

PERFORMANCE OF UPRIGHT TRIANGULAR SHELL FOOTING ON REINFORCED SAND BED

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Abstract— Shell foundations have been used as an alternative to the conventional shallow foundation. Shell foundation can be generally classified as uncurved, singly-curved and doubly-curved. In this paper, results of experimental investigation of uncurved type upright triangular shell footing on unreinforced and reinforced sand bed are presented. Model footing of upright triangular shell footing was made of mild steel. The results were plotted as load settlement curve and ultimate bearing capacity were determined for both reinforced and unreinforced sand bed condition. The results indicate that upright shell footing provides higher bearing capacity as compared with flat strip footing with similar condition.

Keywords— Upright Shell Footing, Peak Angle, Reinforcement.

I. INTRODUCTION

Shell foundations are composed of one or more curved slabs or folded plates whose relative thickness is inferior to its overall planar dimensions. The shell sub-structures such as footings, anchors, panelling, and piles are easily transported to site. Shell structures provides potentially significant time and cost saving implications for a project. To obtain maximum structural performance, shell foundations have been prevalently designed in arched, circular, triangular, conical, cylindrical, spherical, pyramidal, square and strip shapes. Shells are thin-wall structures requiring reduced quantities of concrete material in their construction. A shell foundation is perhaps the anti derivative of the plain form and is typically made of reinforced concrete material.

II. LITERATURE REVIEW

Adel Hanna *et al.* (1990)¹ presented the results of experimental work on Ultimate Bearing Capacity of Triangular shell strip footing on sand. All model footings had the same width B of 4 in. (10.16 cm), length L of 5 in. (12.7 cm), and the peak angle varied from 60 to 180° (flat footing). Results indicated that, at a certain load level, the smaller the peak angle of the foundation, the higher was the bearing capacity and the lower was the measured settlement.

Dr. Pusadkar (2011)² studied the behavior of triangular shell strip footing on geo-reinforced layered sand. Five mild steel models of triangular shell strip footings were used with peak angle $\theta = 180^\circ$ (flat footing), 150° , 120° , 90° and 60° . The width of test tank was taken 130 mm equal to length of footing to simulate the case of strip footing. Results indicated that the load settlement curve for 60° peak angle footing gave maximum ultimate load than all footings, when geotextile was placed at 25 mm below the footing [depth of geotextile (GD) / Unreinforced depth (UL) = 0.33].

M. Ramesh *et al.* (2015)³ presented the results on Experimental Study on Conical Shell Footing to examine the effect of half shell angle. Conical shell footing with two different angles were designed, casted and studied. Results indicated that, footing with half shell angle 45° took about 82% of theoretical load and that of footing with half shell angle 63.44° took about 79% of the theoretical load.

B.B.K. Huat *et al.* (2007)⁴ analysed numerical and field study on triangular shell footing for low rise building. The performance of triangular shell footings using finite element and field numerical analysis was done by finite element program (LUSAS) in both 2D and 3D. Both the finite element analyses and field tests showed that the inverted triangular shell had better load carrying capacity compared with the 'upright' triangular shell, due to its better contact area.

Remo Rinaldi (2012)⁵ analysed inverted shell foundation performance in soil by using PLAXIS software (FEM analysis). Loading on the footing–soil system was applied at 2 kPa load increments till soil media shear strength failure. Results indicated that, Preliminary FE analysis showed inverted Shell footings had higher bearing capacity than upright shell footing by 4%.

III. METHODOLOGY

In the present experimental investigations, the height of fall was 33 cm and the corresponding relative density was maintained at 40% and corresponding density was 15.56 kN/m^3 . The plate load tests were conducted to determine the load-carrying capacity of footing. The laboratory set-up consisted of a tank, a reaction frame, a model footing, hydraulic jack, proving ring, dial gauges, and woven geotextile as reinforcement. The proving ring of 10 kN capacity

was used for all the tests. Two dial gauges were used to measure settlement. The details of parameters selected for experimental investigation as shown in Table 1. The experimental setup as shown in Fig. 1.

