BEHAVIOR OF SQUARE FOOTING RESTING ON REINFORCED SAND SUBJECTED TO INCREMENTAL LOADING AND UNLOADING

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Abstract

The foundations of various structures are subjected to cyclic loading in addition to static loading in many situations. This paper presents the results of laboratory model tests on square footings supported on geogrid reinforced sand bed under incremental loading and unloading conditions for different densities of sand bed and U/B ratio. The incremental values of intensity of loads (loading, unloading and reloading) were applied on the footing to evaluate the response of a square footing and also to obtain the value of elastic rebound of the footing corresponding to each cycle of load. The effect of sand for the density 1.59 gm/cc, 1.69 gm/cc, and 1.79 gm/cc and for different U/B ratio of 0.2, 0.4, and 0.6were investigated on ultimate bearing capacity and the dynamic properties such as coefficient of elastic uniform compression C_u, coefficient of elastic uniform shear C_τ, coefficient of elastic non-uniform shear C_ψ and the coefficient of elastic non uniform compression C_φ. The results shows that the value of ultimate bearing capacity and the value of C_u, C_τ, C_φ and C_ψ of sand were increased by increasing the density of sand and with the increase of U/B ratio up to 0.4. The results of ultimate bearing capacity and values of dynamic properties (C_u, C_τ, C_φ and $C_{\psi)}$ for reinforced sand are greater than unreinforced sand bed.

Keywords: *Geogrid, coefficient of elastic uniform compression, coefficient of elastic uniform shear, coefficient of elastic non-uniform shear, coefficient of elastic non uniform compression.*

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1. INTRODUCTION

Shallow foundations are widely used in transmitting loads from the superstructure to the supporting soils. After the foundation is constructed, the soil is permanently loaded by both the gravity loads and the live loads of the superstructure. In some of the structures like petroleum tanks, docks and harbors, the supporting soil is subjected to repeated loading and unloading whose frequency and load amplitude are dependent on the rate of filling and emptying of oil tanks and ships respectively. Several studies have been carried out to understand the behavior of the model footings resting on sand deposits of different relative densities under cyclic vertical loading[1], and also, few studies were reported the effect of (i) use of new generation of reinforcements, grid-anchor, for the purpose of reducing the permanent settlement of these foundations under the influence of deferent proportions of the ultimate loads [2], (ii)randomly distributed polypropylene fiber reinforcement in modifying the dynamic characteristics of locally available sand [3].

In the present study, an attempt has been made to investigate the effect of square footing for static and cyclic behavior on dry sand bed with and without reinforcement of geogrid at U/B ratios 0.20, 0.40 and 0.60 and at different densities of 1.59gm/cm^3, 1.69gm/cm^3 and 1.79gm/cm^3. The static behavior was ascertained in terms of bearing capacity and the dynamic response in terms of coefficient of uniform compression (C_u).

The dynamic properties of soil, such as the coefficient of elastic shear $C\tau$, the coefficient of elastic non-uniform shear $C\psi$ and the coefficient of elastic non uniform compression $C\varphi$ are determined.

2. BACKGROUND

Terzaghi's(1943) theory of bearing capacity is widely used in practice. Verma *et al.*(2000), Samal (2005) performed cyclic tests in a square tank on river sand. The coefficient of elastic uniform compression (Cu) reduces and depends upon number of reinforcement and its dimension. Mitchel Heming (2012**);** addition of triaxial geogrid provided a substantial reduction in permanent deformation. Moghaddas et. al (2009), (2010), Mostafa and A.K. Nazir (2010**),** Verma and Bhatt (2010) geosynthetic reinforcement on the cumulative settlement of repeatedly loaded rectangular model footings placed on reinforced sand.

3. MATERIALS AND EXPERIMENTAL STUDY

In the present study Gatapraba river sand with symbolic representation SP is filled in the testing tank of size 600mm x 600mm x 600mm using raining technique for densities 1.59gm/cc, 1.69gm/cc 1.79gm/cc with geo-grid (SG-200) as reinforcement placed at U/B ratios 0.2, 0.4 and 0.6. is used. A steel plate of 100 mm x 100 mm x 10 mm is used as footing.

All model tests were conducted using the setup shown in Fig.1. The vertical load was applied on the model footing using screw jack, which provides vertical displacement. Proving ring and two dial gauges placed diagonally on the footing were used for measuring load and settlement respectively. The loading, unloading and reloading was done at five stages.

