby & Yun 2009). The integrated skirts of small diameter timber piles provided around the footing are beneficial in improving the bearing capacity and reduced the settlement in loose sand deposit near the coast line (Sachin, P 2006).

The provision of a continuous box skirt has some practical difficulties of installation around the footing. Also such a skirt is expansive due to high cost of steel and concrete. Confinement to the footing can be provided by a number of small diameter timbers, steel or concrete etc. confining micro piles placed at a distance from the footing. The array of micro piles around footing is called the pile skirt. This technique over come all the practical difficulties of box skirt. These piles can be installed using hand driven hammer blows. In the location near the coast, river bank and desert the water table vary time to time in such condition timber pile may get degraded. In this investiga tion, the confinement of the model footing on loose sand by installation of steel piles around footing reported. The effect of skirt size and pile spacing in the pile skirt are investigated through the laboratory studies on model footings.

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III. LABORATORY MODEL TEST

Footing: A square model footing of size 100 mm x 100 mm and 10 mm in thick made of mild steel is used. The footing is placed on the surface of the sand bed and load is applied on it by hand-operated hydraulic jack. Each load increment is maintained constant till the footing settlement has stabilized. The settlement of footing measured by dial gauge placed on footing.

Model Test Tank: Model tests are conducted in a test tank, having inside dimensions of 1m x 0.75 m in plan and 0.75 m deep. The size of tank is decided by the size of footing and the zone of influence. The test tank is made of steel and coated with the thermocol sheet to minimize the wall effect.

Test Material: Locally available Narmada sand is used as the foundation bed material. The physical properties of Narmada sand are presented in Table 1.the grain size distribution curve of Narmada sand is shown in fig. 1 and is classified as the SP according to IS code 1498:1970.

Pile Skirt: The confining skirts are made from 10 mm diameter mild steel piles. The diameter of pile normalized from side of modal footing (1/10 of footing side) The skirts are provided in different configuration, at 0.5b, b, 1.5b, 2b from side of footing. Here four different pile skirts sizes are studied, have skirt size (B) 200 mm, 300 mm, 400 mm, and 500 mm

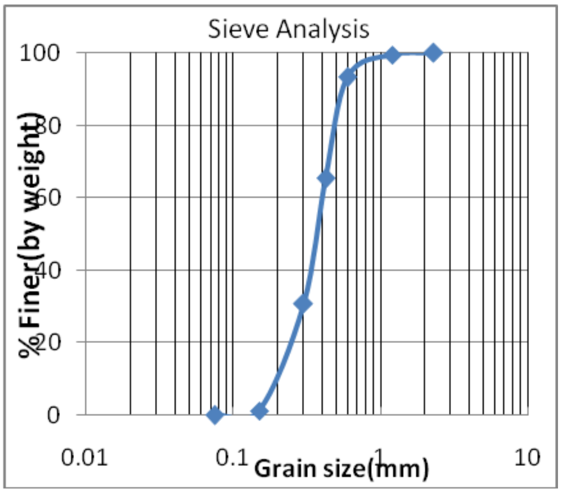

Fig.1 Grain Size Distribution Curve of sand

Table: 1 Properties of Narmada Sand

S.No.	Characteristics	Value
1.	Gravel content	Nil
2.	Sand content	99.83%
3.	Silt and clay content	0.17%
4.	D_{60} = grain diameter corresponding to 60% finer	0.42 mm
5.	D_{30} = grain diameter corresponding to 30% finer	0.30 mm
6.	D_{10} = grain diameter corresponding to 10% finer	0.20 mm
7.	Coefficient of Uniformity, C_u	2.10
8.	Coefficient of Curvature, C_c	2.98
9.	IS Soil Classification	SP, poorly graded sand
10.	Maximum Dry Density, γ_{max}	16.48KN/m^3
11.	Minimum Dry Density, γ_{min}	14.54KN/m^3
12	Field Density, γ_n	15.50KN/m^3
13.	Maximum Void Ratio, e_{max}	0.801
14.	Minimum Void Ratio, e_{min}	0.589
15.	Relative Density, R.D.	50%

IV. EXPERIMENTAL SETUP AND TEST PROGRAM

The footing is placed in position and the load is applied to it by jack. The load is applied in small increments until failure occurred. Each load increment was maintained constant until the footing settlement has stabilized. The settlements of footing are measured by four dial gauges fixed at corners of model footing. The geometry of the soil, model footing and pile skirt shown in fig. 2.

