EXPERIMENTAL STUDIES ON BEARING CAPACITY OF INCLINED SKIRTED FOOTINGS ON C- Φ SOILS

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ABSTRACT: This work discusses the suitability of inclined internal skirts along with outer vertical insertions or skirts on bearing capacity of skirted footings on c-Φ soils. The parameters includes thickness and depth of vertical insertions as well as spacing of inclined internal skirts. The scaled model footings made up of mild steel were considered for this research work. Square and rectangle are the two shapes adopted. The size was designed in such a way that the lateral confinement effect does not affect the test results. The foundation soil was in dry condition. The readings of the applied load measurements were taken using a pressure cell between the jack and the model footing and settlement was measured using the dial gauges placed on the footing. The pressure-settlement curves showed that increase in thickness and reduction in spacing increased bearing capacity.

KEYWORDS: Skirted footings, bucket foundations, confined footings, bearing capacity, settlement, shear failure, vertical insertions.

INTRODUCTION

Various methods of improving bearing capacity of footings have been discussed in the past. The present study focuses on improving the bearing capacity of foundations by soil confinement. The confinement of foundation soil is achieved by providing vertical plates or insertions along the periphery of footings. These vertical plates prevent the lateral movement of foundation soil under the load from superstructure. These vertical plates or insertions are termed as skirts and foundations with these skirts are commonly referred as skirted footings or bucket foundations. These foundations are commonly employed in offshore structures to replace deep foundations. However, skirted foundations are yet to find their place in onshore structures. Many researchers have carried out works on these types of foundation for onshore conditions. The earlier research works mainly focused on footings with vertical skirts on sand or granular soils. The present study is mainly on bearing capacity of footings with internal inclined skirts and vertical skirts along the periphery of footing on c-Φ soils.

LITERATURE SURVEY

Eid, H (2013) conducted numerical studies on axially loaded skirted shallow foundations. The results showed that skirted foundations displayed bearing capacity and settlement values that are close to pier foundations of the same width and depth. Bearing capacity of shallow foundation increases with increasing skirt depth and decreasing relative density of sand. Settlement reduction exceeds 70% for a ratio of skirt-depth/foundation-width equal to 2.
Finite element limit analysis conducted by Divya S. K. Mana, Susan Gourvene, and Christopher M. Martin (2013) identifies the critical internal skirt spacing, show that fewer internal skirts are required with increasing skirt depth, but more internal skirts are required with increasing soil strength non-homogenity. The results also indicate that reduction in number of skirts reduced bearing capacity Laboratory tests were conducted by M. El Sawwaf and A. Nazer to study the

influence of soil confinement on the behavior of a footing resting on granular soil. The parameters included the diameter and depth of cell and the embedded depth of footing. The results showed soil confinement increase bearing capacity of circular footing. The cells with small cell diameters exhibit deep foundation behaviour, while this pattern was not found with large cell diameters.

MATERIALS AND METHODS IN THE PRESENT STUDY

Model Footing

In the present work, square shaped footing with and without skirts are used for the testing. The footing sizes were smaller than (1/5) B (where B = least lateral dimension of container) to avoid lateral confinement effect. The details of the model footings are given in Table 1. The plan area of model footings is 80 mm x 80 mm and 64 mm x 100 mm. The thickness of footings is 10 mm made of mild steel. Vertical plates of thickness 1 mm, 3 mm and 5 mm are used as skirts. The skirt depths of 0.5 B, 1.0 B and 1.5 B were used to understand the effect of bearing capacity due to variation in skirt depth where B is the least lateral dimension of the model footing. Model footings and skirts are connected by welded joints so as to form a monolithic footing. The line diagrams of square footing is shown are Figure 1 and 2.

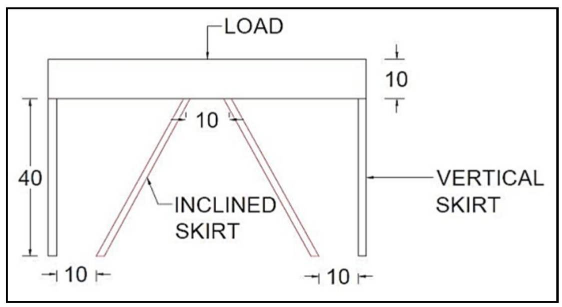

Figure 1: Square Footing with vertical and inclined skirts (S=10 mm)

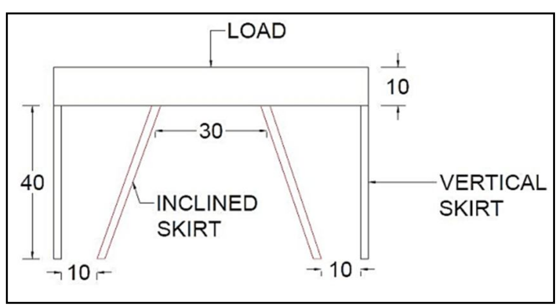

Figure 2: Square Footing with vertical and inclined skirts (S = 30 mm)

Totally 18 model square footings of varying skirt depths and skirt thicknesses were used for the study. The dimensions of all the model square footings are mentioned in Table 1.