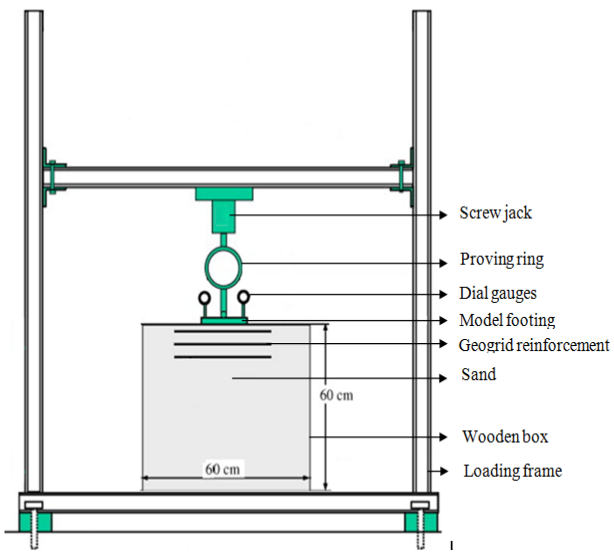

Fig -1: Line diagram of Experimental Setup

The U/B ratio corresponding to depth first reinforcement was given in table 1.

Table -1: U/B ratio corresponding first reinforcement depth

U/B ratio	First reinforcement depth(U)
0.2	2cm
0.4	4cm
0.6	6cm

4. RESULTS AND DISCUSSION

4.1. Static Loading on Un-Reinforced Sand:

The load-deformation curve for the density 1.59 gm/cc, 1.69 gm/cc and 1.79gm/cc are plotted and shown in the fig. 2.

From the Fig.2 it is observed that (i)the increase in the density of the foundation bed leads to increase in the bearing capacity and decrease in the deformation, (ii) the load carrying capacity of the reinforced sand bed of density 1.59 gm/cc, 1.69 gm/cc and 1.79 gm/cc are respectively 32, 98, 108 kN/m^2.

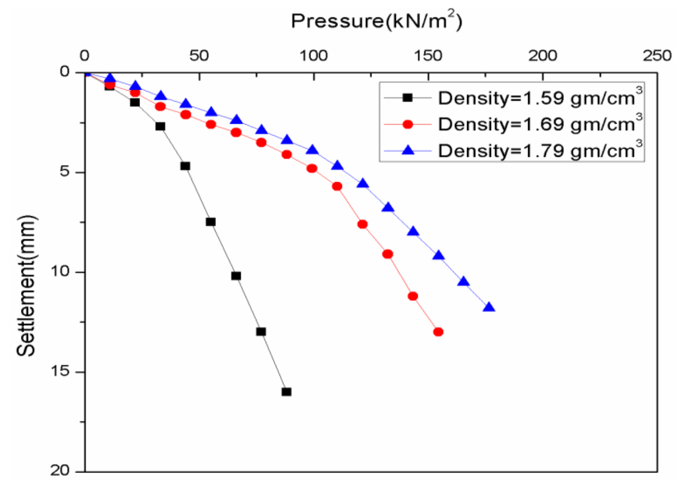

Fig -2: Pressure - Settlement curves for unreinforced sand for different densities

4.2 Effect of U/B on Ultimate Bearing Capacity of the Square Footing on Reinforced Sand Bed for Static Loading:

The pressure-settlement curves for the densities 1.79 gm/cc for U/B = 0.2, 0.4 and 0.6, for geo-grid SG-200 are shown in Fig.3. The value of ultimate bearing capacity of the footing of reinforced sand for different U/B ratios and densities is exclusively given in Table 3.

Table -2: Ultimate bearing capacity of reinforced sand for different densities and U/B ratio

	Ultimate bearing capacity (kN/m^2)		
	γ = 1.59 gm/cc	γ =1.69 gm/cc	γ =1.79 gm/cc
U/B = 0.2	148	164	176
U/B = 0.4	158	174	182
U/B = 0.6	110	128	154

It can be seen that, the pressure v/s footing settlement response of reinforced sand bed is far better than the un-reinforced case. The footing resting on the soil-reinforcement composite will carry more loads. This shows that strength improvement is totally depends on the position of the reinforcement within the sand bed. The response of the reinforced sand bed is seen to improve as the depth ratio U/B= 0.4 and thereafter shows a decreasing trend.

For γ = 1.79 gm/cc, at U/B = 0.4, there is a maximum ultimate bearing capacity of 182 kN/m^2 is observed when compared with densities 1.59gm/cc and 1.69gm/cc the values are 158 kN/m^2 and 174 kN/m^2 respectively.

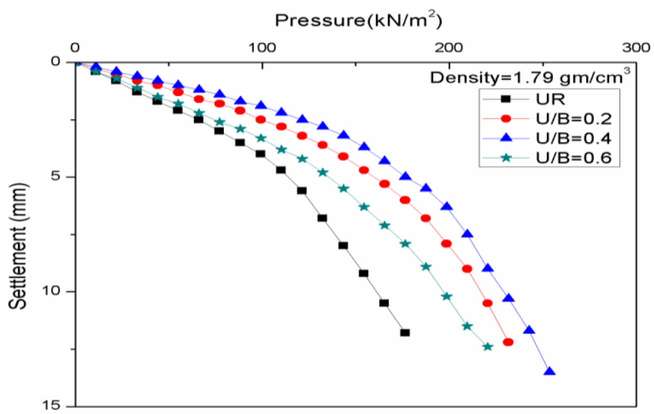

Fig -3: Pressure - Settlement curves for 1.79 gm/cc density at different U/B ratios.