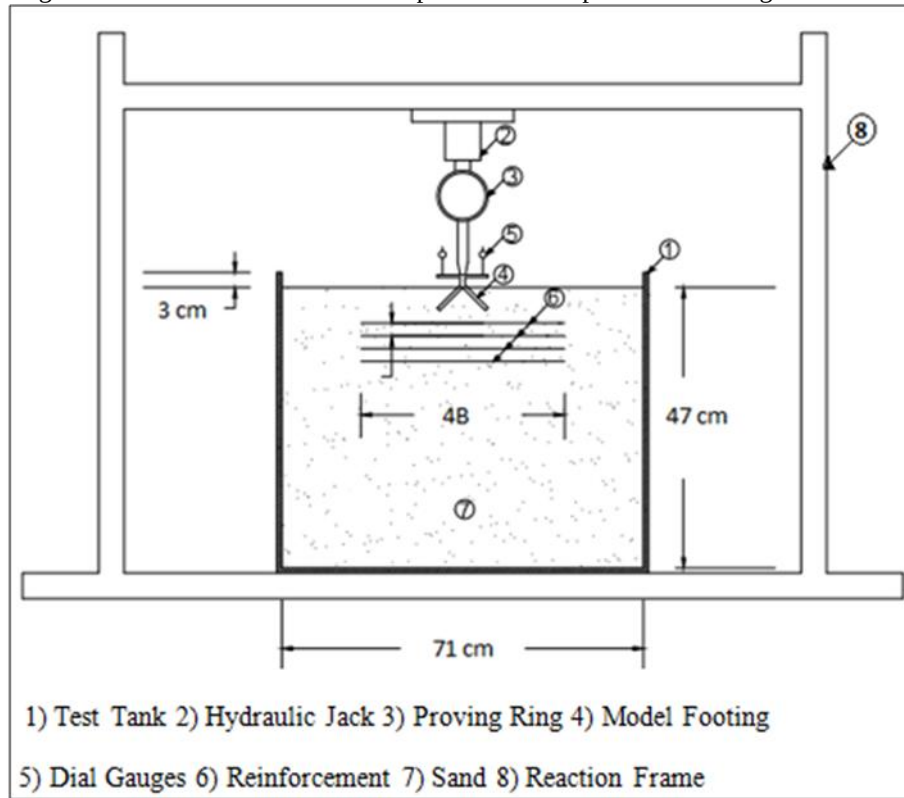


Fig. 1. Experimental setup

Table 1 Details of parameters selected for experimental investigation

Sr. No.	Details of Parameter	Constant Parameter value	Varying Parameter value
1	Length of footing	300 mm	-
2	Width of footing (B)	100 mm	-
3	u/B Ratio of reinforcing layer	$\frac{1}{4}$ B	-
4	h/B Ratio of reinforcing layer	$\frac{1}{4}$ B	-
5	b/B Ratio of reinforcing layer	4B	-
6	Peak angle of shell foundation ($^{\circ}$)	-	30, 45, 60, 75, 90, 110
7	Number of reinforcing layer (N)	-	1, 2, 3, 4
8	Shape of triangular shell footing	Upright	-

Materials

The properties of materials used for experimental investigation are tabulated in Table 2 and 3. The shell footing models used for model plate load test were made up of a mild steel. The length and width of all shell footings were 300 mm x 100 mm and it was kept constant, whereas the peak angle of shell footing was varied from 30 $^{\circ}$, 45 $^{\circ}$, 60 $^{\circ}$, 75 $^{\circ}$, 90 $^{\circ}$, 110 $^{\circ}$ peak angle. Model shell footing as shown in Fig. 2.

