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Behaviour of Skirted Strip Footing Subjected to Lateral Load

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Abstract*: The knowledge of performance of skirted strip footing on slope subjected to lateral load may be useful for industrial machines foundation, footing of retaining walls, bridge abutment on steep river slope and portal framed buildings are not only subjected to vertical or inclined loads but also to moments. Moments on the foundation base are mainly caused by lateral forces acting on the structure. Sometimes footings may be placed on slopes due to the unavailability of land, so it is necessary to use the land on slope for various construction works and architectural needs. Hence, it necessitates to understand the performance of skirted strip footing on slopes subjected to lateral loading conditions. In the present work, static lateral load tests were performed to study the performance of equal and unequal skirted strip footings. This is an extensive program of work, done on equal skirted strip footing having depth to the width of footing ratio (d/B) equal to 0.0, 0.25, 0.5, 1.0 which is published earlier. In this paper, for equal skirted strip footing two depth to the width of footing ratio (d/B) such as 1.5 and 2.0 is an additional work. So in this paper different parameters studied were effect of the ratio of depth of skirt to width of footing, the ratio of distance of footing from crest to the width of footing. Tests were performed for unequal skirted strip footing with longer skirt at the load edge and rear edge, to know the better placement location for longer skirt in unequal type of footing. From the result of experimental work, it was found that as the depth of skirt increases and as the distance of the crest to the width of footing increases, the ultimate lateral load carrying capacity of footing increases significantly.

***Keywords*: Strip footing, Equal skirt, Unequal skirt, Sand slope, Lateral load, Ultimate lateral load capacity**

I. INTRODUCTION

The Geotechnical engineers are in search of an alternative method for improving the bearing capacity and reducing the settlement of footing resting on soil. Though a variety of methods of soil stabilization are known and well-developed, they can be prohibitively expensive and restricted by the site conditions. In some situations they are difficult to apply to existing foundations. In this case, structural skirts hold good as an alternative method of improving the bearing capacity and reducing the settlement of footing resting on soil. Structural skirts have been used for a considerable period to increase the effective depth of the foundations in marine and other situations where water scour is a major problem. Skirts provided with foundations, form an enclosure in which soil is strictly confined and acts as a soil plug to transfer super-structure load to soil. Skirted foundations have been extensively used for offshore structures like wind turbine due to easy installation compared to deep foundation. Shallow skirted foundations have been used in structures for oil, gas industry. An internal arrangement of skirts or stiffeners is provided to increase the stiffness of the foundation system. Skirt foundations have a wide variety of functions such as control of settlement during service life, less impact to environments during operation at installation site. Skirted foundations are used to satisfy bearing capacity requirement, and to minimize the embedment depth and dimensions of the foundation. Vertical loading due to the self -weight of installation (e.g. Jacket structure, wind turbine) is improved as soft surface soils are confined within the skirt and the foundation loads are transferred down to harder underlying layers; lateral load capacity is improved by the skirt resisting lateral sliding. The present study aims at exploring behaviour of skirted strip footing subjected to lateral load under different parameters on sand slope.

II. LITERATURE REVIEW

A review of previous studies on skirted foundations in terms of behaviour, performance, analysis approaches by numerical and analytical study is carried out. The objective of this review is to identify the contributions established by researchers on skirted foundations and identify the gap in research for the present study.

Dhatrak et. al. (2017) studied “Performance of equal skirted strip footing on slope subjected to lateral load” using experimental investigation. Parameter studied were the effect of crest to the width of footing and depth to the width of footing. From the study it was concluded that as the depth to the width of footing ratio and crest to the width of footing ratio increases the lateral load carrying capacity increases.

Saleh et al. (2010) studied “Performance of Skirted Strip Footing Subjected to Eccentric Inclined Load” using PLAXIS version 7.1. Parameters selected for study were various load inclination angles, load eccentricities and skirt length. Study concluded that inserting a skirt under the footing edge reduces the lateral movement of soil.

Amr Z El Wakil carried experimental investigation to determine horizontal capacity of skirted shallow footings on sand. It was concluded that as the length of skirt to footing diameter ratio increased up to 1.5, the ability of skirted footings of resisting lateral load increased.

Al-Aghbari (2007) studied the settlement of shallow circular foundations with structural skirts resting on sand. A series of tests were conducted to study the settlements of a circular footing with and without structural skirts with varying depth of skirts. Test results indicated that use of structural skirts reduced the settlement of footings and modified the stress-displacement behaviour of the footing. A settlement Reduction Factor (SRF) took into account the influence of various parameters that affect settlements. Results show that the use of structural skirts could produce enhanced settlement reduction in the range of 0.1 to 1.0 depending on stress applied and skirt depth

Deepak Kumar P. et al. (2014) studied experimentally the behaviour of circular footing resting on skirted loose sand. The footing of four different diameters (40 mm, 60 mm, 80 mm and 100 mm) were used on loose sand having embedded skirt inside. The skirts of uPVC pipe of different diameter (46 mm, 59 mm, 71 mm and 85 mm) was inserted in the sand centrally in a model test tank filled with sand. . It was concluded that the skirt restricts the lateral displacement of sand leading to a significant improvement in the response of the footing. Increasing the diameter of footing with constant diameter of skirt the load carrying capacity increases.

