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Performance of Vertically Confined Shallow Foundation on Reinforced Sand Under Concentric Loading

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Abstract. In a view to keep a check on economy several methods have been devised up to enhance soil strength characteristics, among which confinement is one of the emerging techniques. This paper presents the performance of vertically confined shallow foundation placed over multi layered geo-grid reinforced sand under concentric loading and the results are validated using PLAXIS 3D software. Parametric variations like top surface dimension of vertical confiner (D) (1B,1.5B,2B), Number of geo-grid layers (N), Length of reinforcements (L), Spacing ($Y_{1\ldots n}$) between horizontal reinforcements (0.25B,0.5B,0.75B,1B) have been investigated with a constant depth (d/B=1).(where d and B are the depth of vertical confiner and width of square footing). The results reveal that with increase in top surface dimension of vertical confiner increases bearing capacity of footing quite appreciably for the specified settlement (25mm) and approaches the optimum value at D/B=2 for a minimum spacing of 0.25B between horizontal reinforcements. It is also noticed that, Number of reinforcement layers and their proper placement inside the confiner plays a vital role in bearing capacity improvement. Overall it can be inferred that the model test results are supported closely by the PLAXIS results.

Keywords: Vertical Confinement; Geogrid; Model Tests; Concentric Loading; Bearing Capacity.

1 Introduction

Bearing capacity and settlement are the two most challenging criteria considered during the design of foundation. In this regard several methods for soil improvement have been applied to enhance the soil characteristics. Out of the different available techniques soil confinement is of the suitably applicable method accepted in the geotechnical field ensuring a safe bearing capacity. Many investigations have been made to study the effect of soil confinement technique to explore more in the geotechnical field. Rajgopal et al. (1999) Studied the influence of geocell confinement on the strength and stiffness behavior of granular soils performing large no of triaxial compression test. Effect of soil confinement on ultimate bearing capacity of square footing under eccentric-inclined loading was investigated by Singh et al. (2007). Work of different researchers have shown that confiners made up of various materials like Unplasticized polyvinyl chloride cylinders (Upvc), semi flexible vertical reinforcement, mild steel casing, plastic hollow cylinder, timber box (El Sawaaf and Nazer 2005; Jha 2007; Krishna et al. 2014; Elsaied 2015; Amarasinghe et al. 2018) etc can be used to improve bearing capacity and reducing settlement. In the above work researchers have recommended some parameters like confiner height, width and diameter of the confiner for obtaining optimum results**.** Eid et al. (2009) carried out both physical and numerical modeling on behavior of shallow foundation resting on laterally confined sand surrounded by sheet-pile walls to support excavation sides of sand underlain by a rock bed. Fattah et al. (2015) reported that use of vertically bounded wall for soil confinement mitigates the settlement from 5 to 160% depending on wall depth and distance from the footing. Some authors have investigated on use skirts to confine the soil resulting a significant improvement in the ultimate bearing capacity (Al-Aghbari and Dutta 2008; El Wakil 2013; Renaningsih et al. 2017; Joseph and A.S 2018). Azzam and El Wakil (2016) reported the behavior of circular footing on confined granular subgrade adjacent to slope. Thakur and Dutta (2020) carried out an experimental and numerical analysis to determine ultimate bearing capacity of un skirted, singly skirted and doubly skirted hexagonal footing on sand varying its D_{10} values as 0.14,0.45,1.45 respectively.In prospect of gaps, in the present work both biaxial geogrids have been used as the confiner and horizontal reinforcement underneath the footing. The aim of this study is to find the improvement in ultimate bearing capacity of square footing resting on horizontally reinforced sand confined laterally by a geogrid confiner under concentric vertical load.

2 Experimental Details

The model tests were conducted in an iron tank with internal dimensions of 1.0mx1.0mx0.8m. To avoid lateral deformation, the tank walls were braced with iron section outside. A square footing of side B (20cm) has been used in the present work. All the tests were carried out on poorly graded medium dense sand with uniformity coefficient (C_u) = 2.62, Coefficient of Curvature(C_c) = 1.13, specific gravity = 2.64, natural dry unit weight of sand =15.24kN/m^3, relative density of sand = 50%, maximum and minimum void ratio = 0.87 and 0.55 respectively, angle of shearing resistance = 32.6˚. The physical properties of biaxial geogrids used for both lateral confiner and horizontal reinforcement are given in table 1.