Table 1: Dimensions of Square Footing

Shape of Footing and Size, mm	Skirt Thickness, mm	Skirt Depth, mm	Internal Skirt Spacing, mm
Square 80 x 80	1	40	10 & 30
		80	
		120	
	3	40	
		80	
		120	
	5	40	
		80	
		120	

c-Φ soil

The soil used in the experiment program was oven dried and sieved as per Indian Standard specifications. The geotechnical properties of the soil is given in Table 2.

Table 2: Geotechnical properties of soil

Property	Value
Specific Gravity (G)	2.67
Effective Particle Size (D_{10}), mm	0.022
Particle Size (D_{30}), mm	0.068
Particle Size (D_{60}), mm	0.36
Uniformity Coefficient (Cu)	16.36
Coefficient of Curvature (Cc)	0.58
Unit Weight (ϒ), kN/m^3	13.73
Angle of internal friction	37^0
Cohesion (c), kN/m^2	11

Test Tank and Loading Frame

Figure 3: Test tank and loading frame (Courtsey: KSSEM Structures Lab)

The test tank was made up of steel and has a size of 0.75 m (length), 0.45 m (width) and 0.75 m (depth) as shown in Figure 3. Stiffeners are used to avoid buckling of side walls of the tank during loading of the model footing. Static vertical loads were applied and Load-settlement readings were taken.

Test Procedure

The foundation soil bed for the testing was prepared by the raining technique in layers of 50 mm thick up to full tank height. The required relative density of soil was obtained by pouring from a pre-determined height and controlled intensity of pouring. The effect of falling height on the relative density was considered. The top of soil layer was levelled so that the model footing had full contact with the soil and that the load applied to the footing was vertical (normal). The unit weight of the soil was maintained at 13.73 kN/m^3 in dry state. After the completion of each test cycle, the pit was excavated up to a depth of 1.5B beneath the footing and refilled to the required density. The footing was placed on the levelled surface of the soil at pre- determined locations in the testing tank. The vertical compressive load was gradually applied to the model footing. The load was applied at constant rate until the settlement seized. Two numbers of dial gauges were used to measure settlements of the footing. The load-settlement readings were recorded for each cycle. The tests were continued until the settlement was reduced considerably.

RESULTS AND DISCUSSION

A series of pressure-settlement experiments on square shaped skirted footings on c- Φ soil have been performed. The pressure - settlement curves for a square footing of size 80 mm x 80 mm with thickness varying from 1 to 5 mm with constant depth of 40 mm is shown in Figure 4. It is evident from the figure 4 that the bearing capacity increases with increase in the skirt thickness. The bearing capacity was improved by 55.50% (6.90 kN/m² to 10.73 kN/m²) for a skirt thickness of 1 mm, 125.60% (6.90 kN/m² to 15.56 kN/m²) for 3 mm skirt thickness and 238.90% (6.90 kN/m² to 23.38 kN/m²) for 5 mm skirt thickness for a constant skirt depth of 40 mm. It is due to increased thickness of skirts increase rigidity of skirt and hence higher resistance to lateral pressure.