Table 2 Properties of Sand used for Experimental Work

Sr. No.	Properties	Values
1	Specific gravity	2.67
2	$\gamma_{\max}$ (kN/m ^{3})	16.74
3	$\gamma_{\min}$ (kN/m ^{3})	14.87
4	Relative Density (%)	40
5	Angle of internal friction(ϕ)	40
6	Cohesion (kN/m ^{2})	5
7	IS classification	SP (Medium Sand)

Table 3 Properties of geo-reinforcement used for Experimental Work

Parameter	Description
Material Geo-textile	100% polypropylene
Thickness	0.3
Tensile Strength	>30 kN
length of fabric	>100 mm
Width of fabric	>3.5 mm
Apparent Opening Size	<0.02 mm
G.S.M.	>190 G.S.M.
Elongation % at designated load	Warp (55 kN/m) <30
	Weft (30 kN/m) <30
Index Puncture Strength	650 N



Fig. 2. Upright Model Shell Footing used for Experimental investigation

IV. EXPERIMENTAL RESULTS

4.1 Load Settlement Behaviour of Strip Footing on Reinforced Sand Bed

Experiments were performed on strip footing subjected to vertical centric loading on reinforced sand bed using woven geotextile. First layer was placed at fixed distance u which was equal to $0.25 B$ below the foundation base and having fixed length equal to $4 B$. Spacing between successive layers of reinforcement was $0.25 B$. The load settlement curves for strip footing corresponding to various number of layers of geotextile are as shown in Fig. 3.

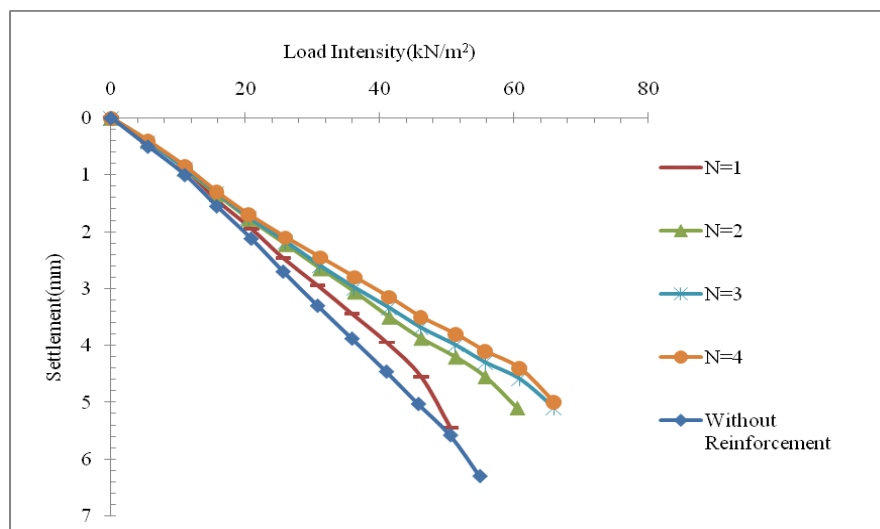


Fig. 3. Load Settlement Curves for Strip Footing Corresponding to Various Number of Layers of Geotextile Reinforcement

From the Fig.3, the ultimate bearing capacity of strip footing on sand bed for various number of layers were determined. These are tabulated in Table 4.

Table 4 UBC of Strip Footing for Different layers of Geotextile Reinforcement

Sr. No.	Number of Layers of Reinforcement	UBC (kN/m ²)
1	Without Reinforced	28.33
2	1	39.33
3	2	51.66
4	3	56.66
5	4	56.66

4.2 Load Settlement Behaviour of Upright Triangular Shell Footing

The experiments are conducted on upright shell footing in buried condition. The angles 30°, 45°, 60°, 75°, 90°, 110° of shell footing subjected to vertical loading in medium dense sand with varying number of reinforcement (N). The load settlement curves for Upright Triangular Shell footing of 30° angle and corresponding to various number of layers of geotextile are as shown in Fig. 4. From Fig. 4, the ultimate bearing capacity of upright shell footing on sand bed for various number of layers were determined. These are tabulated in Table 5.

