Investigation on influence of reinforcement in stress distribution of granular media .

K.Premalatha
Anna University,India (kvprema@annauniv.edu)
S.Pavithra
Anna University,India(spavithra456@gmail.com)

ABSTRACT: The technique of reinforcing soil is one of the most popular and effective in improving the soil in the field of geotechnical engineering. Most of the studies carried out so far on reinfoced soil foundation focuses only on the improvement in the bearing capacity of the soil due to the presence of reinforcement. But the determination of stress distribution in reinforced soil is a very important problem in foundation engineering. It is also essential to examine the changes in the pressure bulb due to the presence of reinforcement. This research is performed to study the effect of reinforcement in the stress distribution using PLAXIS analysis. Changes in the width and depth of vertical stress and shear stress bulb due to reinforcement is established by obtaining a tentative pressure bulb for both reinforced and unreinforced case from numerical analysis. Pressure cells were used to measure the stress developed at various depth along the center of the footing. The vertical stress coefficient obtained from experiment, numerical analysis and theory (Boussinesq equation) is compared.

Keywords: Sand , geogrid , stress distribution , pressure bulb

1. INTRODUCTION

The technique of reinforcing soil is one of the most popular and effective in improving the soil. Most of the available literatures focuses on improvement in bearing capacity due to soil reinforcement in terms of bearing capacity ratio and a very few literatures focuses on the settlement aspect of reinforced soil foundation. Apart from bearing capacity and settlement is it also necessary to examine the changes in stress distribution brought about by the reinforcement though the three aspects – settlement, bearing capacity and stress distribution are interconnected to some extent. Determination of stress distribution in soil is very important. All theoretical consideration about pressure distribution in soil is based on the results given by mathematical theory of elasticity for simplest case of loading. The changes that has to be brought in these theories to incorporate the effect of inclusion of reinforcement is a matter that has to be looked into.

Baran et al (2008) have performed experiment and numerical analysis for unreinforced case to find vertical stresses under square footing resting on sand and have compared the results with the theoretical solution. It is shown that numerical and theoretical results were in good agreement upto the depth equal to twice the width of the footing . It is stated in the work carried out by Kurian et al (1977) that the stress contours gets shifted downwards and there is a rotation of principal stresses due to presence of coir rope as reinforcement incase of a square footing. Enache (2013) has reported that the stresses get concentrated near the reinforcement in case of reinforced soil foundation. Schmertmann (2005) has performed stress diffusion experiment in sand and has evaluated the effect of lateral stress in stress distribution. Anand (2013) has studied the influence of principal stress ratio on the vertical stress distribution of reinforced soil foundation. It was found that with increase in the principal stress ratio, the vertical stress decreased. Marimuthu (2014) has reported that reduction in vertical stress due to the influence of reinforcement is more effective in loose sand when compared to dense sand. With this knowledge of some of the works carried out by previous researchers, this study aims to determine the influence of reinforcement in vertical and shear stress distribution incase of uniformly loaded strip footing.

2. MATERIALS USED FOR THE TESTS

This section gives a brief description about the properties of the material – sand and geogrid, used for the experimental investigation.

2.1 *Sand*

The sand used in this study is tested for its grain size distribution and specific gravity. Tests were conducted as per BIS specifications. The properties of the sand is listed in Table1. Based on the index properties of the sand, it is classified as poorly graded sand (SP) as per IS classification system. Relative density test was performed to find the maximum and minimum dry density of the sand. Direct shear test was performed to find the angle of internal friction corresponding to the relative density of 60%.

2.2 *Reinforcement*

Geogrid was used as reinforcement. It was tested for its tensile strength. The aperture size, shape and weight in g/m^2 was also examined.The properties of geogrid is listed in Table 2.

3. LABORATORY TESTS

This section describes the test set- up and test procedure carried out in the laboratory.

3.1 *Test set-up*

Experimental investigations were carried out in the model tank of dimension 600 mm (length) x 400 mm (width) x 600 mm (depth) combined with the load frame assembly. Model footing made of mild steel , having a dimension of 400 mm (length) x 40 mm (width) x 40 mm (depth) was used. The dimensions of the footing was worked out such that it showed rigid behaviour. L/B ratio of the footing was taken as 10. Load was applied on the footing by means of the hydraulic jack welded against a reaction frame.

3.2 *Peparation of sand bed*

The relative density of sand was kept as 60% and the width of reinforcement was taken equal to twice the width of the footing. For producing the desired density, having known the volume of the tank, the weight of the sand needed to achieve the required density was filled in a controlled manner. For preparation of sand bed, the sand was filled for a height of 100 mm and leveled horizontally by wooden bar. Compaction was carried out when required, using a hammer weighing 2.63 kg and height of fall 290 mm .

Table 1 Properties of Sand

Parameter	Symbol	Value	Unit
Specific gravity	G	2.62	-
Coarse sand	-	4	%
Medium sand	-	80	%
Fine sand	-	16	%
Effective grain size	D_{10}	0.35	mm
Coefficient of uniformity	C_u	2.86	-
Coefficient of curvature	C_c	0.93	-
Maximum dry density	$(\gamma_d)max$	1.64	g/cc
Minimum dry density	$(\gamma_d)min$	1.50	g/cc
Relative density	-	60	%
Angle of internal friction	Φ	34	°
IS Classification	SP-Sand Poorly Graded		

Table 2 Properites of geogrid

Parameter	Propeties
Aperture size in cm	2.3 x 2
Aperture shape	Rectangular
Weight in g/m^2	690
Tensile strength in kN/m	45
Interfacial friction angle	33°

3.3 *Testing procedure*

Stresses developed at various depth in the soil mass along the center of the footing was found using pressure cell for both reinforced and unreinforced case. The pressure cell (Earth pressure cell vibrating wire type – Systel Make: SIS-1101) having a diameter of about 20 cm was placed at depth varying from 0.5B to 4B (B being the width of the footing) along the center of the footing for unreinforced case. For the applied load the stress developed at each depth was measured using the digital read out unit. For reinforced case, the depth of reinforcement was taken as 2B, four layers of reinforcement was placed at a spacing of 0.5B and stress developed was measured at depth 2B, 3B and 4B.