Ashraf Kamal Nazir, Wasim R. Azzam (2010) conducted experimental analysis to improve B.C on soft clay with and without skirts. There was an improvement in the load bearing capacity using both partially replaced sand piles with and without confinement.

Pusadkar and Bhatkar (2013) carried out investigations to study “Behaviour of raft foundation with inclined skirt” using PLAXIS 2D. On the basis of study carried out, it was concluded that there was increase in B.C with decrease in settlement for two sided skirted raft.

Pusadkar and Dhygude (2016) carried out investigation to study “Performance of Vertical Skirted Strip Footing on Slope Using PLAXIS 2D”. and from the study it was concluded that skirted strip foundation had a significant effect in improving the bearing capacity with increase in skirt depth. The skirted strip footing at crest shows significant improvement in bearing capacity.

Thakare and Shukla (2016) carried out investigation to study “Performance of Rectangular skirted footing resting on Sand bed subjected to Lateral load” and from the experimental investigation it was concluded that increase in the number of skirts and depth of skirt increased the ultimate lateral load carrying capacity of footings. Load carrying capacity of footing increases with increase in inclination of load in plan.

III. METHODOLOGY

The main objective of experimental investigation in the present study was to study the response of equal and unequal skirted strip footing resting on sand slope subjected to lateral load.

A. Test sand

For the model tests, cohesion-less, dry, clean and washed Kanhan sand was used as the foundation material. This sand is available in Nagpur region of Vidharabha, Maharashtra. The geotechnical and engineering properties of the sand were determined as per relevant I.S codes and are shown in Table I.

TABLE I

Properties Of Sand Used In Experimental Investigation

Sr. No.	Properties	Values
1	Specific gravity	2.65
2.	γ_{max} (kN/m^3)	17.69
3.	γ_{min} (kN/m^3)	17.19
4.	Angle of internal friction (φ°)	29°
5.	Cohesion (c) (kN/m^2)	0
6.	Coefficient of uniformity (Cu)	2.3125
7.	Coefficient of curvature (Cc)	1.0347
8.	IS classification	SP (Medium Sand)

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B. Model Footing

The model footings of skirted strip footings were fabricated by using mild steel plates having dimensions 420 mm x 80 mm and 10 mm thickness. Footing were provided with skirts welded along their periphery. The skirts were made of M.S plates of thickness 5 mm. The depth of the skirts were corresponding to different width ratio of footing as detailed in the program. The photographs of equal skirted strip footing with skirts used for experimental investigation are shown in the Fig 1 (a) to (d).

(a) (b) (c) (d)

Fig.1: Model skirted footing used in experimental investigation. (a) Front View (b) Top View (c) Equal skirted Strip Footing (d) unequal skirted strip footing

C. Test Setup

The test tank was made of 3 mm thick M.S. sheets having internal dimensions 1050 mm × 450 mm in plan and 600 mm high. Sufficient horizontal and vertical bracings were provided to prevent it from bulging. One of the side of the tank was made of thick glass, to observe the mode of failure of footing. The loading frame used for applying lateral loads on the skirted strip footing consisted of a rectangular horizontal base frame of channel section. The pulley arrangements was fabricated such that the lateral loads could be applied in forward direction (toward sloping ground).The static lateral loads were applied to the footing by means of dead weights placed on a loading hanger connected to a non-extensible steel rope, passing over the pulleys. The photographic view of test setup is shown in Fig. 2

Fig. 2: Test Set-up for Experimental Work

D. Test Procedure

A series of tests were conducted in steel tank 1.05 m x 0.45 m and 0.60 m in depth. The skirted strip footing was then placed on the top of sand slope and pushed into the sand by displacement method till the skirts were inserted in the sand bed for its full height. After skirts were pushed in the sand slope, surface was levelled using sharpened straight steel plate. After driving the footing, it was left undisturbed for 12 hours. One dial gauges was placed against the brace welded to the footing to measure the lateral displacement, and two dial gauges supported on the top surface to measure vertical displacement and rotation of footing. The static lateral load test was conducted on footing as per the procedure recommended by Amr Z El Wakil on skirted footing resting on sand bed for lateral load test. The static lateral loads were applied on the footing using frictionless pulley and a rope connected to the footing at one end and to the hanger at the other end, in increments by adding dead weights through the loading arrangement. Standard weights was used for loading. Each increment was kept constant for ½ hour. The load was applied laterally at 10 mm above the formed sand surface. The lateral displacement, vertical displacement and rotation of the skirted footing was measured within an accuracy of 0.01 mm using three dial gauges. The load were applied till failure of footing which was indicated by sudden

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up-liftment of footing from the sand bed slope. Different load displacement curves versus lateral load were plotted for the tests. The detail of test program is shown in Table II and III.