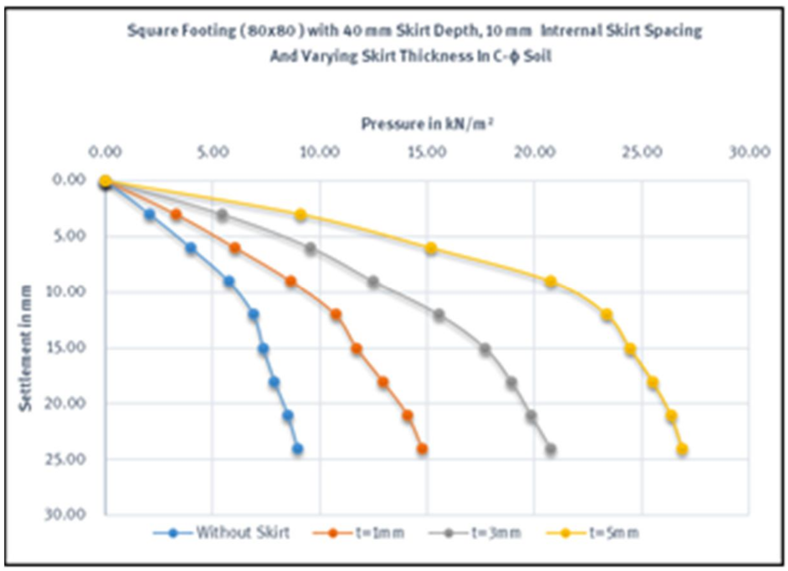

Figure 4: Pressure - Settlement Curves for a Square Footing

Similar to Figure 4, pressure-settlement curves of square footing for other parameters such as, thickness of skirt, depth of skirt, spacing between internal skirts are plotted and percentage of improvement in bearing capacity is shown in Table 3. Graphical representation of these data are shown in Figure 5 to Figure 8.

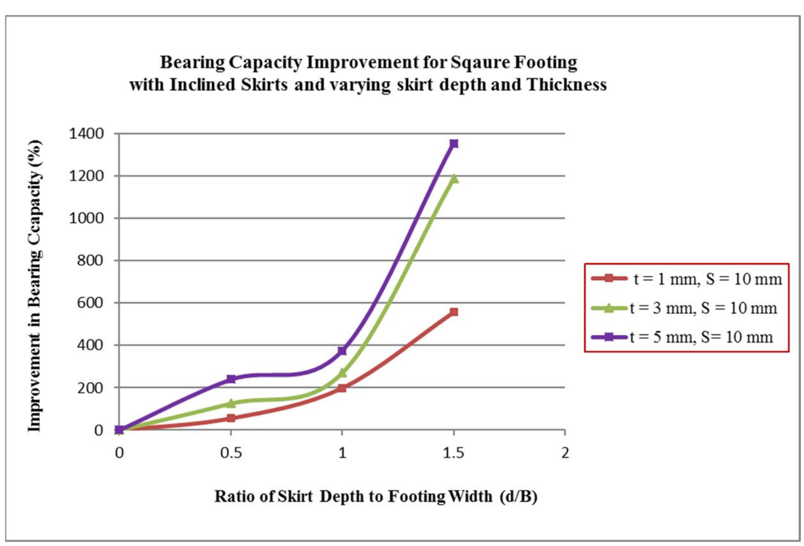

Fig 5: Bearing Capacity improvement in Square Footing with inclined internal skirt and Varying skirt depth and thickness (S=10 mm)

Figure 5 shows that increase in skirt depth increses bearing capacity several folds. For example, incresae in skirt depth from 40 mm to 80 mm (d/B=0.5 to d/B = 1) for 3 mm skirt thickness, bearing capacity increased from 126% to 270%. The similar trend is observed in thickness of skirt as shown in Figure 6. Increase in skirt thickness from 1 mm to 5mm for d/B ratio of 1, incresaes bearing capacity from 128% to 206%. Increase in spacing between internal inclined skirts, reduce bearing capacity as shown in Figure 7 and Figure 8. Increase in spacing of internal skirts from 10 mm to 30 mm for 80 mm skirt depth and 5 mm skirt thickness, reduce the bearing capacity from 375.4% to 255.5%.
The trend is consistent for all other sizes of skirt as observed in Table 3.