4.3 Variation of Density with Constant Depth Ratio (U/B):

The pressure-settlement curves for U/B = 0.2, 0.4 and 0.6 and densities 1.59 gm/cc, 1.69 gm/cc and 1.79 gm/cc using geo-grid 200 are shown in Fig. 4 – 6. From figures obtained it is found that the interfacial frictional resistance increases with increases in soil density. Therefore, with the increase in density of the soil, the frictional resistance between the geo-grid and the sand increases, thereby increasing the resistance to downward penetration of sand below the geo-grid and hence a higher improvement in overall strength. This is due to the frictional resistance at the interface of the sand and reinforcement which would have prevented the soil mass from shearing under vertical applied load (8).

The maximum value of ultimate bearing capacity obtained for U/B ratio 0.2, 0.4 and 0.6 for density 1.79 gm/cc, is 176 kN/m^2, 182 kN/m^2 and 154 kN/m^2 respectively. The ultimate load carrying capacity of reinforced sand bed increases up to U/B ratio 0.4 and afterworlds decreases

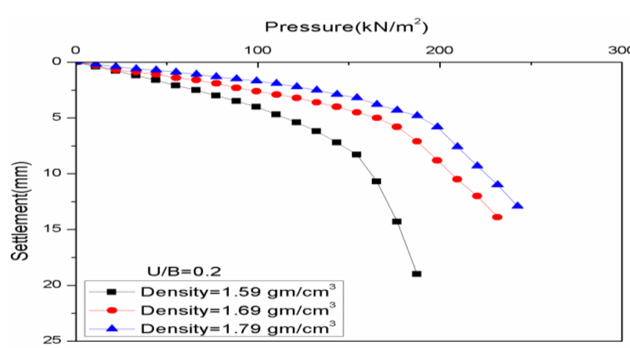

Fig -4: Pressure - settlement curves for U/B ratio 0.2 at different densities

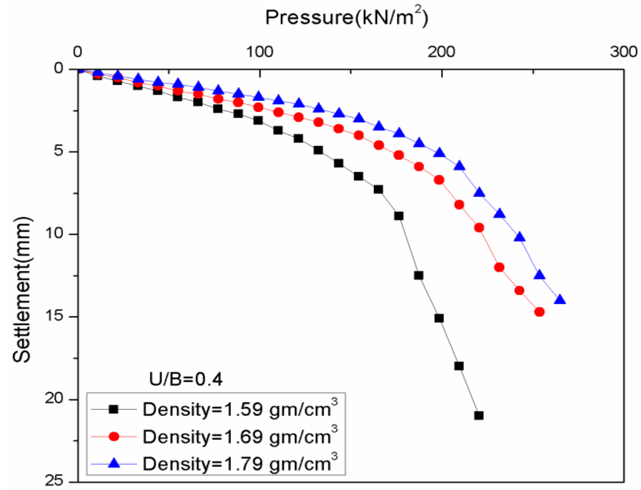

Fig -5: Pressure - settlement curves for U/B Ratio 0.4 at different densities

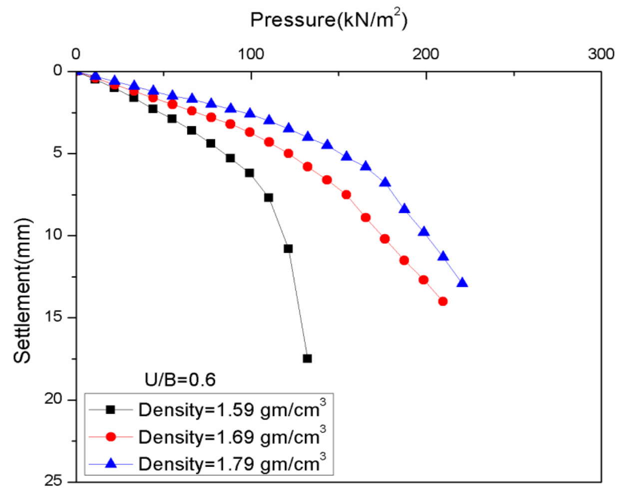

Fig -6: Pressure - settlement curves for U/B Ratio 0.6 at different densities

4.4 Cyclic Tests on Un-Reinforced Sand

The cyclic tests results for the unreinforced foundation bed were plotted; the pressure settlement curve for the densities 1.79 gm/cc, 1.69gm/cc and 1.59 gm/cc are plotted and shown in Fig. 7. From figure it is observed that the (i) for a pressure, the increase in the density of the foundation bed leads to decrease in the settlement, (ii) as the increase in the density of the foundation bed Coefficient of Elastic Uniform Compression(C_u) of sand increases.