Table 1. Properties of Geogrid

parameter	Value
Aperture size of Geogrid (mm)	25×25
Material	HDPE
Peak load (MD)	1.2kN
Peak load (CMD)	2.5kN
Stiffness modulus (kN/m)	2000
Thickness (mm)	1.57
Junction Efficiency (%)	94
Sample Area (sq.mm)	300

2.1 Test program

Tests were performed in three series.In series A, only footing was used under vertical loading. In series B footing with confiner, In series C footing with Confiner of given dimensions along with horizontal reinforcements inside were used underneath the footing. Parameters such as d, D, y, L and Y were normalized with respect to width of the footing (B). The top layer reinforcement layer (y) is kept at 0.1B (constant) below the base of the footing for all the tests. The consecutive horizontal reinforcement layer spacing is varied as 0.25B, 0.5B ,0.75B and 1.0B. Variation in D/B is kept as 1.0, 1.5 and 2.0 for a constant depth of d/B=1.0. The details of laboratory model tests are presented in Table 2.

Table 2. Details of Laboratory model tests

Test Series	Foundation Configuration	Test parameters		No of tests
		Variable	Constant	
A	Only Footing			1
B	Footing with confiner	D/B=1.0,1.5,2.0	d/B=1	3
C	Footing with confiner and reinforcement	D/B=1,1.5,2, N=1-4, Y/B=0.25,0.5,0.75,1, L/B=1,1.5,2.0	d/B=1, , y/B=0.1B	12

3 Methodology

Sand bed was prepared for the model tests maintaining a uniform relative density of 50% through out. In order to achieve the desired density, height of fall was fixed by several trials in the test tank prior to the test. Lateral confiner was placed on the sand bed in the middle of the tank by using a plumb bob after the sand was filled to a required height, followed by the placement of horizontal reinforcement inside the confiner maintaining the certain spacing as mentioned. After the combined entity of confiner and horizontal reinforcements were placed in their desired position rest part of the tank was filled in the same procedure. Top surface of the sand bed was leveled by a wooden plate and footing was placed middle of the tank maintain the concentricity with the confiner. Four dial gauges with an accuracy of 0.01mm placed on the four corner of the footing average of which provide the settlement of footing. Load was applied through a manually operated hydraulic jack associated with a precalibrated proving ring of capacity 30kN measures the transferred load. Bearing capacity in all the model test has been considered for 25mm settlement. Schematic diagram for the experimental program is given in fig. 1.