TABLE II
Details Constant Parameters

Sr. No.	Parameters	Details of Parameters
01	Slope angle (β)	1:1.5
02	Placement of footing	Surface
03	Type of load	Lateral

TABLE III
Details Of Varying Parameters

Type of footing: STRIP FOOTING		
Sr. No	Parameters	Details of parameters
01	Type of footing	a) Both Side Equal Skirt b) Unequal skirt
02	The ratio of distance of footing from crest to the width of footing (b/B)	1.0, 2.0, 3.0
03	The ratio of depth of skirt to width of footing (d/B) for equal skirted strip footing	0.0, 1.5, 2
04	For unequal skirted strip footing Longer depth of skirt to the width of footing (d_l/B) Shorter depth of skirt to the width of footing (d_s/B)	1.0, 2.0 0.5,0.75,1.0, 1.5

IV. RESULTS AND DISCUSSION

The lateral load displacement and vertical displacement behaviour of skirted strip footings were determined by conducting model tests. Rotation of footing edge was also calculated as the difference between vertical displacement at load edge and rear edge divided by distance between two edges of footing. The ultimate lateral load was determined from the load displacement curve. The results for equal skirted strip footings are as shown in fig. 3 to 5 and the results obtained from experimental work are given in table IV.

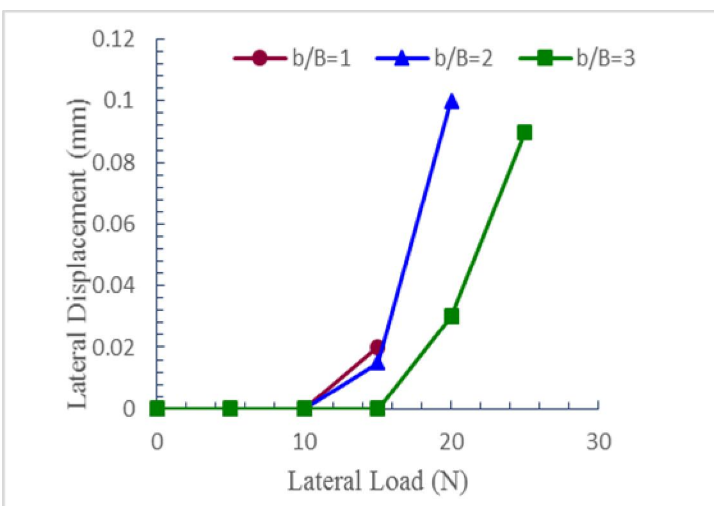

Fig. 3: Lateral Load versus Displacement Curves for Different b/B Ratios (for d/B=0.0)

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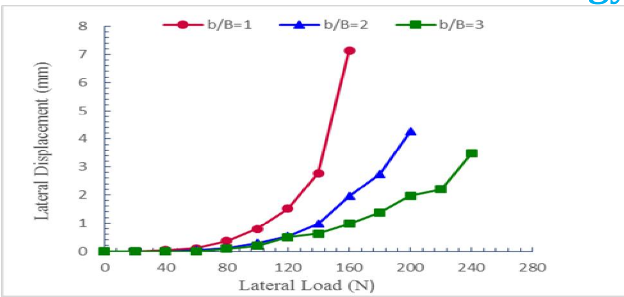
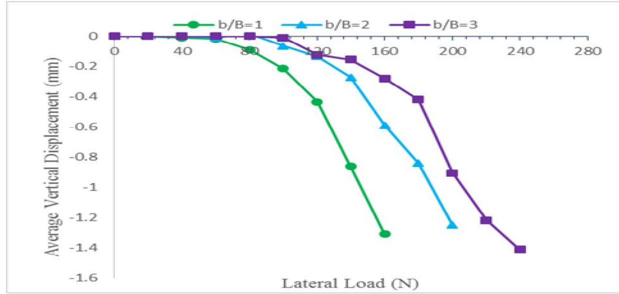


(a)