The test program consists of carrying out four series of tests on square footing to study the effects of soil confinement as shown in table 2. Initially, the test is carried out on the footing resting on unconfined sand bed. Then, each series of test are carried out under axial load to study the effect of one parameter while the other variables are kept constant. The studied variables are the skirt size (D) and pile spacing (s), while the length of pile (h) and footing size (b) kept constant for all the cases. They are elaborated using terminology by ratios as explained below and shown in fig. 2.

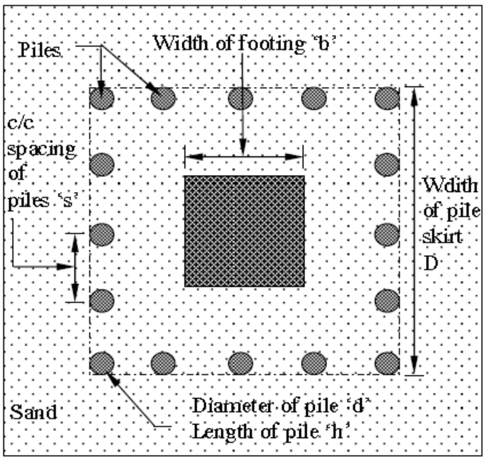

Fig. 2: footing with confining piles around

The confining piles used in the study are made up of mild steel of 10 mm diameter. Results of four pile skirts (D), 200 mm, 300 mm, 400 mm, 500 mm are presented here. The general arrangement of the confining piles around the footing is shown in fig. 2. The different pile spacing (s), 66.7mm, 4.0mm, 28.5mm, 25mm c/c are used.

V. RESULTS AND DISCUSSIONS

The footing settlement is expressed using another non-dimensional factor, Sp/b ratio. This ratio describes the settlement of footing in terms of footing size 'b' as mentioned earlier. The ultimate bearing capacity of unconfined case and confined case are calculated at 20 mm settlement ie. (Sp/b ratio = 20%). The measured ultimate bearing pressure for the unconfined case is 157.5 kPa. The measured ultimate settlement for the unconfined case, corresponding to 150 kPa is 8.75 mm. Response of the confined footing with different s/d ratios of 6.67, 4, 2.85, 2.5 etc. The tests are repeated at a constant h/b ratio of 2(length of pile 20 cm) and the four different skirt size of 200 mm, 300 mm, 400 mm, and 500mm are used. The pressure-settlement behavior of 200mm skirt size for different pile spacing is shown in fig. 4 for pile length of 200mm (h/b). The tests are repeated with 300mm, 400mm, and 500mm skirt with the same s/d ratios are used shown in fig. 4, fig. 5, fig. 6. It can be conclude that, as the spacing of the piles and skirt size reduced, the mode of failure showed the tendency to change to general shear failure. Well defined failure is indicated with closer spacing of piles. With the introduction of confining piles the shear strength of same soil increases. The load-settlement relationship and the ultimate bearing capacity of the footing with and without confinement are obtained. The bearing capacity improvement due to the soil confinement is presented using a nondimensional factor, called the bearing capacity ratio (BCR).

Table 2: Summary of Experimental Programme for Model Plate Load Test

Test Program for Experimental model						
Test series	Constant Parameters					Variable
	Skirt size (D) (mm)	Diameter of pile(h) (mm)	Length of pile(h) (mm)	D/h	R.D. %	s/d
1	Unconfined test	-	-	-	50	-
2	2b = 200	10	200	1	50	2.5, 2.85, 4, 6.67
3	3b = 300	10	200	1.5	50	2.5, 3, 3.75, 4.2, 6, 10
4	4b = 400	10	200	2	50	2.5, 2.83, 3.33, 4
5	5b = 500	10	200	2.5	50	2.5, 2.95, 3.33, 3.9
*Each test is performed 3 times to confirm the behavior and the maximum variation in values obtained as %.s						