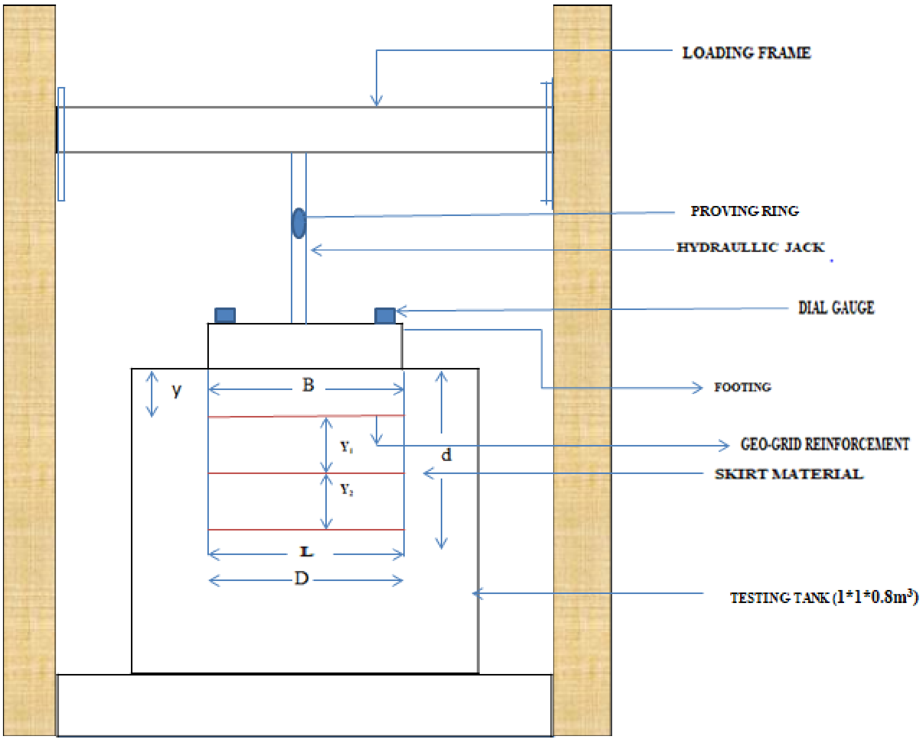


Fig. 1. Schematic diagram of the set up

3.1 Numerical analysis

Finite element software PLAXIS 3D has been used to verify the laboratory model test results. The nonlinerity of sand was modelled using the hardening soil model, an elasto plastic second order hyperbollic isotropic hardening model. Input parameters(E_{50}, E_{oed} , E_{ur}) for sand were estimated using co-relation between angle of shearing resistance and relative density. Numerical values for some basic parameters have been taken from the manual. The footing was modelled as a plate element and the elastic geogrid element was used to model both the confiner and horizontal reinforcements. A prescribed displacement of 25 mm was applied and load corresponding to 25mm settlement was considered as ultimate load which was compared with the ultimate load obtained from experimental results. Table 3 provides the values considered for the analysis.

Table 3. Material properties

Parameter	Sand	Footing	Geogrid
Secant modulus of stiffness (E_{50})(kN/m^2)	18,600	--	--
Tangent Oedometer stiffness(E_{oed}) (kN/m^2)	10,000	--	--
Unloading/Reloading stiffness(E_{ur}) (kN/m^2)	55,800	--	--
Angle of internal Friction	32.6	--	--
Unit Weight (kN/m^3)	15.21	78.5	--
Thickness of Footing(m)		0.025	
E_1=E_2 value of Footing(kN/m^2)	--	13.4e6	--
G_1=G_2 Value of Footing(kN/m^2)		5.36e6	--
Poisson's Ratio		0.25	
Stiffness modulous for Geogrid(kN/m)	--	--	2000