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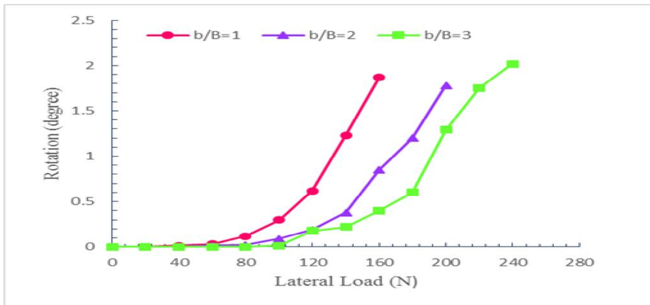
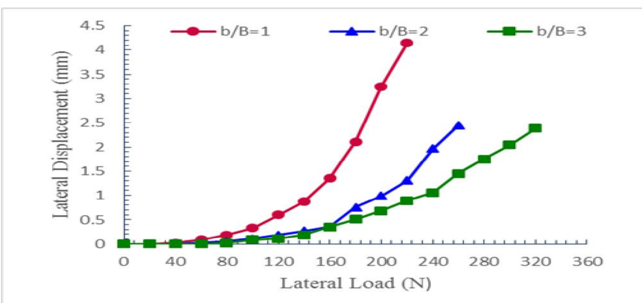
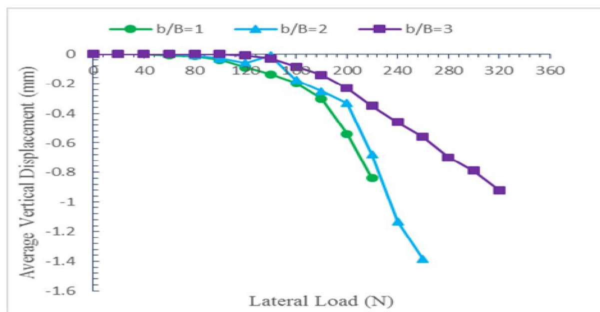


(c)

Fig. 4: Lateral Load versus Displacement Curves for Different b/B Ratios (for d/B= 1.5) (a) Lateral Displacement (b) Avg. Vertical Displacement (c) Rotation



(a)



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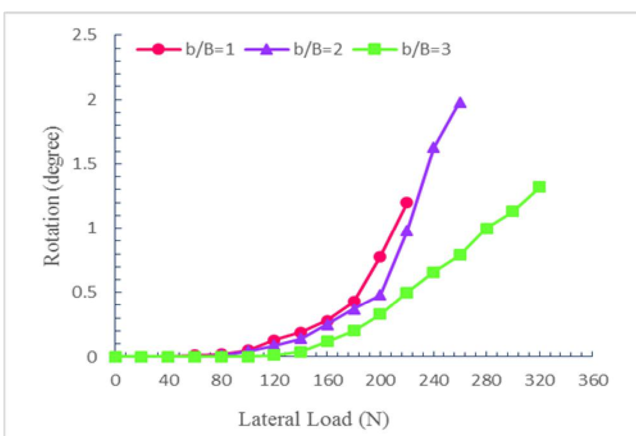

(c)

Fig. 5: Lateral Load versus Displacement Curves for Different b/B Ratios (for d/B= 2.0) (a) Lateral Displacement (b) Avg. Vertical Displacement (c) Rotation

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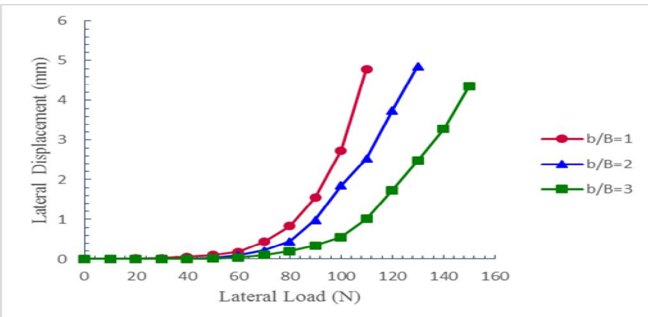
Table IV

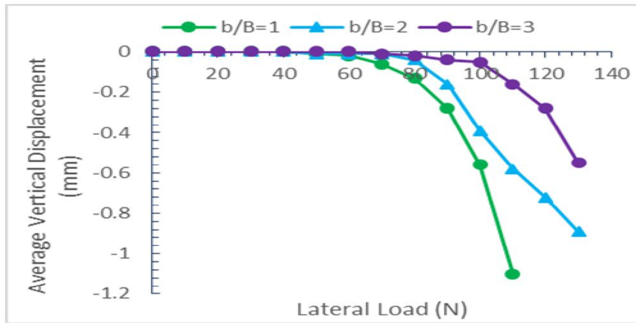
Ultimate Lateral Load Capacities of Equal Skirted Strip Footing

Sr. No.	Depth of skirt to the width of footing ratio (d/B)	Ultimate Lateral Load Capacity of Equal Skirted Strip Footing for different depth to the width of footing ratios (b/B) (N)		
		1	2	3
1.	0.0	20	25	30
2.	1.5	180	220	265
3.	2.0	240	280	340

The result of unequal skirted strip footing when longer skirt was at rear edge are as shown in fig. 6 and the results obtained from experimental work are given in table V.