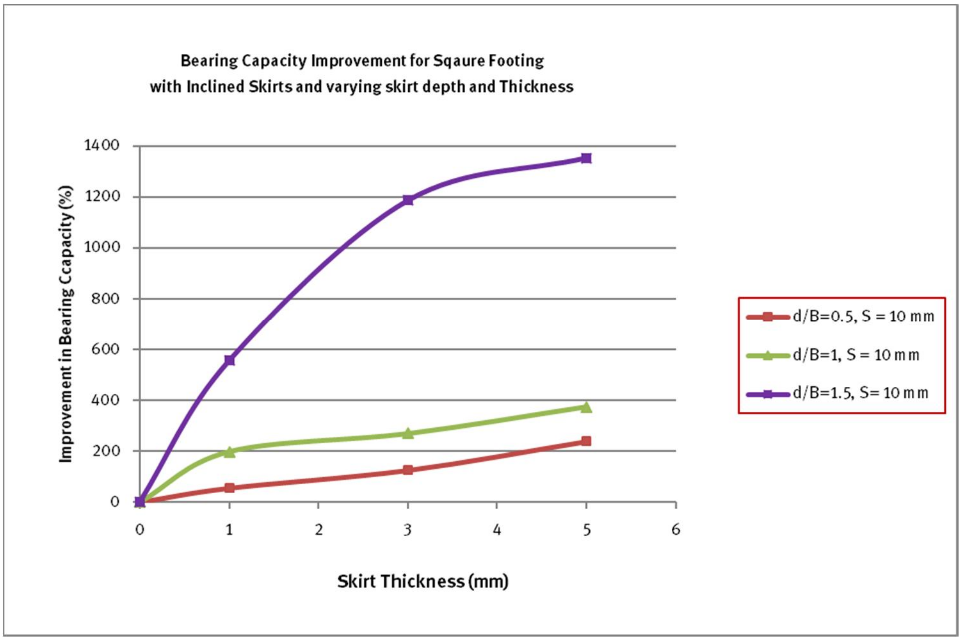

Fig 6: Bearing Capacity improvement in Square Footing with inclined internal skirt and varying skirt depth and thickness (S=10 mm)

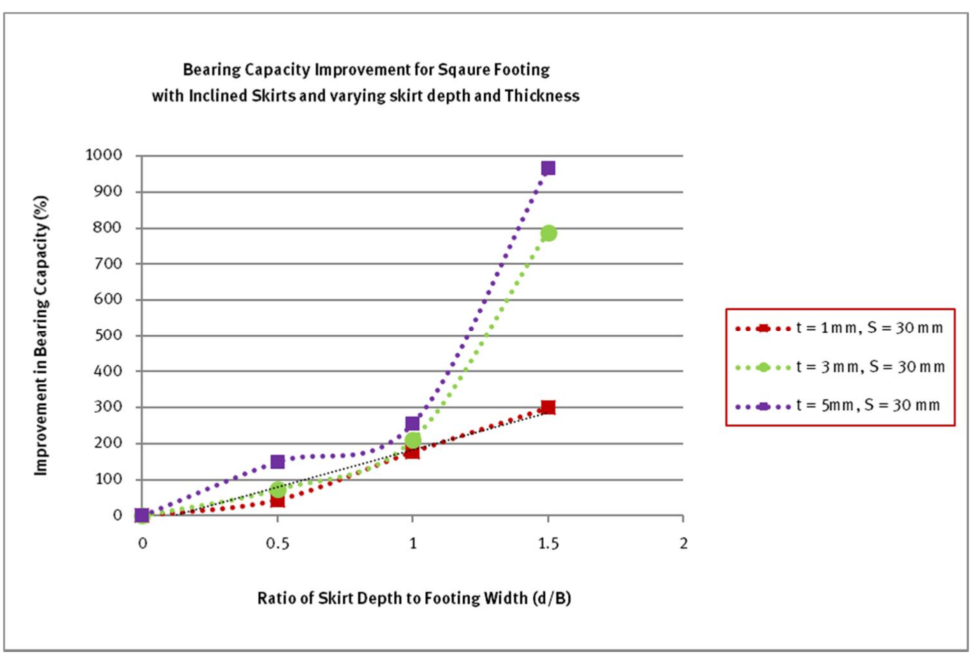

Fig 7: Bearing Capacity improvement in Square Footing with inclined internal skirt And Varying skirt depth and thickness (S=30 mm)

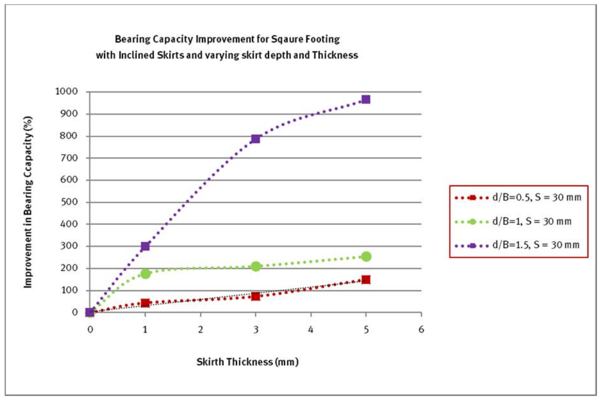

Fig 8: Bearing Capacity improvement in Square Footing with inclined internal skirt and Varying skirt depth and thickness (S=30 mm)