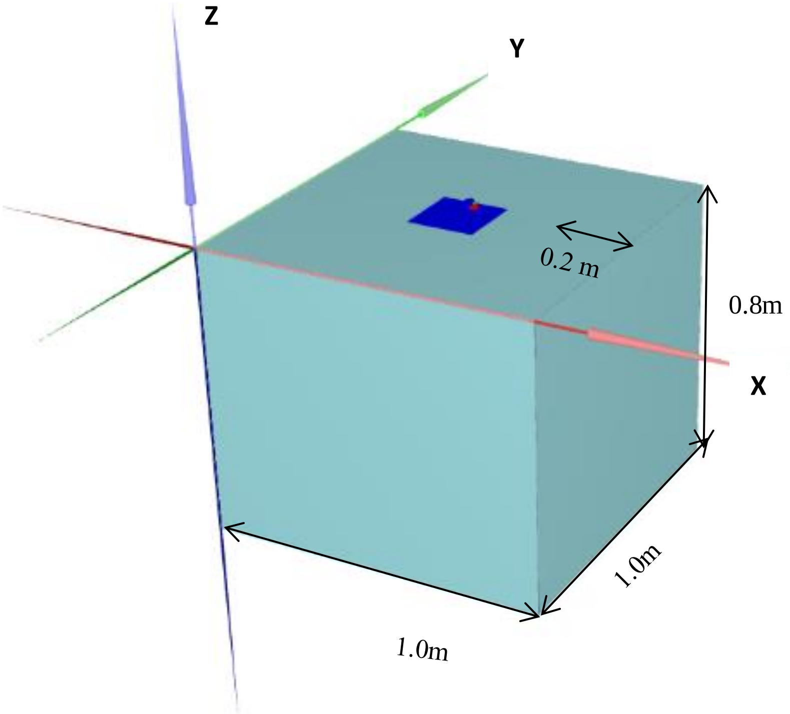


Fig. 2. Geometry modelled in Plaxis

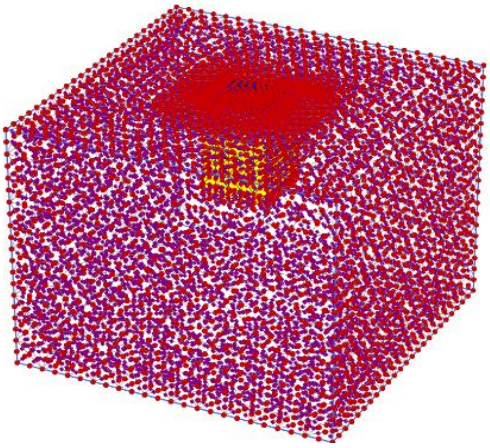


Fig. 3. Connectivity plot for Footing+confiner+Reinforcement

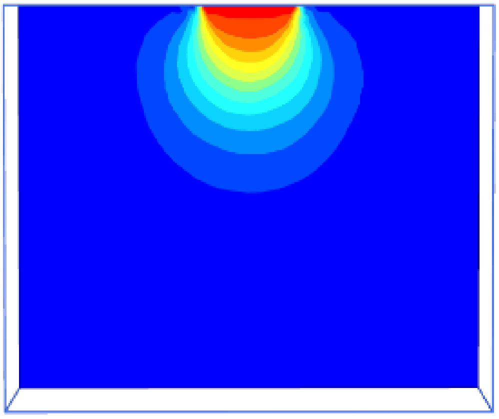


Fig. 4.vertical c/s for surface footing (Total displacement)

4 Results and Discussion

Number of laboratory tests, as detailed in Table 2, were carried out on model laterally confined footing resting on geogrid-reinforced medium dense sand. The results obtained from PLAXIS 3D have also been validated with the experimental results (fig.9 to 12). The improvement in bearing capacity of square footing with confiner and geogrid reinforced sand is represented using a non-dimensional factor, called Bearing capacity ratio (BCR). BCR is defined as the ratio of footing ultimate bearing load intensity for reinforced sand ($q_{reinforced}$) to footing ultimate bearing load intensity for unreinforced ($q_{unreinforced}$) sand. Fig. 5 to Fig. 8 illustrates the load intensities – settlement curves providing ultimate bearing capacity corresponding to 25mm settlement. Fig. 5. Shows the load intensity-settlement curve for footing with only confiners in which depth of the confiner is kept 20.0cm (d/B=1) constant where as top surface dimension of the confiner is varied as 20 cm x 20 cm (D/B=1), 30 cm x 30 cm (D/B=1.5), 40 cm x 40 cm (D/B=2). Fig.6,7,8 explains the variation of load intensity for footing with lateral confiner and horizontal reinforcements with a variation in spacing of reinforcement as 0.25B,0.5B,1.5B and 2.0B. Overall it can be concluded that use of both lateral confiner and reinforcement underneath the footing shows a noticeable effect which is enumerated below individually. Load intensities and Bearing capacity ratios for all the combinations are given in Table 4. Failure pattern for different arrangements of reinforcement and confiner observed in plaxis has been discussed below in the fig. 13 to fig. 16.

4.1 Effect of confiner

It can be observed from fig. 5 that with increase in top surface dimension of the confiner the load intensity starts decreasing as 59.5kN/m^2(D/B=1,d/B=1), 50.3kN/m^2 (D/B=1.5,d/B=1), 42.7kN/m^2 (D/B=2,d/B=1) respectively. The corresponding BCRs are found to be 1.65, 1.4, 1.18 respetively also showing a decremental nature substantiating the fact that with increase in top surface dimension of the confiner the degree of confinement decreases and more amount of sand spills out laterally due to little higher aperture size of geogrid. From Table 4 it can be observed that even though the load intensity decreased with increment in D/B value still it shows a noticeable increment of 1.65 fold increase for the confiner (D/B=1,d/B=1) compared to the surface footing (35.9kN/m^2) .

Table 4. Comparison between Load intensities and BCR

Footing Configuration	Confiner Dimension (cm)	Horizontal Geogrid Spacing	Load Intensity (kN/m^2) (Experimental)	Load Intensity (kN/m^2) (Plaxis)	BCR (Experimental)	BCR (Plaxis)
Only Footing		-	35.9	28.4	-	-
Footing+Confiner	20*20*20	-	59.5	37.5	1.65	1.32
	30*30*20	-	50.3	76.75	1.4	2.71
	40*40*20	-	42.7	59	1.18	2.08
Footing+Confiner+Reinforcement	20*20*20 (D/B=1,d/B=1)	0.25B	81	55.7	2.25	1.96
		0.5B	73.6	27.95	2.05	1.04
		0.75B	65.1	100.4	1.81	3.53
		1.0B	53.2	43.4	1.68	1.52
	30*30*20 (D/B=1.5,d/B=1)	0.25B	138.2	179	3.84	6.3
		0.5B	98.2	106.5	2.73	3.75
		0.75B	82.7	76	2.3	2.67
		1B	71.4	82.5	1.98	2.90
	40*40*20 (D/B=2,d/B=1)	0.25B	143.1	158.75	3.98	5.59
		0.5B	92.9	94	2.58	3.3
		0.75B	87.5	91.5	2.43	3.22
		1B	75.8	72.25	2.11	2.54