(a)



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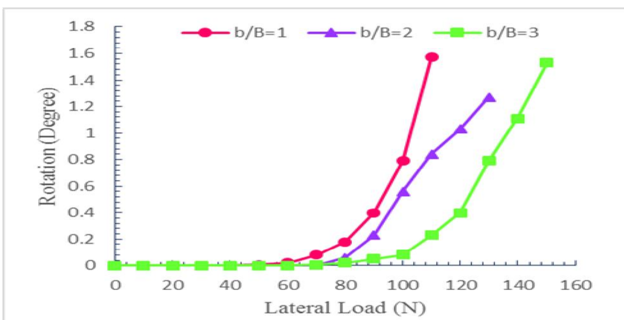


(c)

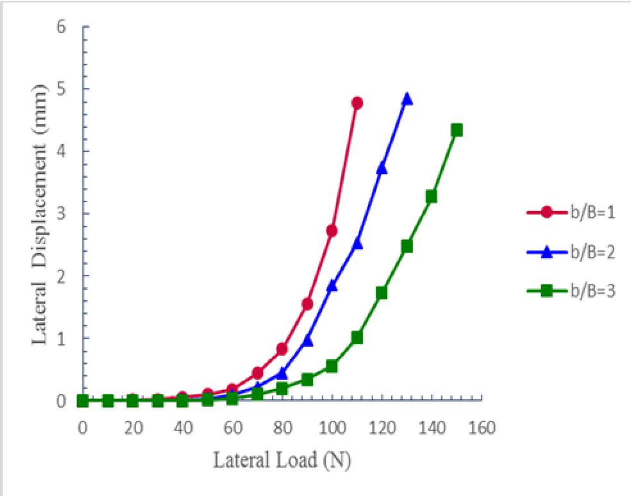
Fig. 6: Lateral Load versus Displacement Curves for Different b/B Ratios for $d_l/B = 1$ and $d_s/B = 0.5$ (a) Lateral Displacement (b) Avg. Vertical Displacement (c) Rotation

TABLE V

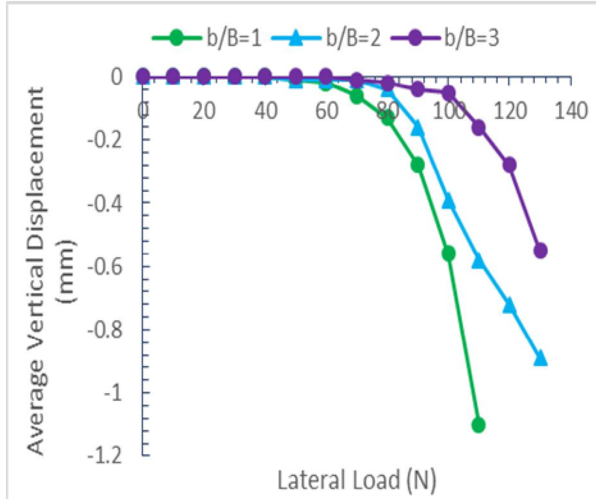
Ultimate lateral load capacities of unequal skirted strip footing with longer skirt at rear edge

Sr. No.	Depth of longer skirt to the width of footing ratio (d_l/B)	Depth of shorter skirt to the width of footing ratio (d_s/B)	Ultimate Lateral Load Capacity of Unequal Skirted Strip Footing for different depth to the width of footing ratios (b/B) (N)		
			1	2	3
1.	1	0.5	120	140	155
2.	1	0.75	125	150	165
3.	2	1	180	185	215
4.	2	1.5	190	220	240

The result of unequal skirted strip footing when longer skirt was at load edge are as shown in fig. 7 and the results obtained from experimental work are given in table VI.



(a)



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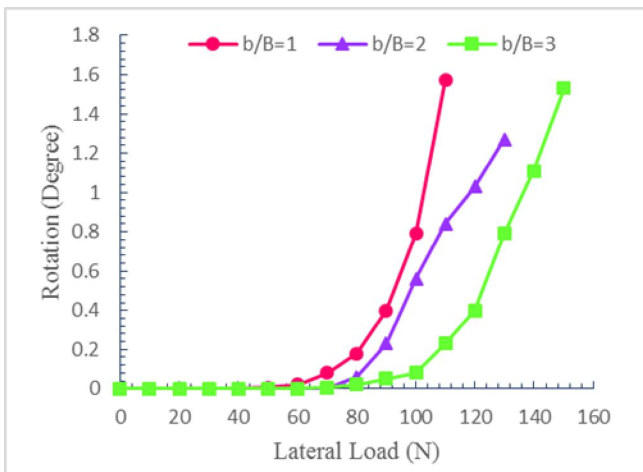

(c)

Fig. 7: Lateral Load versus Displacement Curves for Different b/B Ratios for $d_s/B = 0.5$ and $d_l/B = 1$ (a) Lateral Displacement (b) Avg. Vertical Displacement (c) Rotation

TABLE VI

Ultimate lateral load capacities of unequal skirted strip footing with longer skirt at load edge

Sr. No.	Depth of shorter skirt to the width of footing ratio (d_s/B)	Depth of longer skirt to the width of footing ratio (d_l/B)	Ultimate Lateral Load Capacity of Unequal Skirted Strip Footing (b/B) (N)		
			1	2	3
1.	0.5	1	95	115	130
2.	0.75	1	115	130	155
3.	1	2	150	170	205
4.	1.5	2	165	185	225

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A. Effect of Location of Skirted Strip Footing from Crest for equal skirted footings

Effect of location of equal skirted strip footing was studied by providing skirted strip footing at different crest distances. The crest to the width of footing ratio *b/B* was varied as 1, 2, and 3. Figure 8 shows ultimate lateral load capacity of footing having different *d/B* ratios for various crest distances.