Table 3: Bearing Capacity Improvement in Square Footings (80 mm x 80 mm)

Depth of **skirt**	Skirt thickness	Bearing capacity improvement in square footing having 10 mm internal spacing	Bearing capacity improvement in square footing having 30 mm internal spacing
40 mm (d/B=0.5)	t = 1 mm	55.50%	44.40%
	t = 3 mm	125.60%	73.40%
	t = 5 mm	238.90%	150%
80 mm (d/B=1)	t = 1 mm	198.80%	177.70%
	t = 3 mm	269.90%	211%
	t = 5 mm	375.40%	255.50%
120 mm (d/B=1.5)	t = 1 mm	556.40%	299.90%
	t = 3 mm	1188.40%	788.60%
	t = 5 mm	1355%	966.40%

The same type of work is carried with varying spacing of skirt, thickness and depth of skirt for Rectangle footing as shown inn Table 4.

Table 4: Bearing Capacity Improvement in Rectangular Footings (64 mm x 100 mm)

Depth of **skirt**	Skirt thickness	Bearing capacity improvement in square footing having 10 mm internal spacing	Bearing capacity improvement in square footing having 30 mm internal spacing
32 mm (d/B=0.5)	t = 1 mm	46.80%	28.50%
	t = 3 mm	82.60%	53.30%
	t = 5 mm	126.70%	69.80%
64 mm (d/B=1)	t = 1 mm	162.50%	112%
	t = 3 mm	193.80%	151%
	t = 5 mm	267.20%	230%
96 mm (d/B=1.5)	t = 1 mm	369%	216.60%
	t = 3 mm	642%	627.90%
	t = 5 mm	950.90%	793%

The behavior of rectangular shaped skirted footing showed similar trend as in the case of square footing. Increase in spacing of internal skirts from 10 mm to 30 mm reduces bearing capacity significantly. For example, 5 mm thick skirt with 32 mm skirt depth showed reduction in bearing capacity from 126.7% to 69.8% as shown in Table 4. This trend confirms that smaller cells are more effective in confining foundation soil.

Increase in skirt depth beyond shear failure zone also increased bearing capacity. Rectangular footing with 3 mm thick skirt and 10 mm internal spacing of skirts, increase skirt depth from 32 mm to 64 mm increased the bearing capacity from 82.6% to 193.8% as shown in Table 4.

Increase in skirt thickness increase the rigidity of skirts. Rectangular footing with 32 mm depth skirt and 10 mm internal spacing of skirts, increase in skirt thickness from 1 mm to 5 mm increased the bearing capacity from 46.8% to 126.7% as shown in Table 4.

CONCLUSION

Results showed that spacing of internal inclined skirts has significant effect on the bearing capacity for both square and rectangular footings on c-Φ soil. Increase in spacing of internal skirts from 10 mm to 30 mm for square footing with 5 mm thick skirt with 40 mm skirt depth showed reduction in bearing capacity from 238% to 150%. Increase in spacing of internal skirts from 10 mm to 30 mm for rectangle footing with 5 mm thick skirt with 32 mm skirt depth showed reduction in bearing capacity from 126% to 69%. This trend confirms that smaller cells are more effective in confining foundation soil.

Pressure-settlement curves showed improvement in bearing capacity with the increase in skirt depth for both square and rectangle footings. The maximum effect on bearing capacity value was found to be for a skirt depth of 1.5 B. For example, in square footing, for a 5 mm thick skirt, 40 mm skirt depth and 10 mm internal skirt spacing, increase in bearing capacity observed was 238.9%. If the depth of skirt is increased to 120 mm keeping all other parameters constant, the bearing capacity was increased by 1355%. Similar trend was observed in rectangular footing. This phenamemnon could be attributed tot he fact that as the depth of inclined skirt increases, the compression of the soil under inclined skirts will also increases.

Increase in skirt thickness for square footing increased the bearing capacity. For a skirt thickness of 5 mm, the bearing capacity was found to be higher when compared to 1 mm and 3 mm thick skirts. For square footing, the highest improvement in bearing capacity was 1355% for skirt depth of 120 mm with skirt thickness of 5 mm and internal skirts spacing of 10 mm. For rectangular footing, the largest improvement in bearing capacity was 950.9% for skirt depth of 96 mm with skirt thickness of 5 mm and internal skirts spacing of 10 mm. This trend is attributed to increased thickness of skirts increase end bearing capacity at the tip of the skirts. Also increase in thickness of skirt increases rigidity of skirt and hence higher resistance to lateral pressure.

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