4. NUMERICAL MODELING

To find the effect of soil reinforcement in stress distribution, PLAXIS analysis was carried out. PLAXIS 2D version 8.2 was used. PLAXIS is a finite element code that has been developed specifically for analysis of deformation and stability in geotechnical engineering projects.

4.1 *PLAXIS input*

The present problem was formulated using 15 noded triangular elements. Plane strain case was considered. Mohr coulomb model was used. Modulus of subgrade reaction (k_S) was obtained from model test on strip footing. From this using Mekkiyah's correlation between Elastic modulus E and k_S, the value of E was obtained. Value of Φ was obtained from direct shear test. Footing and work space dimensions was kept the same as that of model footing and tank size respectively.

Table 3 Input parameters used for PLAXIS analysis

Input parameters	Sand	Footing	Geogrid
Model	Mohr- Columb	Elastic	Elastic
E (MPa)	1.5	-	-
Φ	34°	-	-
c (kPa)	1	-	-
γ(kN/m^3)	17	-	-
μ	0.3	0.3	-
*EA (kN/m)	-	$32\text{x}10^4$	270
EI (kN/m^2)	-	42.67	-

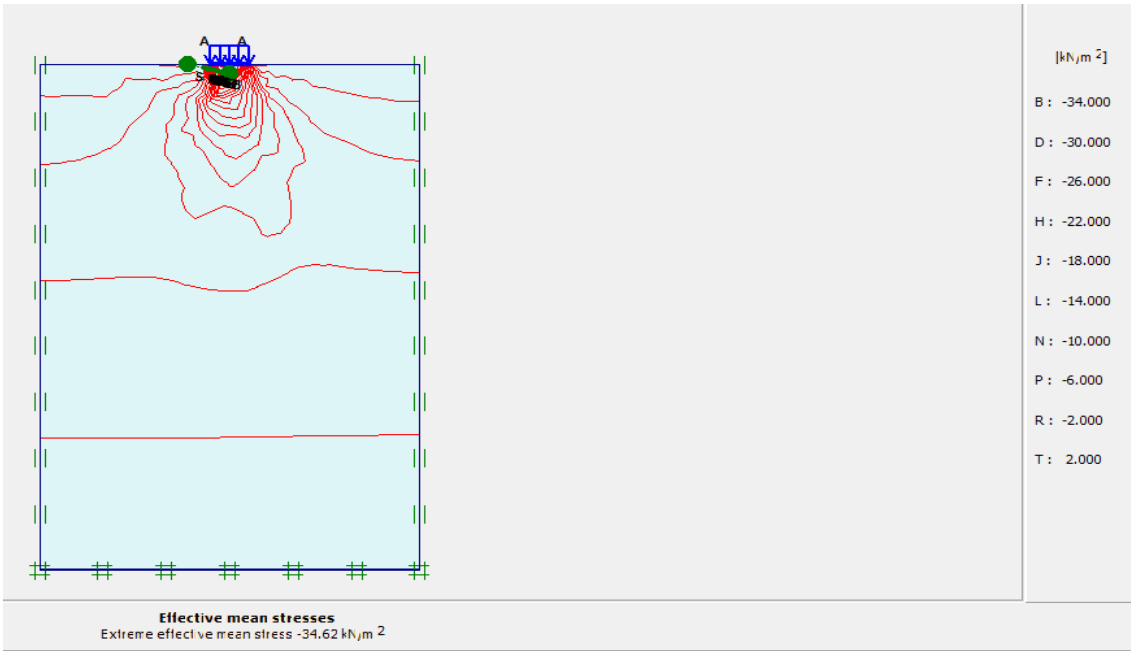
*EA corresponds to the tensile modulus of the geogrid per unit length.

The cross section of the geogrid was kept equal to twice the width of the footing. This was considered from literature review.