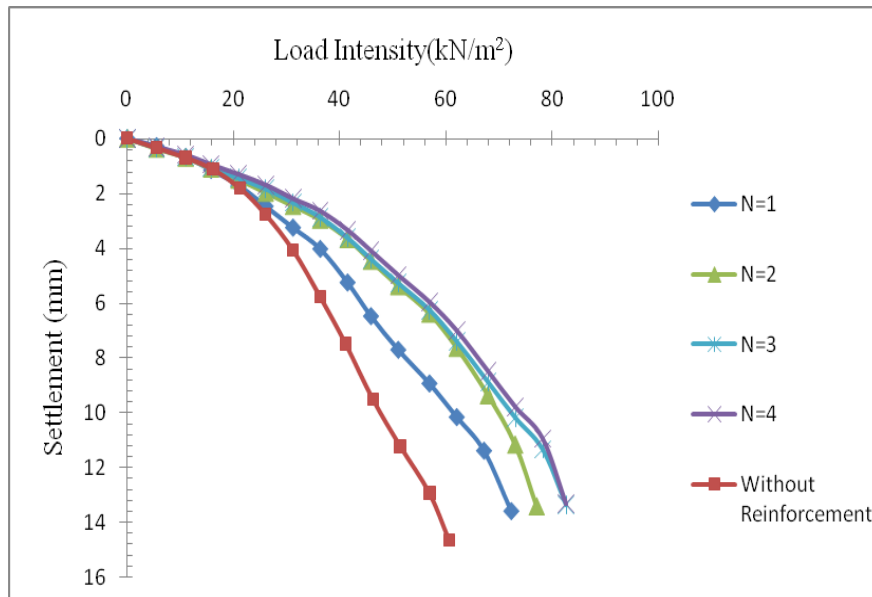


Fig. 4. Load Settlement Curves for Upright Triangular Shell footing of 30° Angle corresponding to Various Number of Layers of Geotextile Reinforcement

Table 5 UBC of Upright Triangular Shell footing of 30° Angle

Sr. No.	Number of Layers of Reinforcement	UBC (kN/m ²)
1	Without Reinforced	37.03
2	1	49.381
3	2	60.05
4	3	66.06
5	4	66.06

The load settlement curves for Upright Triangular Shell footing of 45° angle and corresponding to various number of layers of geotextile are as shown in Fig. 5. From Fig. 5, the ultimate bearing capacity of upright shell footing on sand bed for various number of layers were determined. These are tabulated in Table 6.

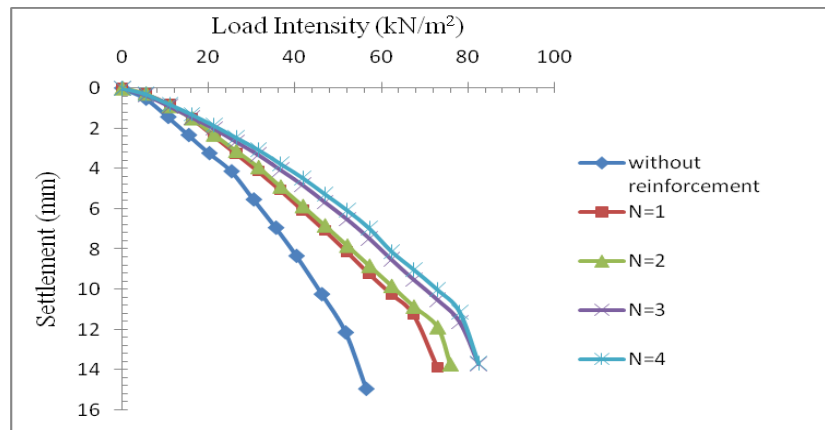


Fig. 5. Load Settlement Curves for Upright Triangular Shell footing of 45° Angle corresponding to Various Number of Layers of Geotextile Reinforcement

Table 6 UBC of Upright Triangular Shell footing of 45° Angle

Sr. No.	Number of Layers of Reinforcement	UBC (kN/m^2)
1	Without Reinforced	40.25
2	1	51.56
3	2	63.20
4	3	69.86
5	4	69.86

The load settlement curves for Upright Triangular Shell footing of 60° angle and corresponding to various number of layers of geotextile are as shown in Fig. 6. From Fig. 6, the ultimate bearing capacity of upright shell footing on sand bed for various number of layers were determined. These are tabulated in Table 7.