For γ = 1.79 gm/cc, there is a maximum value of C_u 12.67x10^4kN/m^3 is observed when compared with other density 1.59, 1.69gm/cc the values are, 6.4x10^4, 10.76x10^4kN/m^3 respectively.

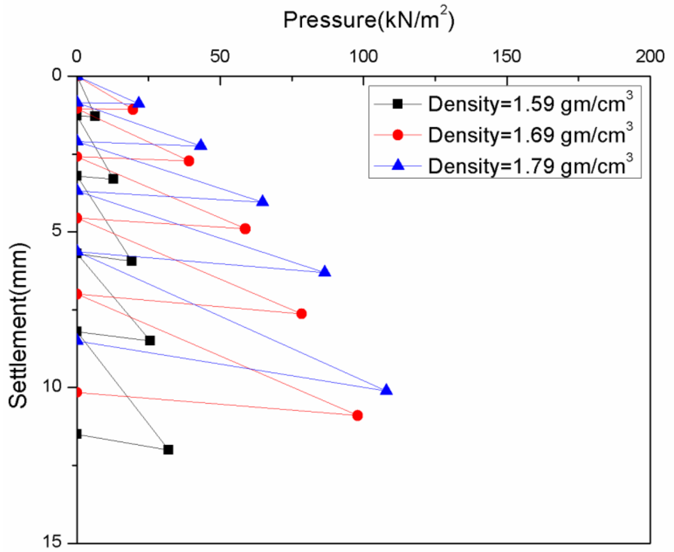

Fig - 7: Pressure -settlement curves for unreinforced sand with different densities

4.5 Cyclic Test on Reinforced Sand Bed:

The experimental results of the applied cyclic loads, incrementally (loading, unloading and reloading) with footing settlement rested on reinforced sand with density of 1.59 gm/cc, 1.69 gm/cc and 1.79 gm/cc for U/B = 0.2, 0.4 and 0.6 are shown in Fig.8 - 10 and the following observations were made. It indicates that in each stage due to unloading, a small amount of settlement rebounds which named elastic or recoverable settlement (the amount of elastic rebound of the soil increases with increase in the stress level) while a major part of the settlement is plastic settlement and remains in the system.

It can be seen that, the pressure v/s footing settlement response of reinforced sand bed is far better than the un-reinforced case. This is due to the frictional resistance at the interface of the sand and reinforcement which would have prevented the soil mass from shearing under vertical applied pressure.

The footing resting on the soil-reinforcement composite will carry more loads. This shows that coefficient of elastic uniform compression of sand improvement is totally depends on the position of the reinforcement and density within the sand bed. The response of the reinforced sand bed is seen to improve as the depth ratio u/B= 0.4 and thereafter shows a decreasing trend.

As the increase in the density of the foundation bed coefficient of elastic uniform compression of sand also increases. For γ = 1.79 gm/cc and U/B=0.4 there is a maximum value of C_u $16.54*10^4 kN/m^3$ is observed when compared with other density 1.59, 1.69gm/cc the values are, $16.12*10^4 kN/m^3$, $16.40*10^4 kN/m^3$ respectively.