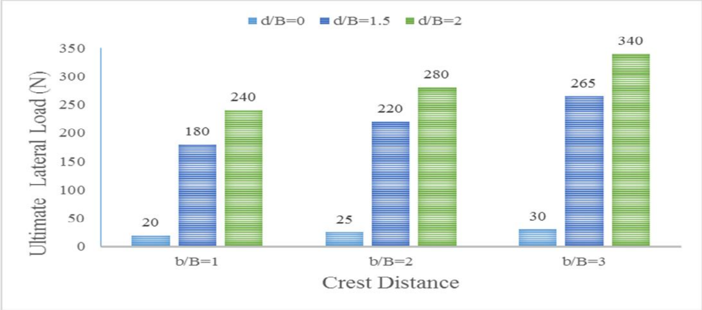

Fig. 8: Ultimate Lateral Load Capacities of Equal Skirted Strip Footing for Various Crest Distances

From the Figures 8, it is observed that the lateral load carrying capacity of equal skirted strip footing increases rapidly with increase in crest distance. The increase of lateral load carrying capacity may be due to the increase in confinement which was provided by the surrounding soil.

B. Effect of Location of Skirted Strip Footing from Crest for unequal skirted strip footing

Effect of location of unequal skirted strip footing was studied by providing skirted strip footing at different crest distances. The crest to the width of footing ratio *b/B* was varied as 1, 2, and 3. Figure 9 shows ultimate lateral load capacity of footing for various crest distances for unequal skirted strip footing having different d_l/B and d_s/B ratios.

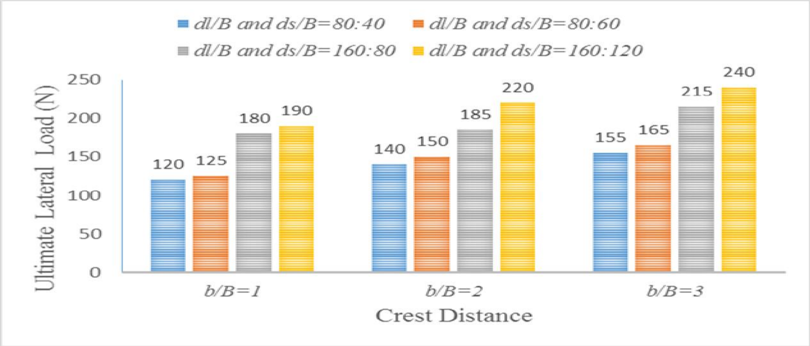

Figure 9: Ultimate Lateral Load capacities of Unequal Skirted Strip Footing for Various Crest Distances with Longer Skirt at Rear Edge

Figure 10 shows ultimate lateral load capacity of footing for various crest distances for unequal skirted strip footing having different d_s/B and d_l/B ratios.

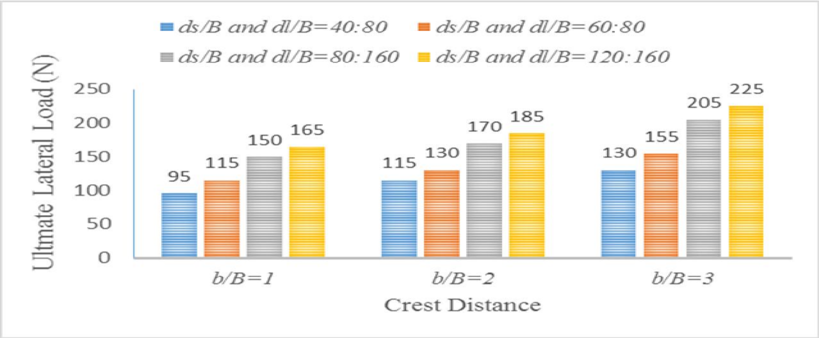

Fig. 10: Ultimate Lateral Load Capacities of Unequal Skirted Strip Footing for Various Crest Distances with Longer Skirt at Load Edge

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From the Figure 9 and 10, it is observed that the lateral load carrying capacity of skirted strip footing increases rapidly with increase in crest distance. The increase in lateral load carrying capacity may be due to the increase in confinement which was provided by the surrounding soil.

C. *Effect of Depth of Skirt*

Effect of depth of skirt was explored by varying d_l/B and d_s/B ratios of unequal skirted strip footing. Longer skirt depth to the width of footing ratios (d_l/B) were 1, 2 and shorter skirt depth to the width of footing ratios (d_s/B) were 0.5, 0.75, and 1.5. Figure 11 shows variation of ultimate lateral load capacity with respect to d_l/B and d_s/B ratio with longer skirt at rear edge.