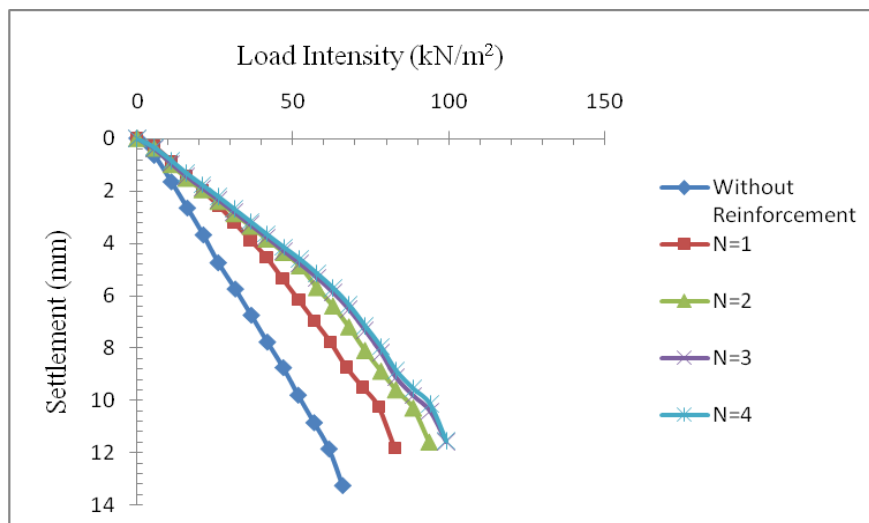


Fig. 6. Load Settlement Curves for Upright Triangular Shell footing of 60° Angle corresponding to Various Number of Layers of Geotextile Reinforcement

Table 7 UBC of Upright Triangular Shell footing of 60° Angle

Sr. No.	Number of Layers of Reinforcement	UBC (kN/m^2)
1	Without Reinforced	48.33
2	1	63.33
3	2	78.33
4	3	82.66
5	4	82.66

The load settlement curves for Upright Triangular Shell footing of 75° angle and corresponding to various number of layers of geotextile are as shown in Fig. 7. From Fig. 7, the ultimate bearing capacity of upright shell footing on sand bed for various number of layers were determined. These are tabulated in Table 8.

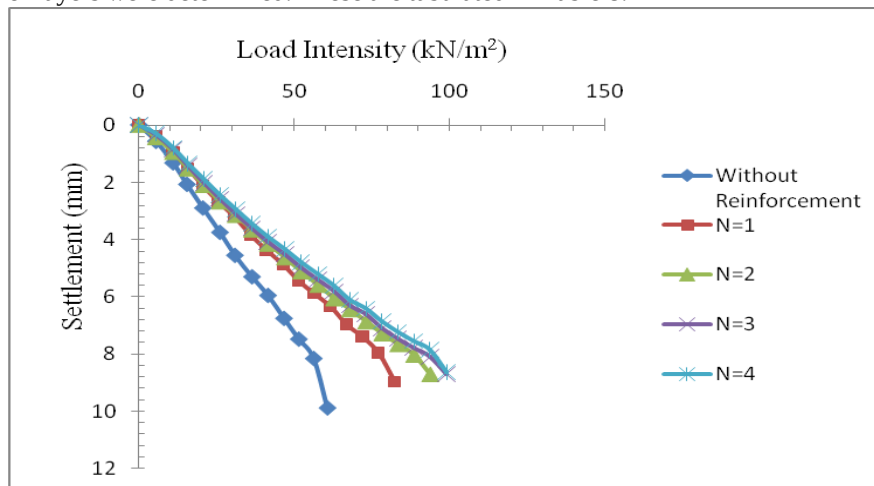


Fig. 7. Load Settlement Curves for Upright Triangular Shell footing of 75° Angle corresponding to Various Number of Layers of Geotextile Reinforcement

Table 8 UBC of Upright Triangular Shell footing of 75° Angle

Sr. No.	Number of Layers of Reinforcement	UBC (kN/m^2)
1	Without Reinforced	52.77
2	1	70.14
3	2	83.50
4	3	88.51
5	4	88.51

The load settlement curves for Upright Triangular Shell footing of 90° angle and corresponding to various number of layers of geotextile are as shown in Fig. 8. From Fig. 8, the ultimate bearing capacity of upright shell footing on sand bed for various number of layers were determined. These are tabulated in Table 9.