This factor is defined as the ratio of the footing ultimate load with soil confinement to the footing ultimate load in test without confinement. Fig. 5 shows the variation of BCR with normalized spacing (s/d) for a constant pile length of 200mm. It can be noticed that the reduction in spacing leads to an improvement in the ultimate bearing capacity of soil. As the spacing between piles increased, the improvement in BCR reduced. The curve relating the BCR with normalized spacing showed the tendency to become parallel to the X axis, rather than becoming asymptotic. This could be due to improvement resulting from the densification of the loose sand bed because of the pile driving. Maximum BCR improvement noticed is 2.06 for a normalized spacing of 2.5 and normalized skirt size (D/b) of 2. For the same configuration, with a normalized skirt size (D/b) of 3, the improvement is 2. By increasing the D/b from 2 to 3, the improvement in BCR is 2.9%. However, the corresponding improvement in BCR between normalized skirt size (D/b) is only 2.9%. this point an optimum skirt size beyond which the improvement in bearing capacity will not be significant. Fig.4 shows the relation between the BCR and the normalized skirt size for various pile spacing. It can be noticed that the influence of skirt size is dependent on the pile spacing. As already mentioned, with closer spacing of pile (s/d = 2.5), significant improvement took place as normalized skirt size become 2. The improvement that resulted in further increase of skirt size is not significant

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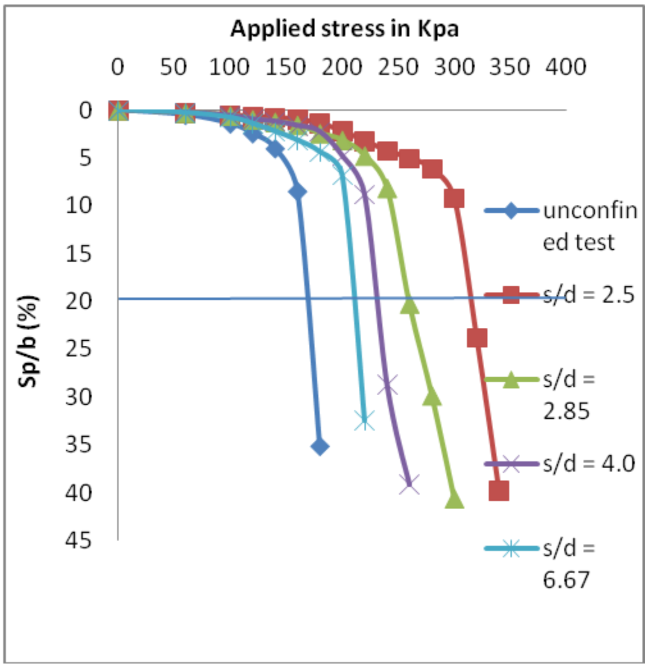