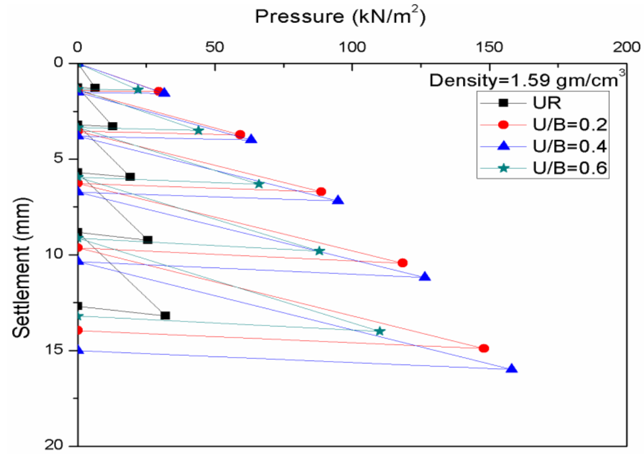

Fig -8: Pressure - settlement curves for 1.59density at different U/B ratio

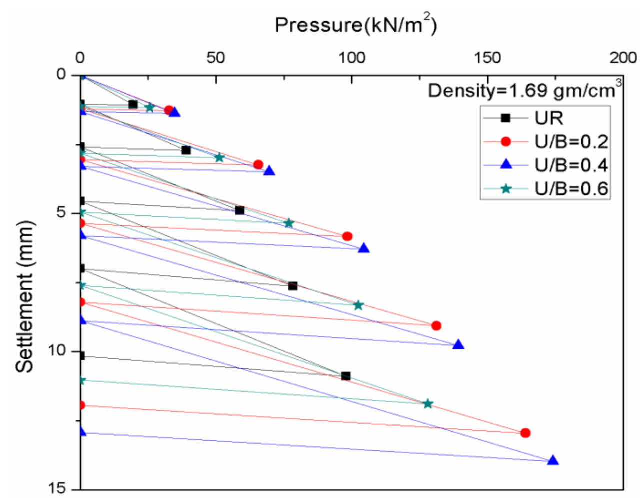

Fig -9: Pressure - settlement curves for 1.69 density at different U/B ratio

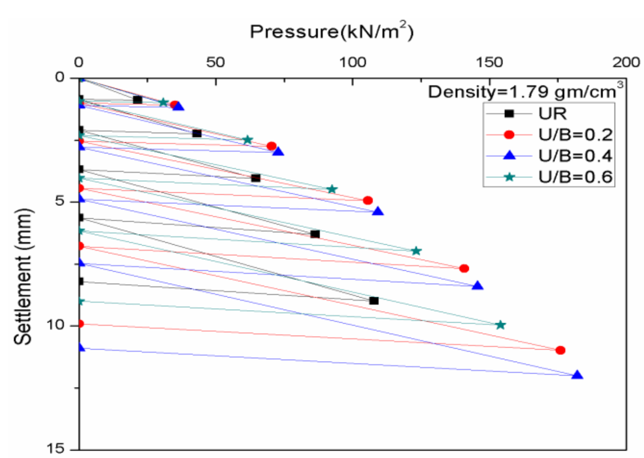

Fig -10: Pressure - settlement curves for 1.79 density at different U/B ratio

The value of C_u of the footing of reinforced sand for different u/B ratios and densities is exclusively given in table 3.

Table -3: Coefficient of elastic uniform compression of reinforced sand for different density and U/B ratio

	Coefficient of elastic uniform compression (KN/m^3)		
	γ = 1.59 gm/cm³	**γ =1.69 gm/cm³**	**γ =1.79 gm/cm³**
U/B = 0.2	$15.57x10^4$	$16.20x10^4$	$16.42x10^4$
U/B = 0.4	$16.12x10^4$	$16.40x10^4$	$16.54x10^4$
U/B = 0.6	$13.75x10^4$	$14.88x10^4$	$16.00x10^4$

4.6 Variation of Densities with Constant Depth Ratio (U/B):

The pressure-settlement curves for the constant depth ratio U/B = 0.2, 0.4 and 0.6 for densities 1.59 gm/cc, 1.69 gm/cc and 1.79 gm/cc using geo-grid 200 are shown in Fig. 11-13, from fig it is found that,

The interfacial frictional resistance increases with increases in soil density. Therefore, with the increase in density of the soil, the frictional resistance between the geo-grid and the sand increases, thereby increasing the resistance to downward penetration of sand below the geo-grid and hence a higher improvement in coefficient of elastic uniform compression.

The maximum value of coefficient of elastic uniform compression (C_u) for density 1.79 gm/cc for U/B ratio 0.2, 0.4 and 0.6 is $16.42x10^4$ kN/m^3, $16.54x10^4 kN/m^3$ and $16.00x10^4 kN/m^3$ respectively. The C_u value increases up to U/B ratio 0.4 and afterworlds decreases As increase in density, the settlement goes on reducing..