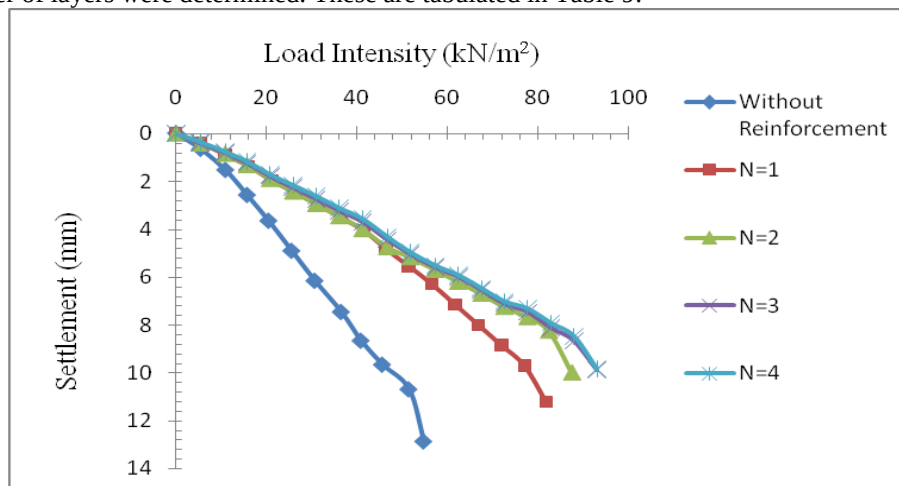


Fig. 8. Load Settlement Curves for Upright Triangular Shell footing of 90° Angle corresponding to Various Number of Layers of Geotextile Reinforcement

Table 9 UBC of Upright Triangular Shell footing of 90° Angle

Sr. No.	Number of Layers of Reinforcement	UBC (kN/m^2)
1	Without Reinforced	44.15
2	1	59.76
3	2	74.70
4	3	79.01
5	4	79.01

The load settlement curves for Upright Triangular Shell footing of 110° angle and corresponding to various number of layers of geotextile are as shown in Fig. 9. From Fig. 9, the ultimate bearing capacity of upright shell footing on sand bed for various number of layers were determined. These are tabulated in Table 10.

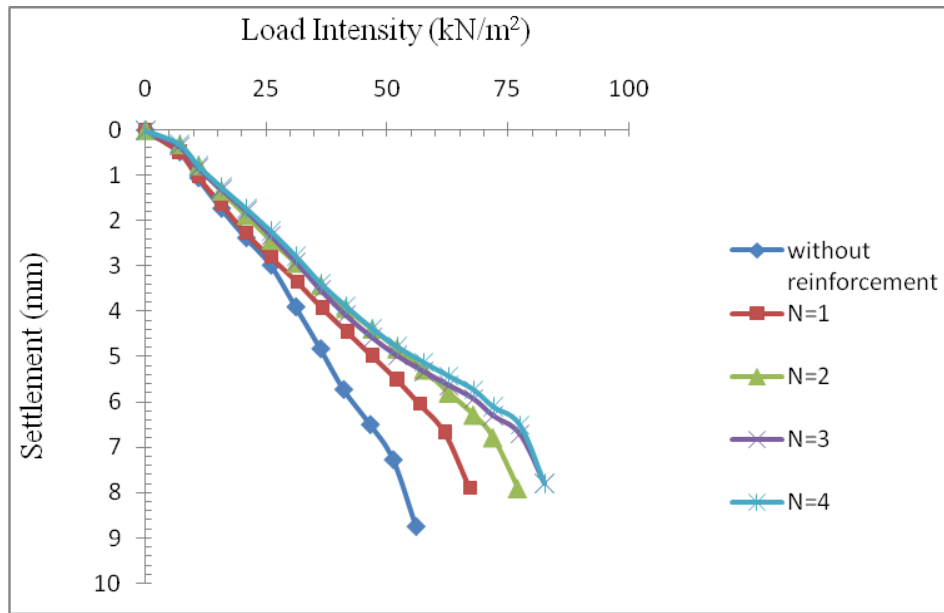


Fig. 9. Load Settlement Curves for Upright Triangular Shell footing of 110° Angle corresponding to Various Number of Layers of Geotextile Reinforcement