4.2 *PLAXIS output*

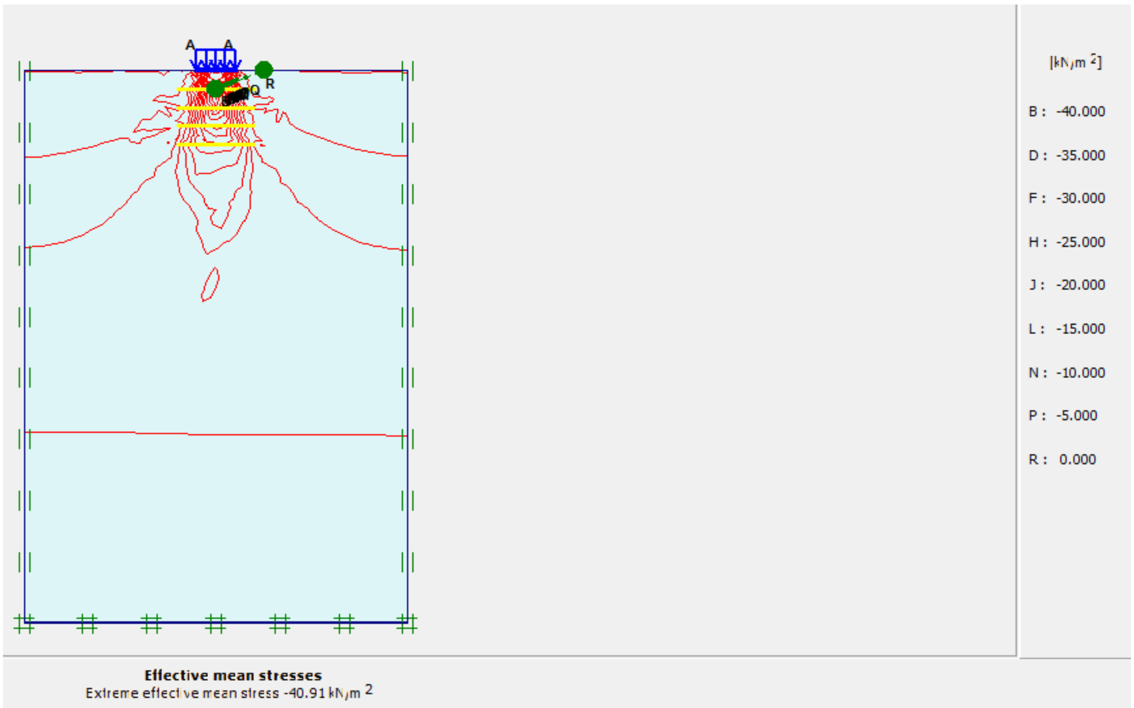
From PLAXIS analysis, vertical and shear stress contour for both reinforced and unreinforced case was obtained and the results were compared. The number of reinforcements (N), was varied from one to four. The contours seen in Figure 1 and 2 shows the comparison of stress distribution for unreinforced and reinforced case.

4.2.1 *Vertical Stress Contour*



Effective mean stresses
Extreme effective mean stress -34.62 kN/m 2

Figure 1 Unreinforced case

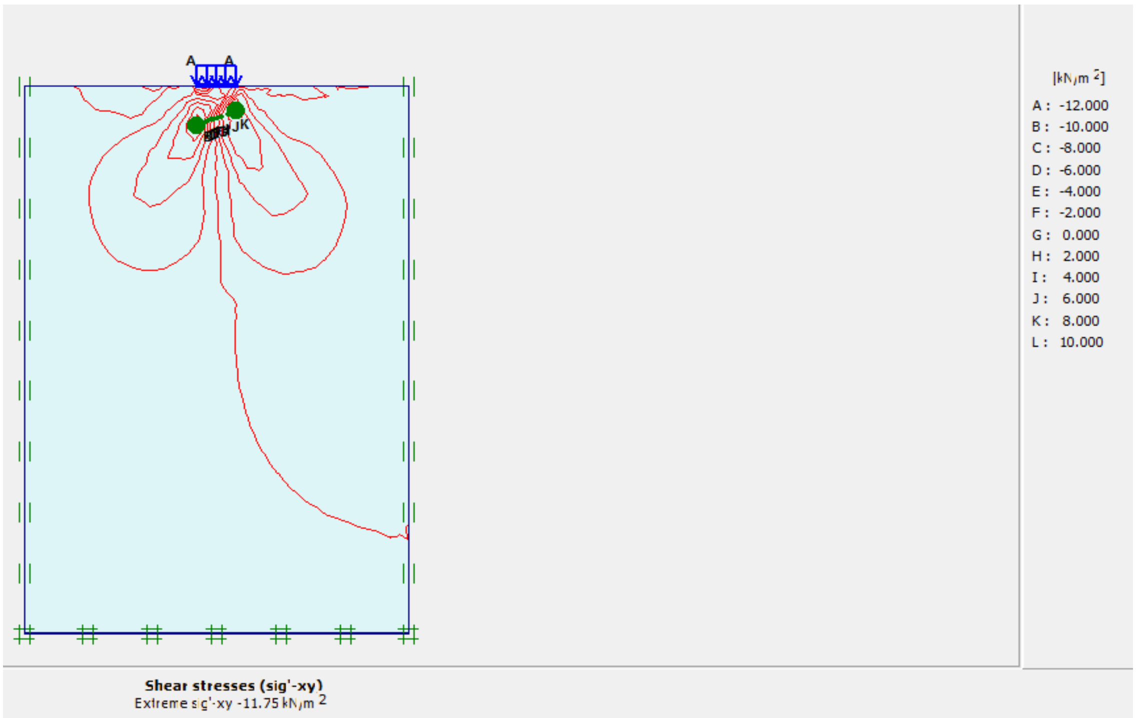


Effective mean stresses
Extreme effective mean stress -40.91 kN/m 2

Figure 2 Reinforced case with N = 4

4.2.2 *Shear stress contour*

Figure 3 and 4 shows the shear stress contour for unreinforced and reinforced case.