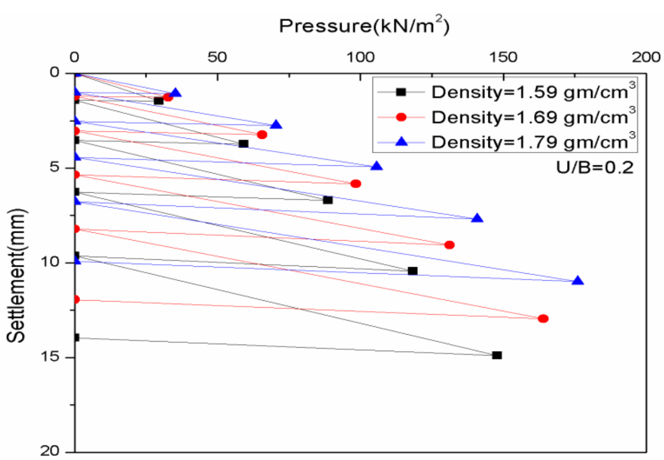

Fig -11: Pressure - settlement curves for U/B Ratio 0.2 at different densities

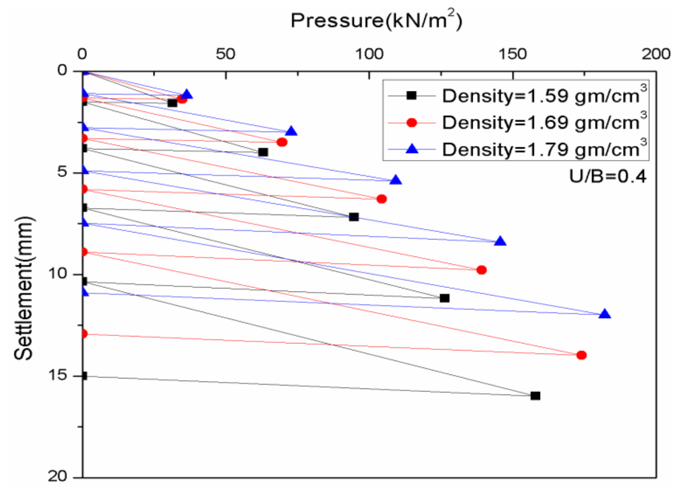

Fig -12: Pressure - settlement curves for U/B Ratio 0.4 at different densities

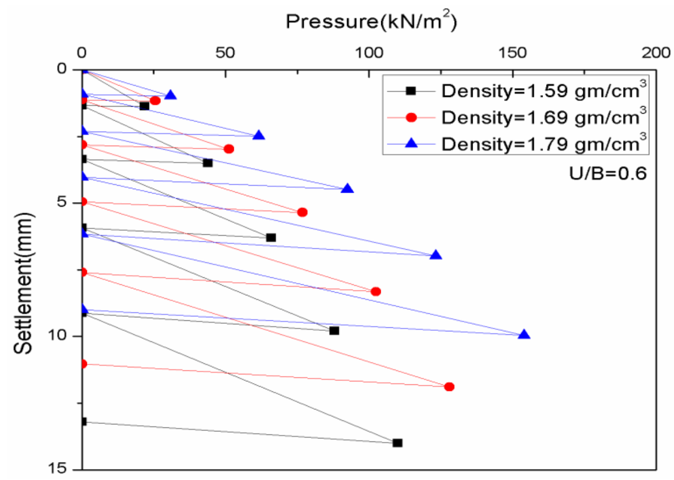

Fig -13: Pressure - settlement curves for U/B Ratio 0.6 at different densities

4.7 The role of Soil Density

The elastic rebound of the square footings on sand with three relative densities of 1.59 gm/cc, 1.69 gm/cc and 1.79 gm/cc corresponding to each intensity of load respectively is shown in Figure 14-16 for U/B ratio of 0.2, 0.4 and 0.6 respectively.

The Figure 14-16 for U/B ratio of 0.2, 0.4 and 0.6 shows that the slope of elastic lines which is representative of the coefficient of elastic uniform compression, C_u, increases with an increase in the density of the sand, irrespective of U/B ratio.

From Fig-14 to 16, For γ = 1.79 gm/cc and U/B=0.2, there is a maximum value of C_u $16.42x10^4 kN/m^3$ is observed when compared with other density 1.59, 1.69gm/cc the values are, $15.57x10^4$, $16.20x10^4 kN/m^3$ respectively.

From Fig-14 to 16, For γ = 1.79 gm/cc, at U/B=0.4 there is a maximum value 0f C_u 16.54x10^4kN/m^3 is observed when compared with other density 1.59, 1.69gm/cc the values are, 16.12x10^4 , 16.40x10^4kN/m^3 respectively.

From Fig-14 to 16, For γ = 1.79 gm/cc, at U/B=0.6 there is a maximum value 0f C_u 16.00x10^4kN/m^3 is observed when compared with other density 1.59, 1.69gm/cc the values are, 13.75x10^4 , 14.88x10^4kN/m^3 respectively.