Effect of horizontal reinforcement and spacing inside confiner

The effect of horizontal reinforcement inside the confiner have been shown in the fig. 6 to 8. Load intensities corresponding to 25mm settlement for the 0.25B spacing was found to be 81kN/m^2 (D/B=1), 138.2 kN/m^2 (D/B=1.5), 143.1kN/m^2 (D/B=2) which shows a significant improvement in load carrying of the square footing. This can be explained as horizontal reinforcements placed at closer spacing like 0.25B it increases interlocking effect consequencing an increase in shearing resistance underneath the footing due to which lateral displacement of sand is restrained. From the Table 4 it is found that as the spacing increases between the reinforcements the load bearing capacity starts reducing and mostly stays closer for 0.75B and 1.0B spacing.

Length of horizontal reinforcements

Observing Table 4 it is found that for series B with increase in D/B value the load intensities have found to be decreased whereas for series C the load intensity value shows a significant increment. This noticeable effect is ascertained not only due to spacing of reinforcements but also complimented by the length and number of geogrids placed inside the confiner. As the D/B value increases, it simultaneously increases the L/B value which provides a good anchorage for reinforcements. In the present work length of reinforcement equal to twice of footing width is considered for giving optimum value of bearing capacity.

Failure pattern

Cross section of total vertical displacement at 25mm settlement under concentric vertical loading are shown in the figs. 13 to 16. It is seen that the failure mechanism for minimum spacing of 0.25B has shown a slow gradual vertical settlement which is found to be more prominent with the increment of spacing. Fig. 16 shows the failure pattern for footing with only confiner which clears the fact that with increase in D/B value effect of confiner reduces consequencing a rapid settlement.

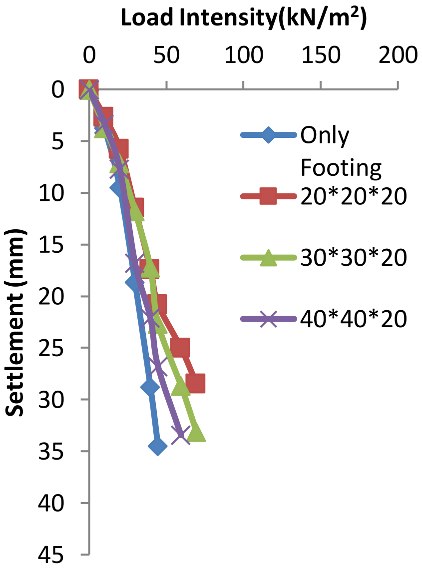


Fig. 5. Footing +Confiner (D/B =1, 1.5, 2)