Shear stresses (sig'-xy)
Extreme sig'-xy -11.75 kN/m 2

Figure 3 Unreinforced case

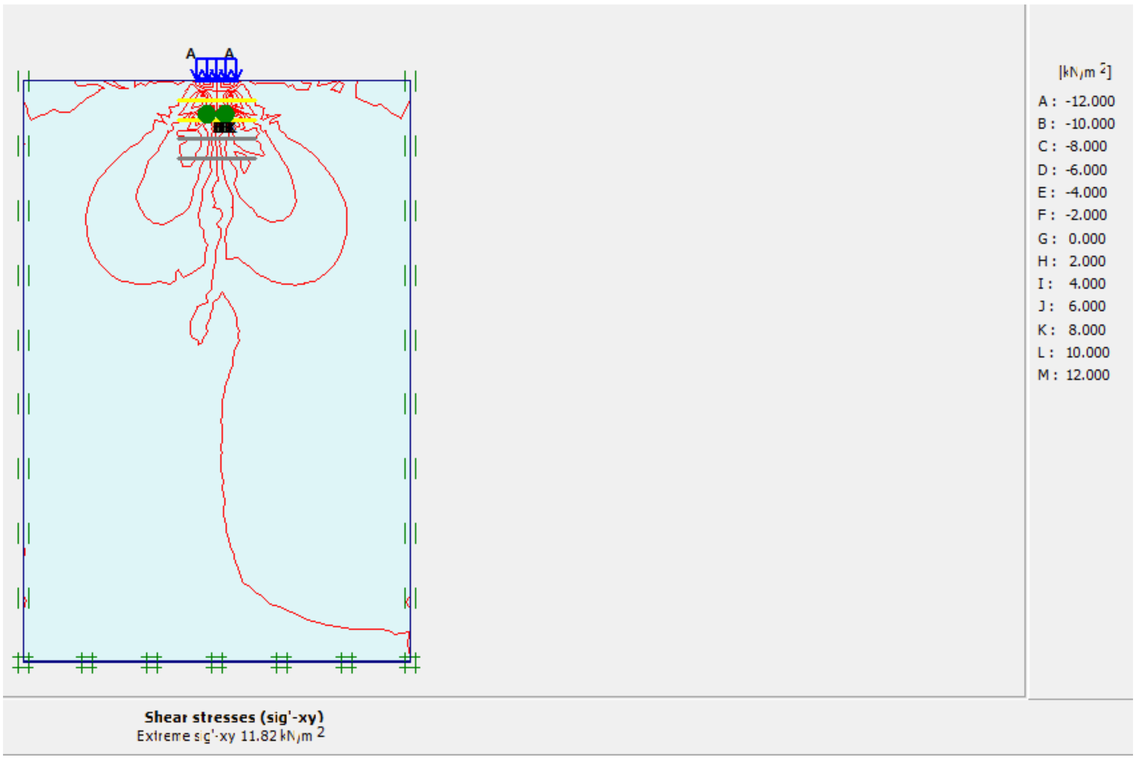


Figure 4 Reinforced case with N = 2

5 RESULTS AND DISCUSSIONS

This section discusses in detail the changes in the stress distribution in the soil due to the introduction of geogrid.

5.1 *Influence of reinforcement in Vertical stress distribution*

The vertical stress coefficient obtained theoretically and numerically for unreinforced case as seen in Table 4 ,showed good agreement. The depth of influence for 0.1q pressure bulb is 6B as per theory whereas from numerical analysis, it was found to be around 5.25B. 0.05q pressure bulb extended upto a depth of 6B in case of numerical analysis. The depth of pressure bulb is denoted by ‘z’,and its width from the center of the footing is denoted by ‘x’.

The vertical pressure at different depths z, below the center of a uniform load of intensity q and width of footing B, according to Boussinesq theory is given by,

$$\sigma_z = kq \qquad (1)$$

where ‘k’ is the vertical stress coefficient. $k = (\theta + \sin\theta)/\pi$, θ being the angle subtended at the center of the footing.
It is seen that the vertical stress coefficient ‘k’ obtained from numerical and experimental procedure is slightly lesser than that obtained theoretically.

Table 4 Variation of vertical stress coefficient with depth for unreinforced case

z/B	**Vertical stress coefficient ‘k’**		
	Theoretical	**Numerical**	**Experimental**
0.5	0.82	0.72	0.7
1	0.55	0.48	0.42
2	0.31	0.28	0.25
3	0.21	0.2	0.15
4	0.16	0.16	0.095
5	0.13	0.12	
5.5	0.11	0.08	
6	0.1	0.04	