Table 10 UBC of Upright Triangular Shell footing of 110° Angle

Sr. No.	Number of Layers of Reinforcement	UBC (kN/m^2)
1	Without Reinforced	40.37
2	1	55.05
3	2	65.06
4	3	72.73
5	4	72.73

4.3 Effect of Shell Angle on Performance of Shell Footing

The percentage increase in UBC of shell footing corresponding to shell angle was evaluated. Table 11 illustrates the percentage increases in UBC of shell footing under centric point load for different shell angles.

Table 11 Percentage increase in UBC for Upright shell footing with different shell angles

Shell Angle	Percentage increase in UBC (%)
30°	30.70
45°	42.07
60°	70.59
75°	86.26
90°	55.84
110°	42.49

From the Tables 11, it is observed that the UBC of Upright shell footing is greater than flat footing. Fig. 10. shows the variation of Percentage increase in UBC for upright shell footing with different shell angles on unreinforced sand bed respectively.

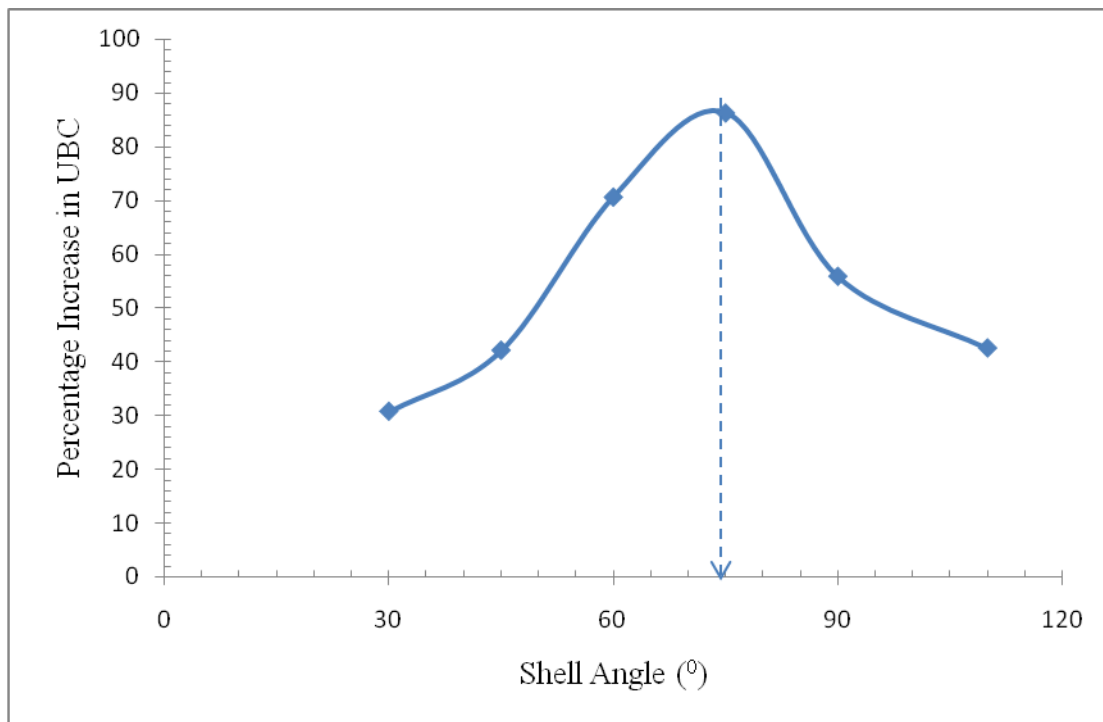


Fig. 10. Variation of Percentage increase in UBC for upright shell footing with different shell angle

From the Fig. 10, it is observed that upright shell footing with angle 75° shows the maximum UBC than other angles. Thus the optimum shell angle for shell footing may be adopted as 75° .