Fig. 3. Applied Stress vs Normalized Settlement for D/b=2

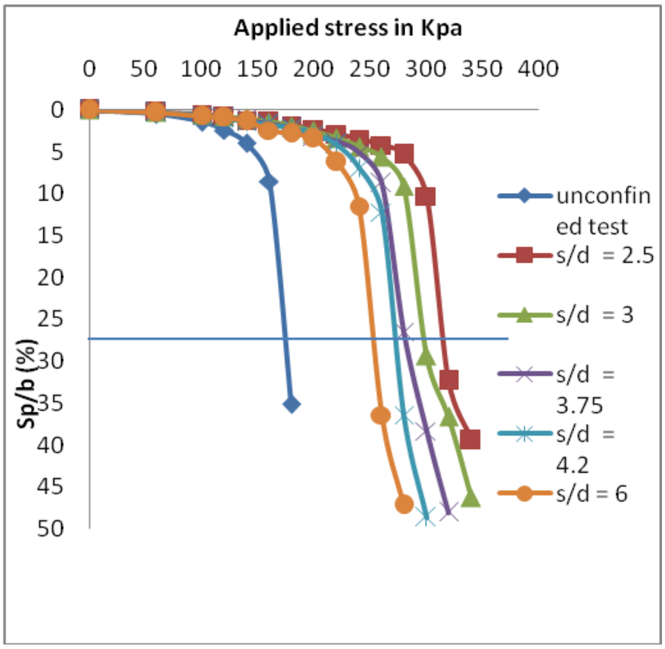

Fig. 4. Applied Stress vs Normalized Settlement for D/b= 3

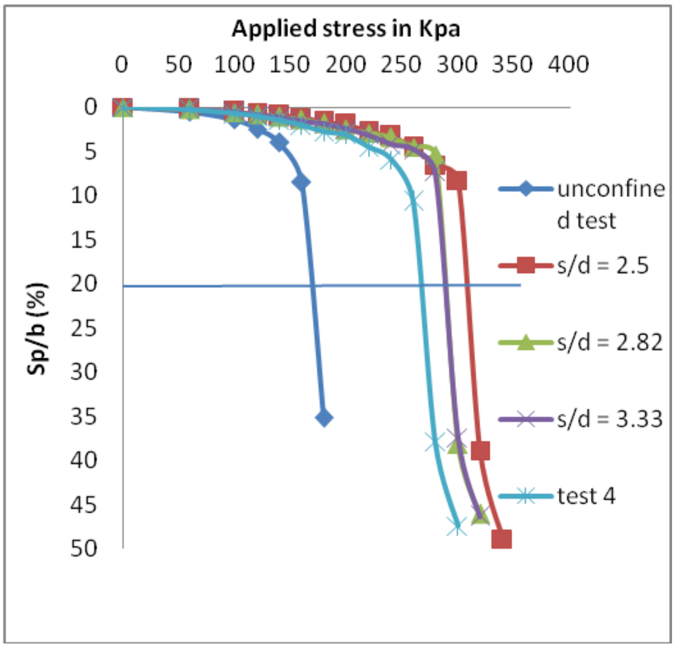

Fig. 5. Applied Stress vs Normalized Settlement for D/b=4

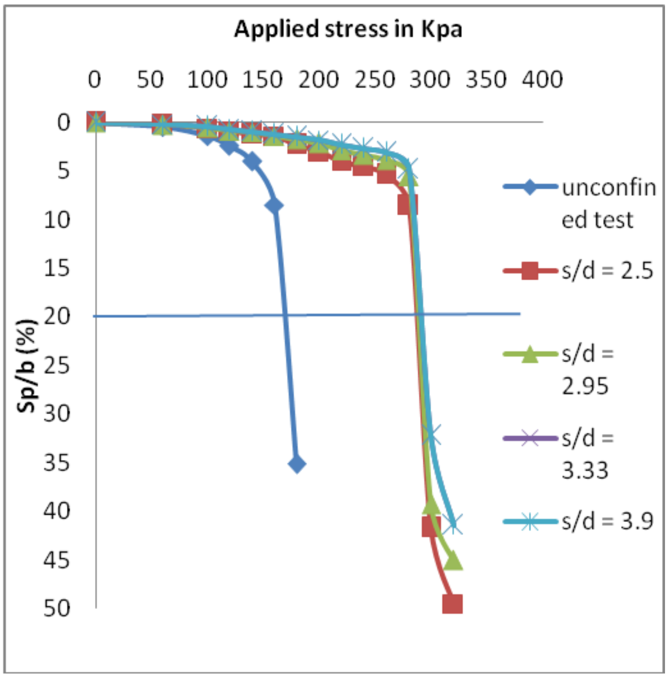

Fig. 6. Applied Stress vs Normalized Settlement for D/b = 5

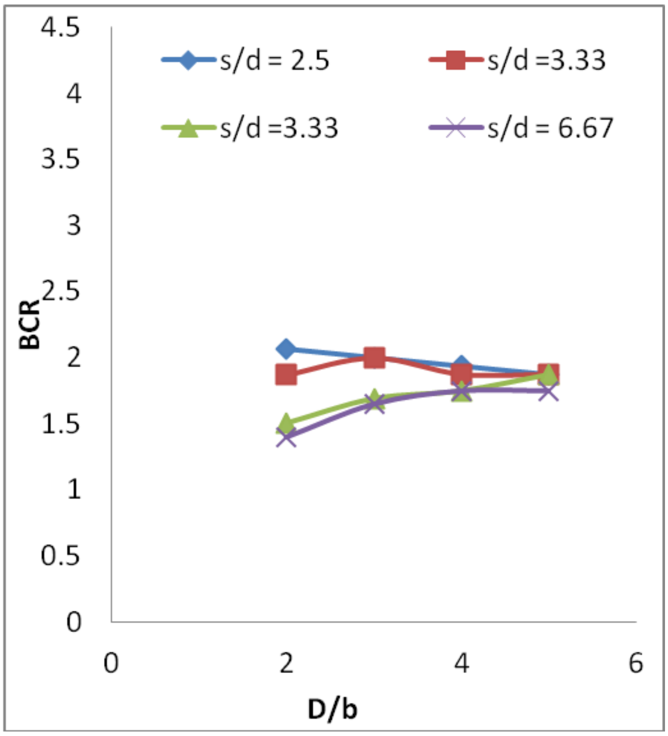

Fig. 8. Change in BCR with Skirt Size

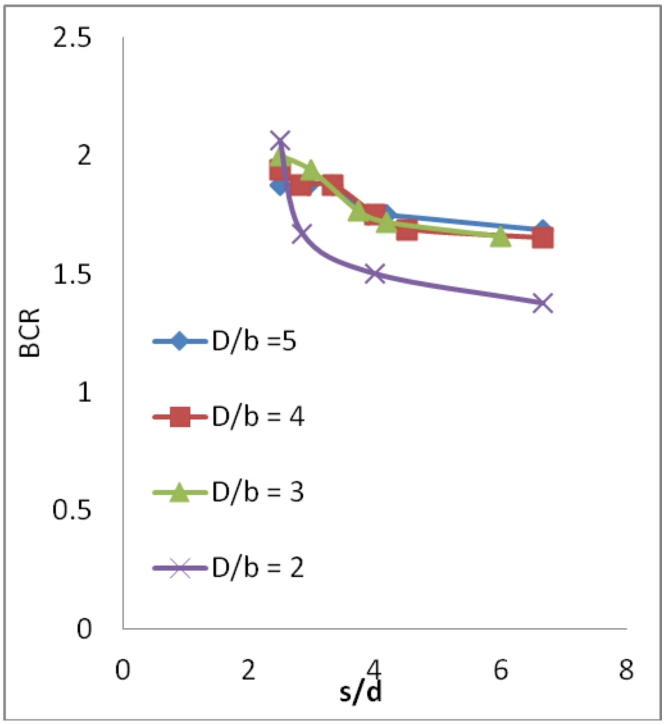

Fig. 8. Change in BCR with Pile Spacing

VI. CONCLUSIONS

- Soil confinement using small diameter confining piles skirt has a significant effect on improving the bearing capacity of the square footing supported on loose granular soil.

- In case where structures are very sensitive to settlement, soil confinement using piles skirt can be used to obtain to obtain the same allowable bearing capacity at much lower settlement.
- For small piles skirt relative to footing size, the skirt-sand-footing system acts as a single unit and settles all together. The failure occurs as a general shear failure in the soil surrounding the skit.
- For large piles skirt relative to footing size, the skirt-sand-footing system behaves initially as single unit but as the failure approaches, the footing only settles while the skirt seems to be unaffected.
- Higher load carrying capacity for footings on loose sand deposits can be obtained with closer spacing of confining piles. Improvement of bearing capacity up to 2.06 times that of the unconfined footing is observed with close spacing of piles (s/d=2.5).
- As the spacing of piles reduced, the mode of failure showed the tendency to change to general shear failure. Load settlement relation showed well defined failure with closer spacing of piles.
- As the size of skirt increases the BCR get reduced after a certain optimum valuing it did not significantly improve the ultimate bearing *capacity. The skirt size of 200 mm corresponding to s/d ratio of 2.5 gives the maximum BCR.*

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