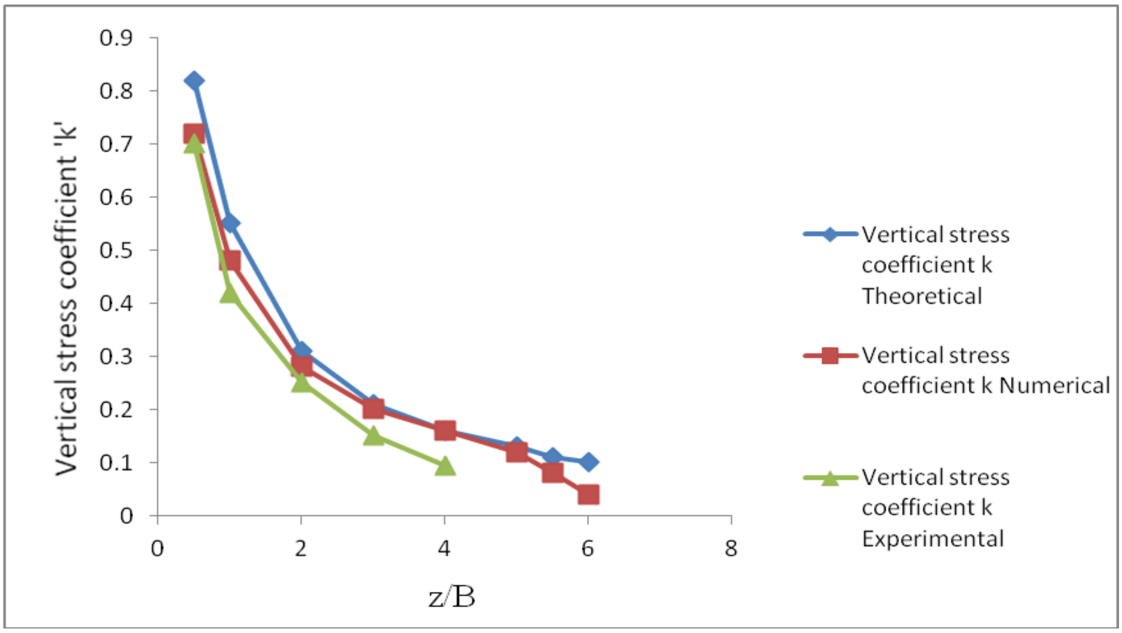


Figure 5 Variation of vertical stress coefficient with depth for unreinforced case.

Table 5 Comparison of vertical stress coefficient with increase in number of reinforcement obtained from numerical analysis.

z/B	Vertical stress coefficient 'k'				
	Without reinforcement	With N = 1	With N = 2	With N = 3	With N = 4
0.5	0.72	0.8	0.84	0.85	0.85
1	0.48	0.56	0.6	0.76	0.7
2	0.28	0.36	0.4	0.5	0.5
3	0.2	0.28	0.3	0.3	0.3
4	0.16	0.2	0.2	0.2	0.2
5	0.12	0.16	0.14	0.12	0.12
5.5	0.08	0.12	0.13	0.11	0.11
6	0.04	0.08	0.09		

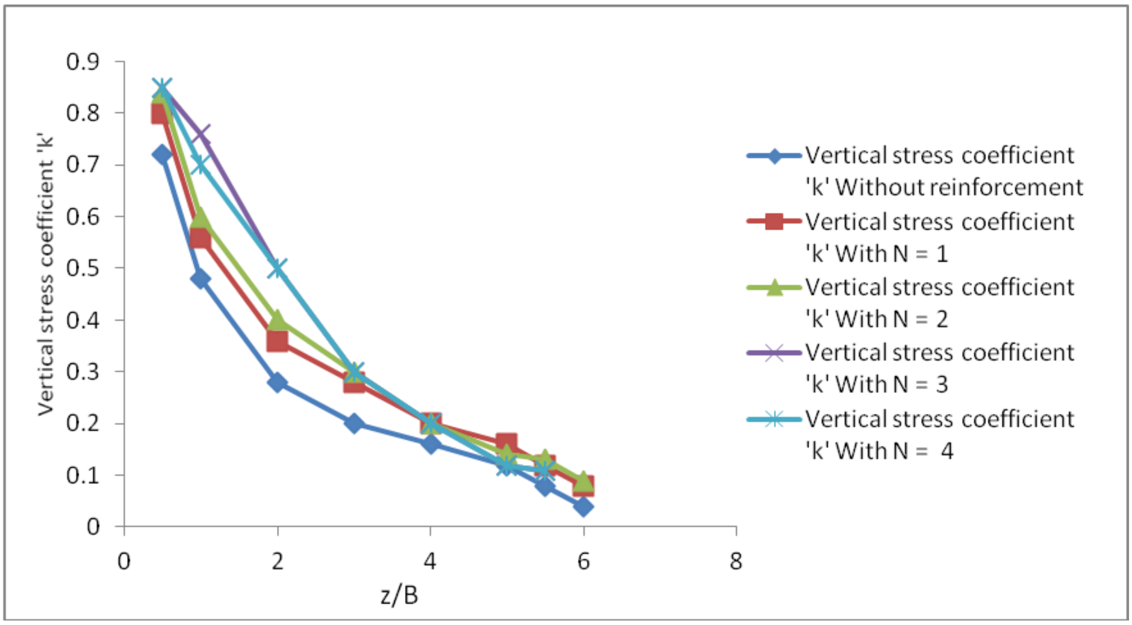


Figure 6 Comparison of vertical stress coefficient with increase in number of reinforcement obtained from numerical analysis

It is observed from table 5 , that with introduction of reinforcement, the vertical stress gets concentrated in the region near the reinforcement, as the vertical stress coefficient at the same depth is higher in reinforced case as compared to unreinforced case.The vertical stress coefficient obtained from experiment with N = 4 was compared with the results from the numerical analysis as shown in Figure 7 and the results showed good agreement.From PLAXIS analysis the variation in the depth and width of vertical and shear stress bulb with increase in number of reinforcement layers was traced and is shown in Figure 8 and 9.