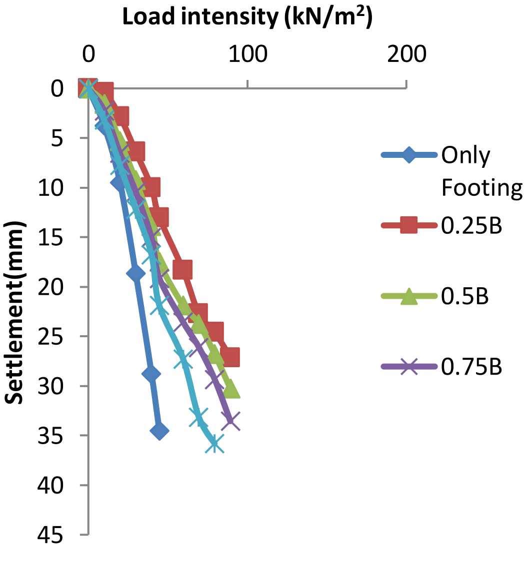


Fig. 6. Footing + Confiner(20*20*20)+Reinforcement

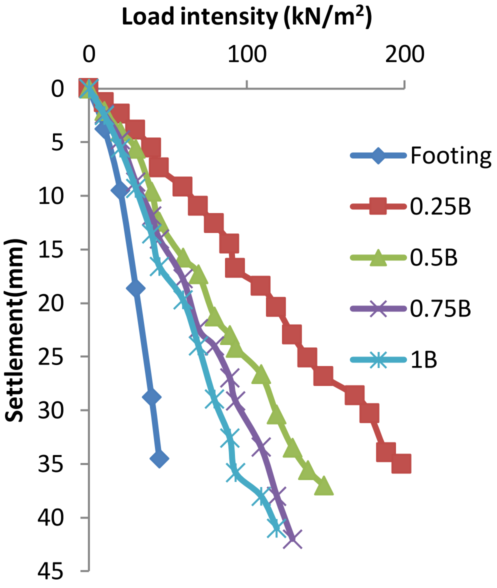


Fig. 7. Footing + Confiner(30*30*20)+Reinforcement

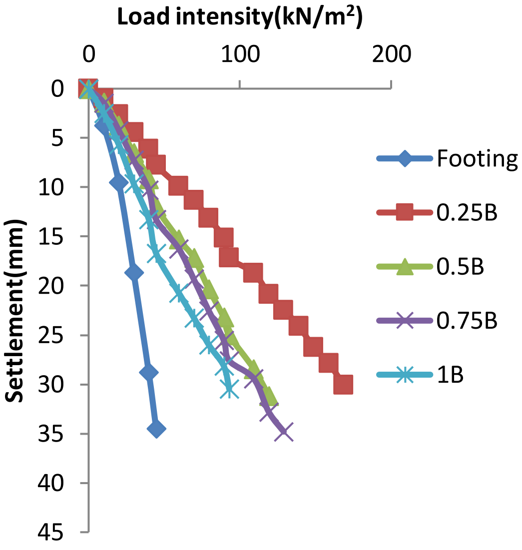


Fig. 8. Footing+ Confiner(40*40*20)+Reinforcement

Comparative analysis of load-settlement curve (PLAXIS and Experimental Results)