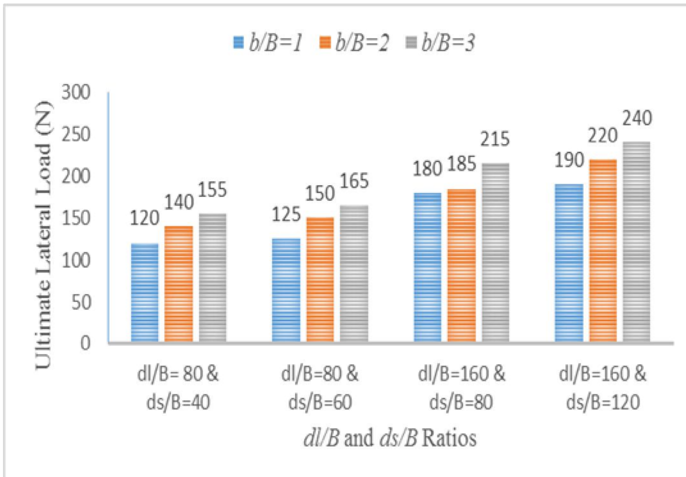

Fig. 11: Ultimate Lateral Load Capacities of Unequal Skirted Strip Footing for Various d_l/B and d_s/B Ratios

Figure 12 shows variation of ultimate lateral load capacity with respect to d_s/B and d_l/B ratio with longer skirt at load edge.

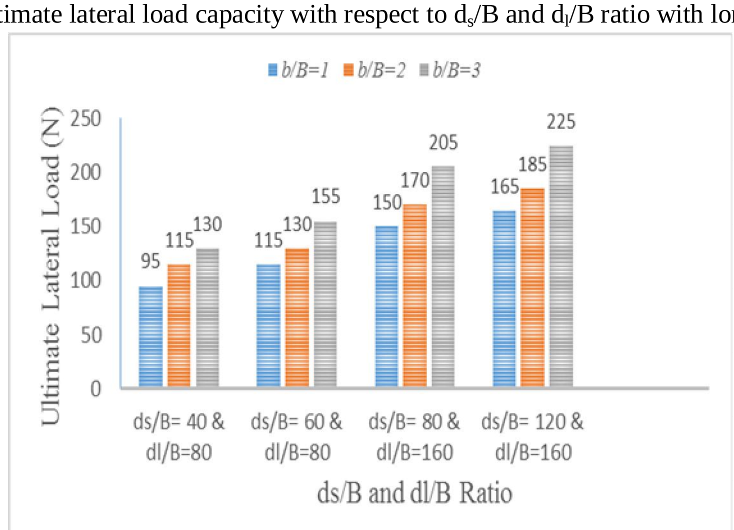

Fig.12: Ultimate Lateral Load capacities of Unequal Skirted Strip Footing for Various d_s/B and d_l/B Ratios

From Figure 11 and Figure 12, it is observed that the ultimate lateral load carrying capacity of skirted strip footing increases rapidly with increase of skirt depth to width of footing ratio. The increase in ultimate lateral load carrying capacity may be due to the increase in confinement which was provided by the surrounding soil, and with increase of skirt ratio may be due to the contribution of larger surface area for resisting lateral load.

D. *Effect of Location of Longer Skirt with respect to loading edge*

The effect of location of longer skirts with respect to loading edge was studied by performing tests with longer skirt at rear edge and load edge side. Table VII shows ultimate lateral load for each d_l/B and d_s/B ratio at various b/B ratio.

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TABLE VII

Ultimate lateral load capacities at different depth of skirt to the width of footing ratio

b/B	Ultimate lateral load capacity for different d/B ratios (N)							
	$d_l/B=1$ & $d_s/B=0.5$		$d_l/B=1$ & $d_s/B=0.75$		$d_l/B=2$ & $d_s/B=1$		$d_l/B=2$ & $d_s/B=1.5$	
	Longer skirt at rear edge	Shorter skirt at load edge	Longer skirt at rear edge	Shorter skirt at load edge	Longer skirt at rear edge	Shorter skirt at load edge	Longer skirt at rear edge	Shorter skirt at load edge
1	120	95	125	115	178	155	192	165
2	145	115	150	130	184	170	210	185
3	155	135	167	155	215	205	238	225

Figure 13 shows the comparison of results for depth of longer skirt to the width of footing ratio (d_l/B) equal to 1 and depth of shorter skirt to the width of footing ratio (d_s/B) equal to 0.5.