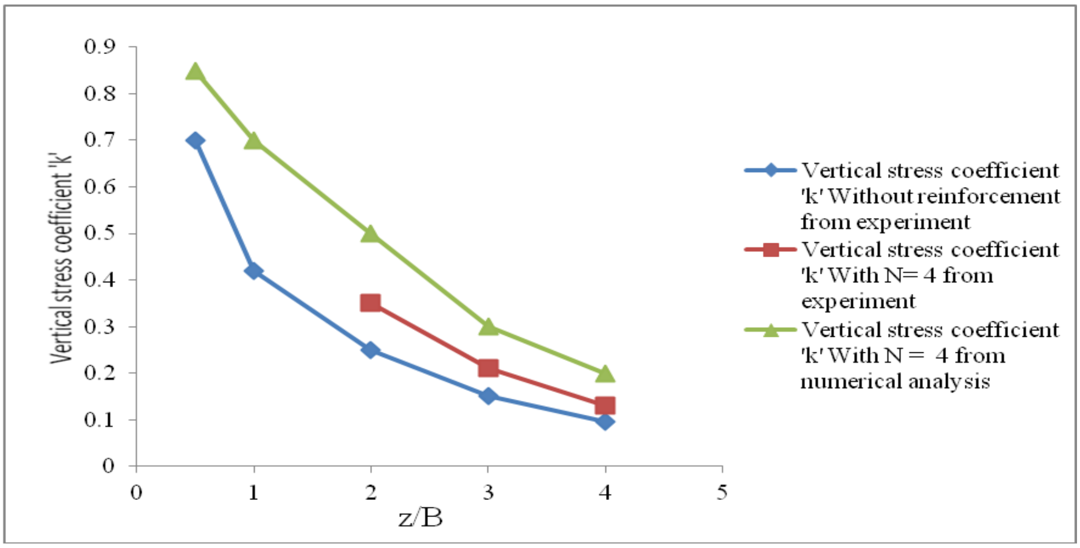


Figure 7 Comparison of 'k' for N = 4 obtained from experiment and numerical analysis

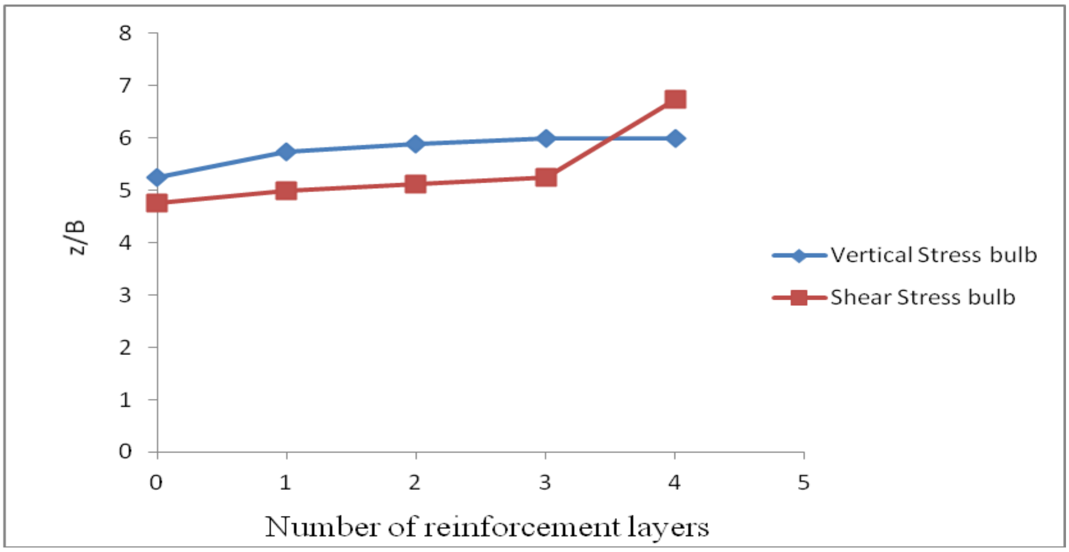


Figure 8 Variation in the depth of 0.1q pressure bulb and the depth of shear stress bulb with increase in number of reinforcement layers

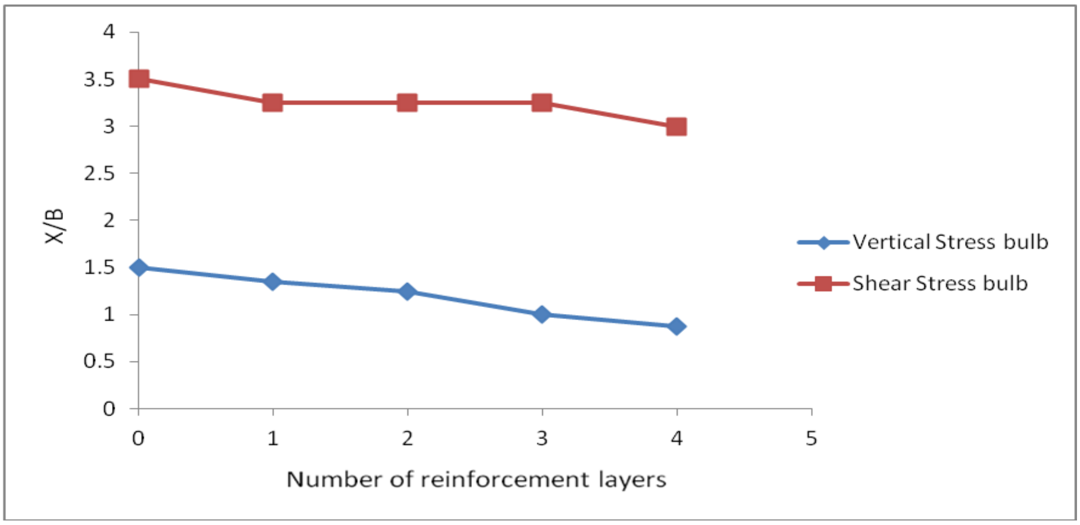


Figure 9 Variation in the width of 0.1q pressure bulb and the width of shear stress bulb with increase in number of reinforcement layers

It is found from Figure 8 and 9 that with introduction of reinforcement the depth of pressure bulb increases slightly and its width decreases. The same trend is observed for shear stress bulb too. Also, rotation of the principal stresses due to introduction of reinforcement was observed.