4.4 Effect of Reinforcement in Sand Bed on Performance of Shell Footing

Experiments were performed on shell footing subjected to vertical centric loading on both unreinforced and reinforced sand bed using woven geotextile. First layer was placed at fixed distance u which was equal to $0.25 B$ below the foundation base fixed length equal to $4 B$. Spacing between successive layers of reinforcement was $0.25 B$.

Table 12 shows Bearing Capacity Ratios for upright shell footing on sand bed with reinforcement for various shell angle. Fig. 11. shows variation of BCR for Upright shell footing with different shell angle with respect to number of reinforcement layers.

Table 12 Bearing Capacity Ratios for upright triangular shell footing on sand bed with reinforcement for various shell angle

Shell Angle	BCR			
	Number of Reinforcement Layers (N)			
	N=1	N=2	N=3	N=4
30°	1.74	2.11	2.33	2.33
45°	1.81	2.23	2.46	2.46
60°	2.23	2.76	2.91	2.91
75°	2.47	2.94	3.12	3.12
90°	2.10	2.63	2.78	2.78
110°	1.94	2.29	2.56	2.56

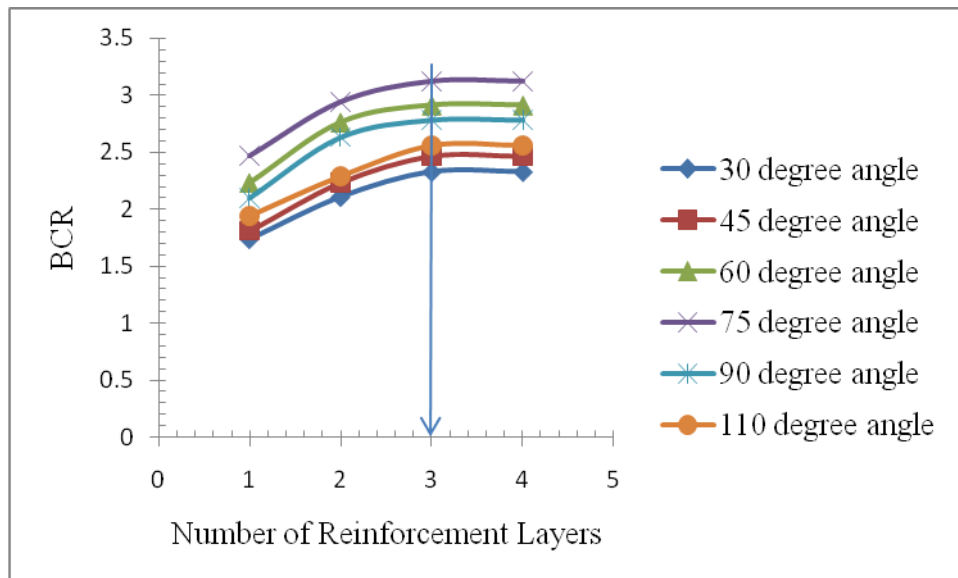


Fig. 11. Variation of BCR for Upright shell footing with different shell angle with respect to number of reinforcement layers

From the Fig. 11, it is seen that BCR increases significantly with increase in number of layers of reinforcement up to three layers of reinforcement. Thereafter further increase in number of layers, ($N > 3$), BCR remains unchanged.

V.CONCLUSIONS

Based on the results of the present study, the following broad conclusions are drawn

1. Upright shell footing has higher ultimate bearing capacity on medium dense sand as well as reinforced sand bed as compared to flat strip footing.
2. The ultimate bearing capacities of shell footing increases with increase in shell angle up to 75° with further increase in shell angle, ultimate bearing capacities of shell footing decreases. Thus 75° is the optimum shell angle for Upright shell footing.
3. BCR of Upright shell footing increases significantly with provision of three layers of geotextile reinforcement. With further increase in number of layers BCR remains unchanged. Hence optimum number of layers of reinforcement may be considered as three, for upright shell footing on reinforced sand bed.

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