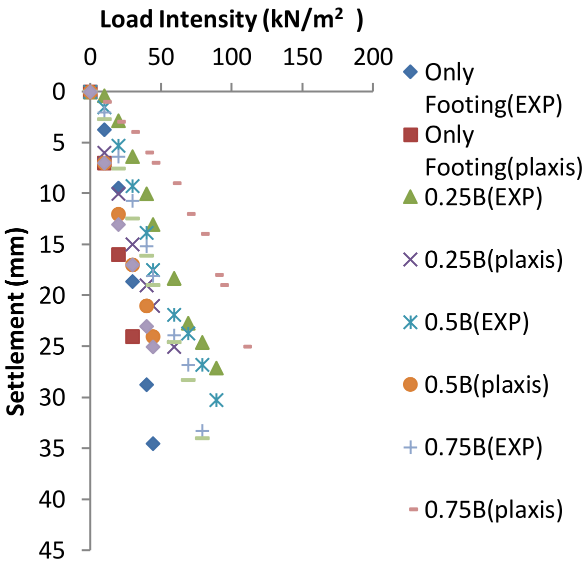


Fig. 9. Footing+Confiner(20*20*20)+Reinforement

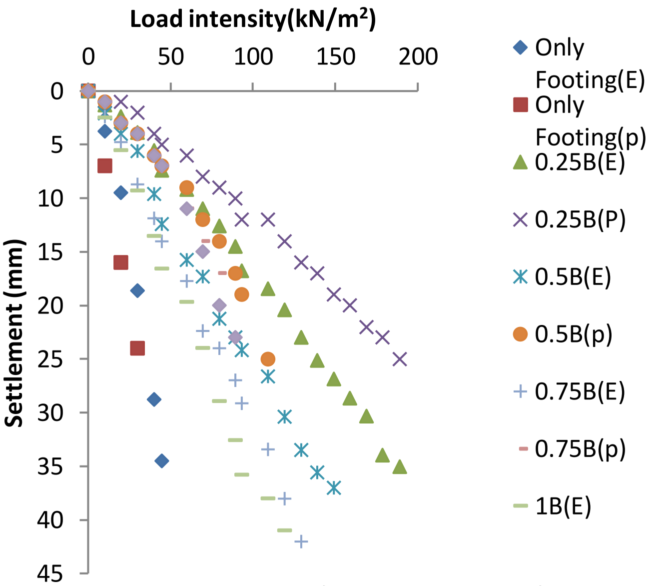


Fig. 10. Footing+Confiner(30*30*20)+Reinforement

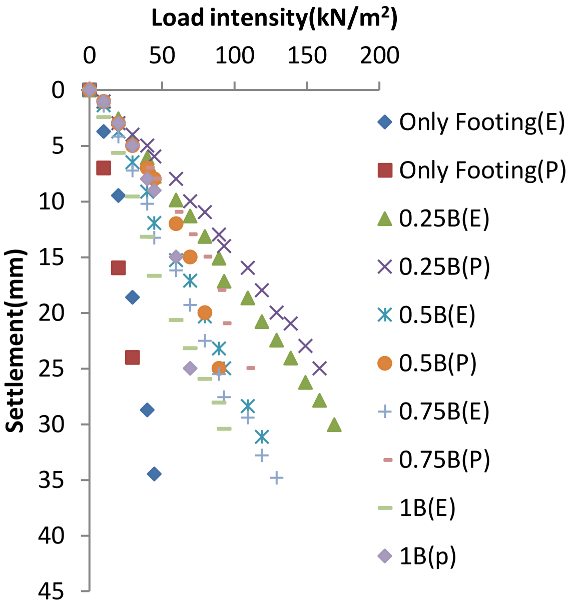


Fig. 11. Footing+Confiner(40*40*20)+Reinforement

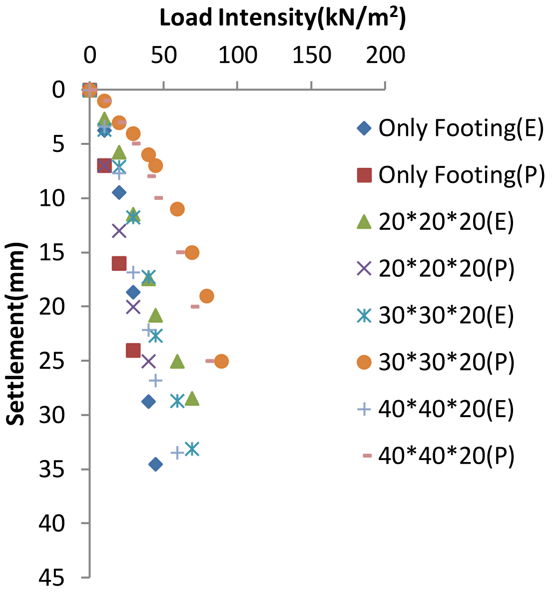
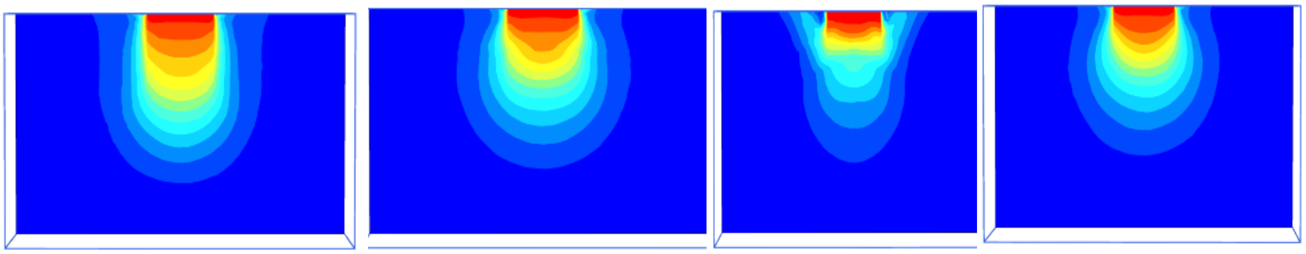
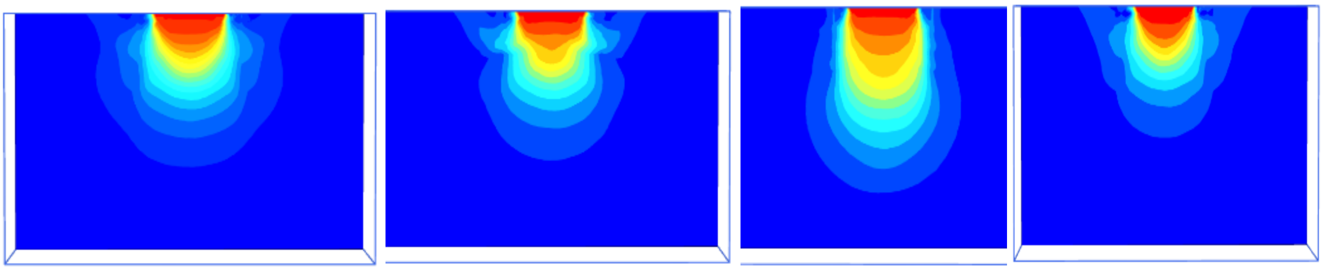