5.2 *Influence of reinforcement in Shear stress distribution*

The distribution of shear stress at a depth z/B = 0.5, along the width of the footing was obtained and is shown in Figure 10. It is found that the shear stress increases initially at a distance x = 0.5B from the center of the footing and then decreases subsequently.

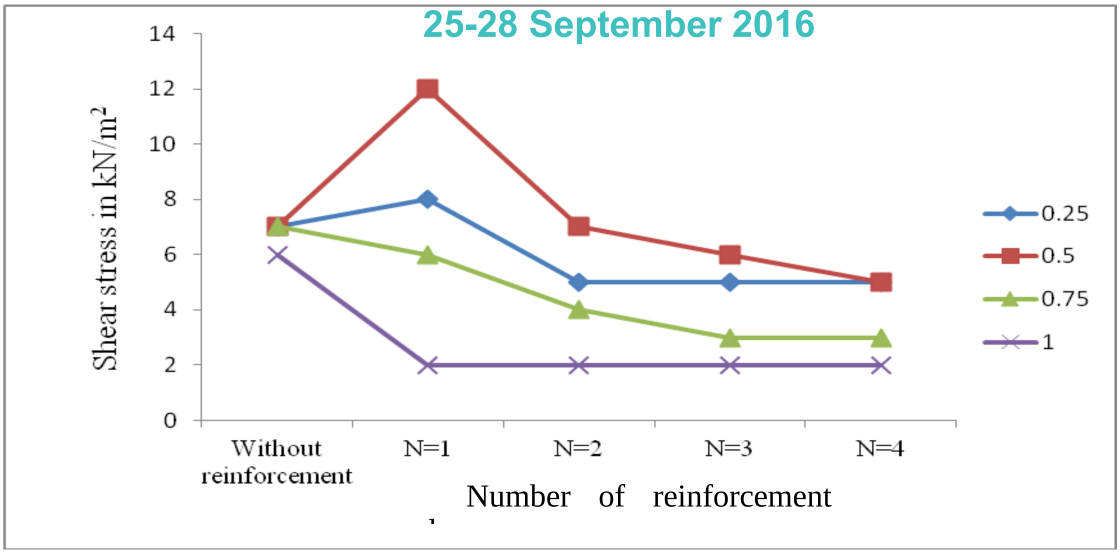


Figure 10 Variation of shear stress along the footing width at z/B = 0.5

The distribution of shear stress at x/B = 0.25, for various values of z/B was obtained and is shown in Figure 11. It is found that the shear concentration is more at z/B = 1 and then its value decreases below that depth.

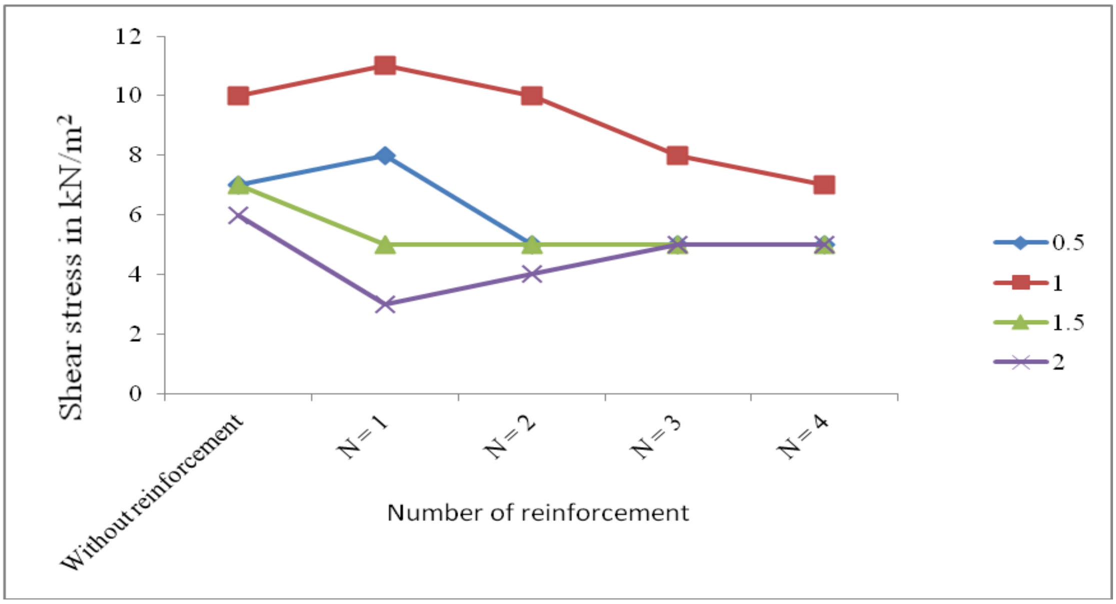


Figure 11 Variation of shear stress along the depth for x/B = 0.25

5.3 Comparison of vertical and shear stress bulb of reinforced and unreinforced case obtained from numerical analysis

The vertical and shear stress bulb obtained from numerical analysis was compared and a tentative bulb was obtained for both reinforced and unreinforced case. The depth of reinforcement was taken as 2B and four layers of reinforcement at a spacing of 0.5B was considered for obtaining the pressure bulb for reinforced case.