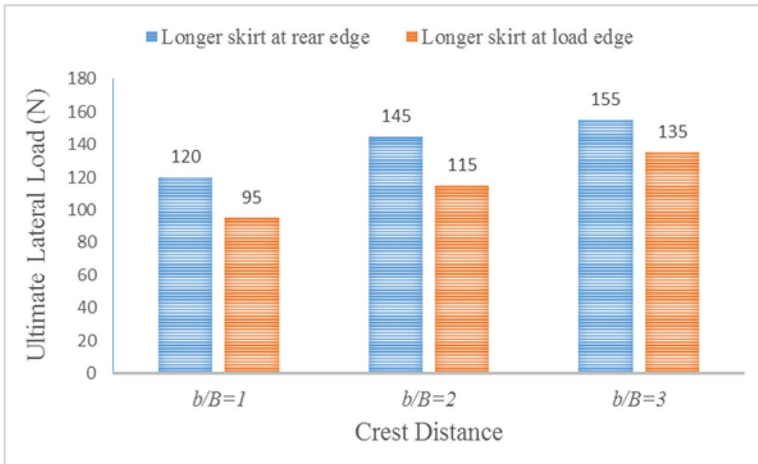

Fig. 13: Ultimate Lateral Load Capacities of Unequal Skirted Strip Footing with Larger Skirt at Different Location (d_l/B= 1 & d_s/B=0.5)

Figure 14 shows the result for depth of longer skirt to the width of footing ratio (d_l/B) equal to 1 and depth of shorter skirt to the width of footing ratio (d_s/B) equal to 0.75.

Fig. 14: Ultimate Lateral Load Capacities of Unequal Skirted Strip Footing with Larger Skirt at Different Location (d_l/B= 1 & d_s/B=0.75)

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Figure 15 shows the result for depth of longer skirt to the width of footing ratio (d_l/B) equal to 2 and depth of shorter skirt to the width of footing ratio (d_s/B) equal to 1.

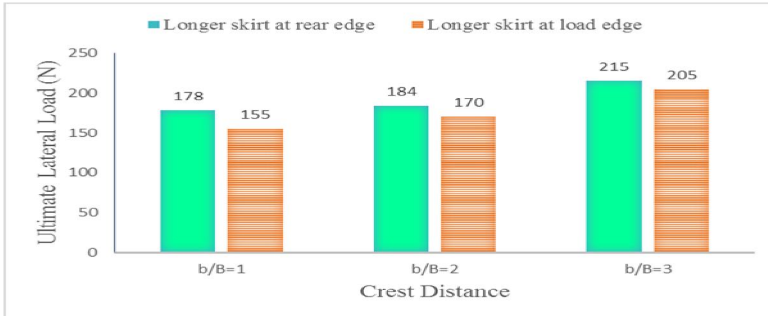

Figure 15: Ultimate Lateral Load Capacities of Unequal Skirted Strip Footing with Larger Skirt at Different Location (d_l/B= 2 & d_s/B=1)

Figure 16 shows the result for depth of longer skirt to the width of footing ratio (d_l/B) equal to 2 and depth of shorter skirt to the width of footing ratio (d_s/B) equal to 1.5.

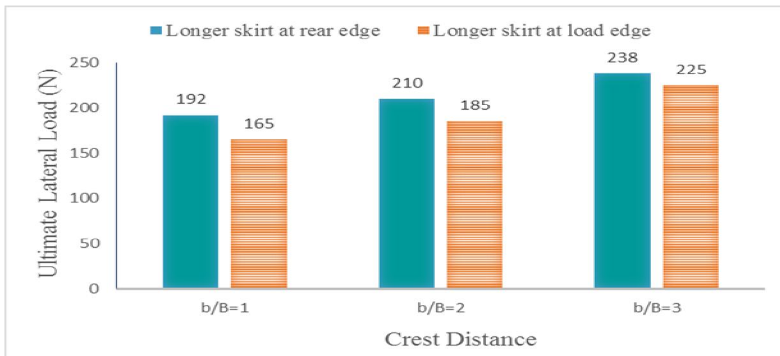

Figure 16: Ultimate Lateral Load Capacities of Unequal Skirted Strip Footing with Larger Skirt at Different Location (d_l/B= 2 & d_s/B=1.5)

From above figures 13 to 16, it is concluded that, lateral load carrying capacity of skirted strip footing was higher when longer skirt was at rear edge than at the load edge. This may be due to the fact that more passive resistance might have developed when skirt was provided at rear edge. Hence at the time of construction, the longer skirt at rear edge (opposite to the direction of load) can be provided.

V. CONCLUSIONS

From the experimental study, the following conclusions are drawn.

A. The lateral load capacity of skirted strip footing is much higher, as higher as 11 times, than that of strip footing.

B. The lateral load capacity of equal skirted strip footing increases with increase in the depth of structural skirt; maximum up to 250%.

C. The lateral load capacity of unequal skirted strip footing increases with increase in the depth of structural skirt; maximum up to 50%.

D. The lateral load capacity of equal skirted strip footing increases with increase in crest to the width of footing ratio; maximum up to 50 %.

E. The lateral load capacity of unequal skirted strip footing increases with increase in crest to the width of footing ratio; maximum up to 30 %.

F. For unequal skirted strip footing, with longer skirt at rear edge has more lateral load capacity; maximum up to 26% and less lateral displacement and rotation as compared to longer skirt provided at load edge.

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