Fig. 12. Footing+ Confiner(D/B=(1,1.5,2)



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

Fig. 13. Failure pattern for Footing + Confiner (D/B=1, d/B=1) +Reinforcement (spacing @ (a) 0.25B, (b) 0.5B, (c) 0.75B, (d) 1B)



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

Fig. 14. Failure pattern for Footing + Confiner (D/B=1.5, d/B=1) +Reinforcement (spacing @ (a) 0.25B, (b) 0.5B, (c) 0.75B, (d) 1B)

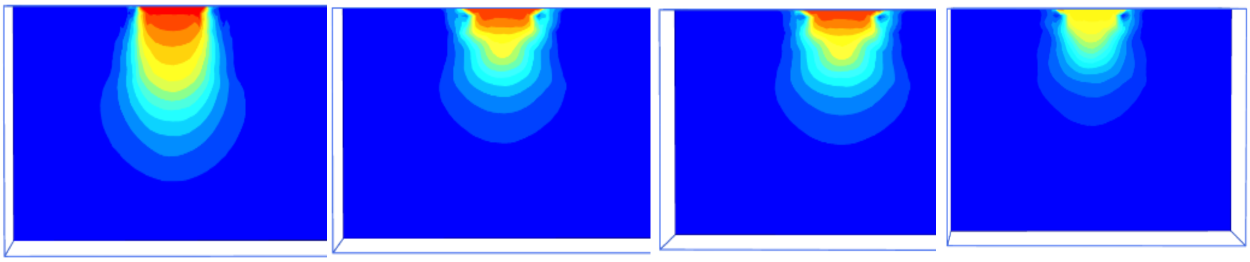


Fig. 15. Failure pattern for Footing + Confiner (D/B=2, d/B=1) +Reinforcement (spacing @ (a) 0.25B, (b) 0.5B, (c) 0.75B, (d) 1B)

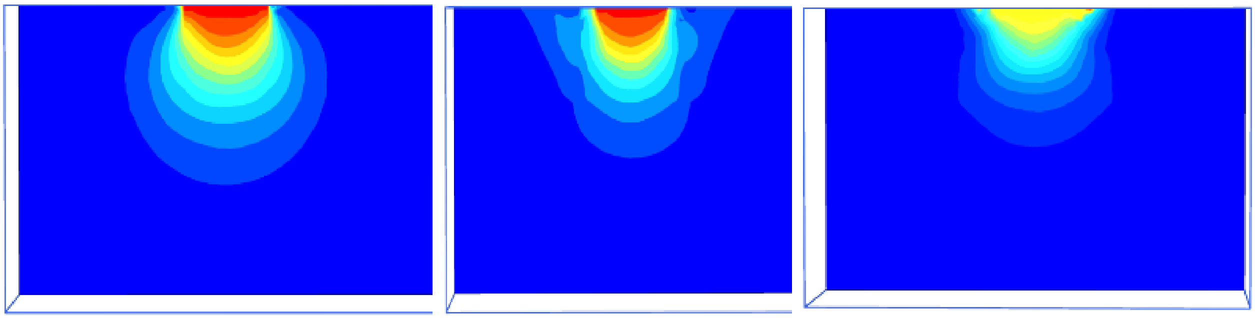


Fig. 16. Failure pattern for Footing+ Confiner (a) D/B=1,d/B=1; (b) D/B=1.5,d/B=1;(c) D/B=2,d/B=1

5 Conclusions

Based on the laboratory investigations, the study brings forth the following conclusions which are closely supported by the PLAXIS results

1. Use of both confiner and horizontal reinforcements show significant improvement in load intensity as compared to only confiner. With increase in top surface dimension of confiner (d/B=2) and minimum spacing of 0.25B gives optimum value in load intensity i.e 143.1kN/m^2 which is validated closely with plaxis results of 158.75kN/m^2.
2. In case of confiner better performance is observed at (D/B= 1, d/B=1) which found to be providing lesser load intensity with increment in D/B value.
3. Increase in spacing value between reinforcement reduces down the load intensity and bearing capacity ratio together.
4. Aperture size and placement of confiner-reinforcement configuration play vital role in the analysis.
5. From the failure pattern it can be observed that with increase in D/B value failure plane spreads more on both the sides of the footing.
6. Both numerical and experimental results show very close validation though an unconventional value for 0.75B spacing of horizontal reinforcement for confiner dimension (D/B=d/B=1) is noticed due to some execution error.

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