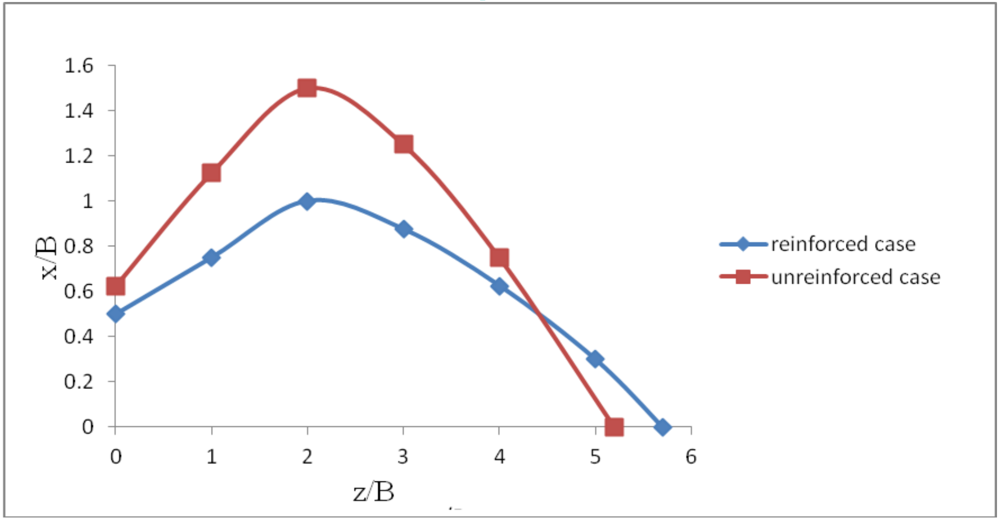


Figure 12 Comparison of 0.01q pressure bulb for reinforced and unreinforced case obtained from numerical analysis

Figure 12 shows the comparison of 0.01q pressure bulb for reinforced and unreinforced case obtained from numerical analysis. From Figure 11, it is observed that there is reduction in the width and increase in the depth of the vertical stress bulb. The same strend is observed for shear stress buld too. Figure 13 shows the comparison of shear stress bulb for reinforced and unreinforced case obtained from numerical analysis. The shear stress bulb is plotted with the origin as the central axis (taken as center of the footing) and it is symmetrical on either side of the central axis.

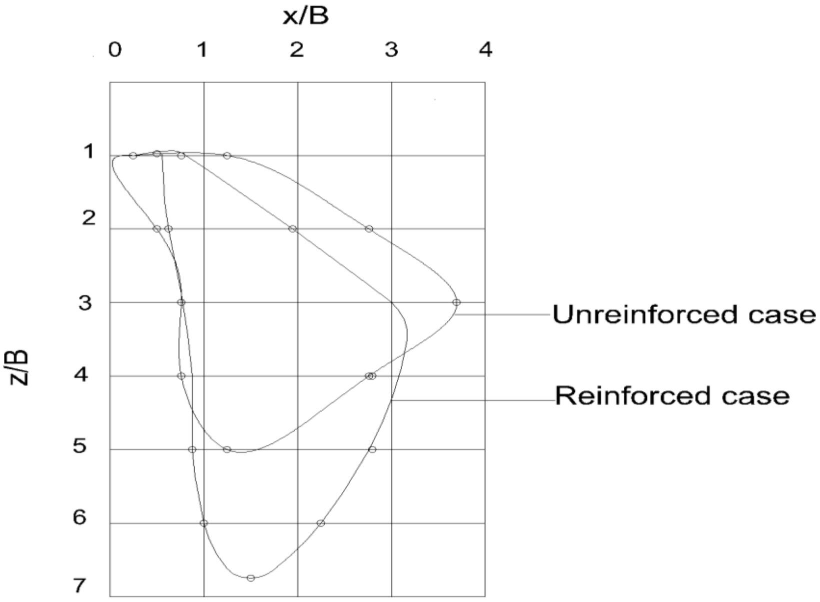


Figure 13 Comparison of shear stress bulb for reinforced and unreinforced case obtained from numerical analysis

Kurian et al (1997) have reported that incase of a square footing, the stress contours shift downwards and the stresses get concentrated near the reinforcement for the reinforced case.

The results of this study shows the same trend signifying that the same observation is appropriate for case of strip footing also .

6 CONCLUSION

From the experimental work and PLAXIS analysis, the following conclusions were obtained:

1. The vertical stress coefficient ‘k’ obtained from numerical and experimental procedure is slightly lesser than the one obtained theoretically.
2. With introduction of reinforcement, the vertical stress gets concentrated in the region near the reinforcement.Increase in the vertical stress in that region results in increase in the strain, which inturn results in the mobilisation of maximum tensile strength in the reinforcement. Thus there is a reduction in the settlement as the strain developed is utilised for the mobilisation of tensile strength of reinforcement and it doesn’t travel downward. Shear stresses increases at a distance x/B = 0.5B from the center and then decreases gradually. Presence of reinforcement confines the shear stresses and doesn’t allow the distribution of shear stresses to a greater distance from the center of the footing. The shear stress is maximum at a distance of x = 0.5B from the center and at a depth of z = B.
3. With introduction of reinforcement the depth of pressure bulb increases slightly and its width decreases. The same trend is observed for shear stress bulb. Most of the stresses is felt within the depth 4B. Only a smaller proportion of the stress extends upto a greater depth for reinforced case. Also, rotation of principal stresses is observed due to the presence of reinforcement.
4. With introduction of reinforcement there is a reduction in the interference effect as the width of the vertical and shear stress bulb is reduced.

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