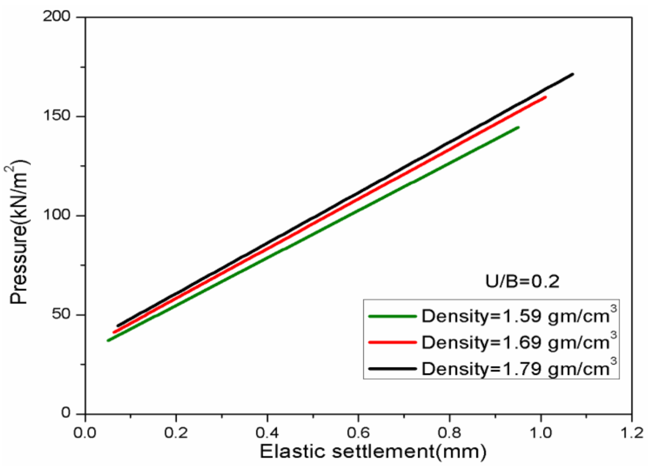

Fig -14: Pressure - settlement for three densities at U/B=0.2

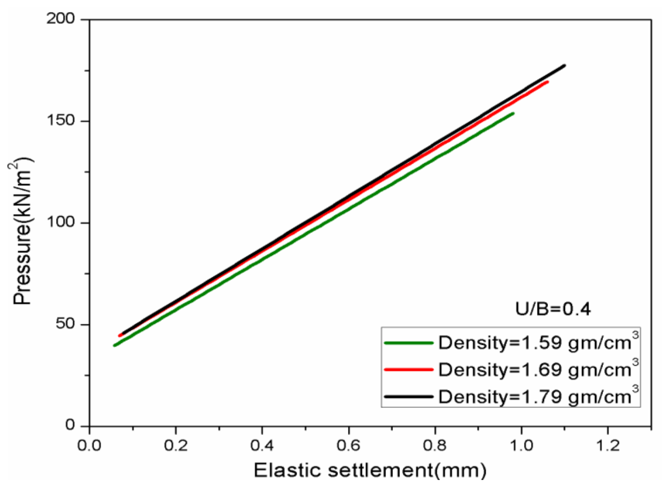

Fig -15: Pressure - settlement for three densities at U/B=0.4

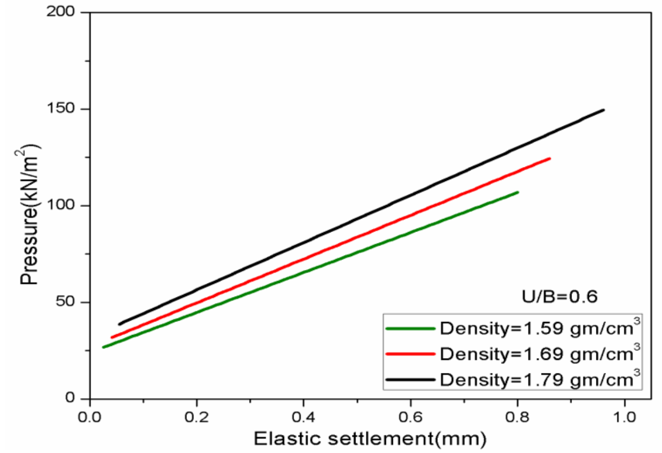

Fig -16: Pressure- settlement for three densities at U/B=0.6

4.8 The Role of U/B Ratio

Figure 17-19, shows the elastic rebound of the square footing with three different U/B ratios of 0.2, 0.4 and 0.6, corresponding to each intensity of load and for sand densities of 1.59 gm/cc, 1.69 gm/cc and 1.79 gm/cc, respectively.

The U/B ratio 0.2,0.4 and 0.6 for sand densities1.59 gm/cc, 1.69 gm/cc and 1.79 gm/cc shows that the slope of elastic lines which is representative of the coefficient of elastic uniform compression, C_u, lines increase at U/B 0.4 compare to 0.2 and 0.6, irrespective of sand relative density.

As the increase in the density of the foundation bed C_u of sand increases For γ = 1.79 gm/cc, at U/B=0.4 there is a maximum value 0f C_u 16.54x10^4 kN/m^3 is observed when compared with other density 1.59, 1.69gm/cc the values are, 16.12x10^4 , 16.40x10^4kN/m^3 respectively.

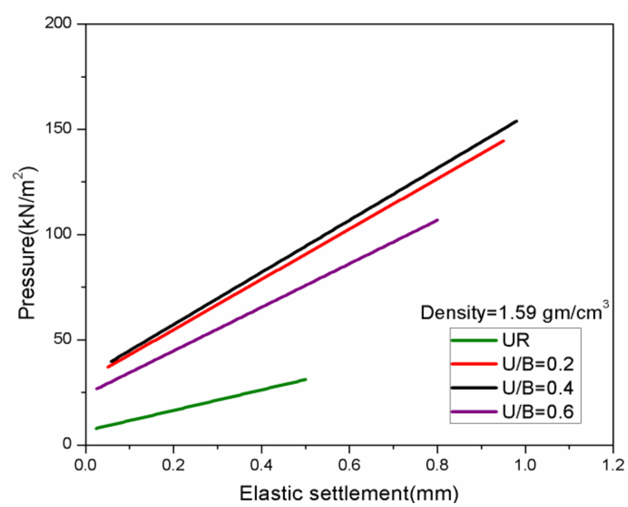

Fig -17: Pressure - settlement for three U/B ratios at density=1.59 gm/cm^3

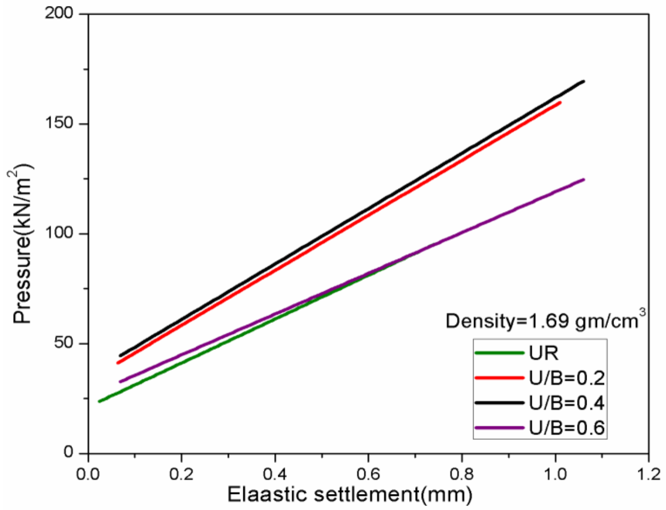

Fig -18: Pressure - settlement for three U/B ratios at density=1.69 gm/cm^3

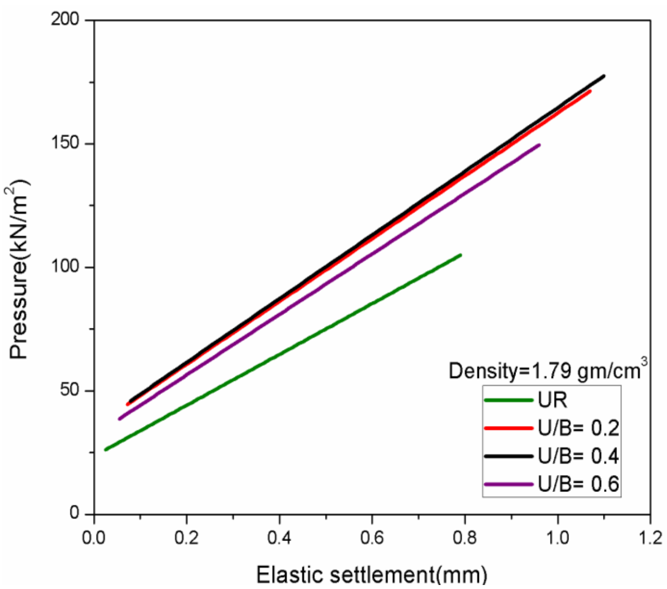

Fig -19: Pressure - settlement for three U/B ratios at density=1.79 gm/cm^3

4.9. The Effect of U/B Ratio on Coefficient of Elastic Uniform Compression

In order to clarify the effect of U/B ratio on coefficient of elastic uniform compression, the variation of C_u (11) with U/B ratio of square footing for sand densities of 1.59 gm/cc, 1.69 gm/cc and 1.79 gm/cc is shown in Figure 20.

The figure 20, imply that the value of coefficient of elastic uniform compression, C_u increases at U/B ratio 0.4 compare to 0.2 and 0.6, irrespective of sand density.

As the increase in the density of the foundation bed Coefficient of elastic uniform compression of sand increases For γ = 1.79 gm/cc, at U/B=0.4 there is a maximum value of C_u 16.54x10^4kN/m^3 is observed when compared with other densities 1.59 gm/cc and 1.69 gm/cc the values are, 16.12x10^4kN/m^3 and 16.40x10^4 kN/m^3 respectively.

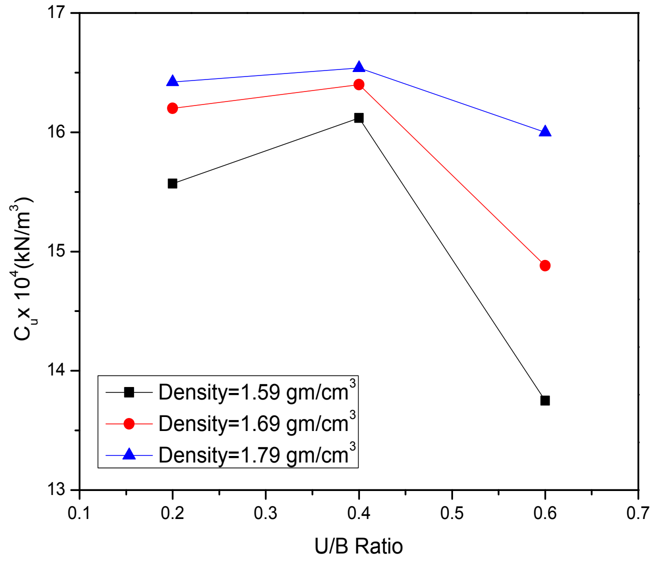

Fig -20: Variation of C_u with U/B ratios for different densities

4.10 The Effect of Densities on Coefficient of Elastic Uniform Compression for Reinforced Case

The coefficient of Elastic Uniform compression Vs densities are plotted for different U/B ratio.

Figures.21, implies that the value of coefficient of elastic uniform compression, C_u increases with increase in densities

From Fig-21, For γ = 1.79 gm/cc, at U/B=0.2 there is a maximum value 0f C_u 16.42x10^4kN/m^3 is observed when compared with other density 1.59, 1.69gm/cc the values are, 15.57x10^4 , 16.20x10^4kN/m^3 respectively.

From Fig-21, For γ = 1.79 gm/cc, at U/B=0.4 there is a maximum value 0f C_u 16.54x10^4kN/m^3 is observed when compared with other density 1.59, 1.69gm/cc the values are, 16.12x10^4 , 16.40x10^4kN/m^3 respectively.

From fig-21, For γ = 1.79 gm/cc, at U/B=0.6 there is a maximum value 0f C_u 16.00x10^4kN/m^3 is observed when compared with other density 1.59, 1.69gm/cc the values are, 13.75x10^4 , 14.88x10^4kN/m^3 respectively.

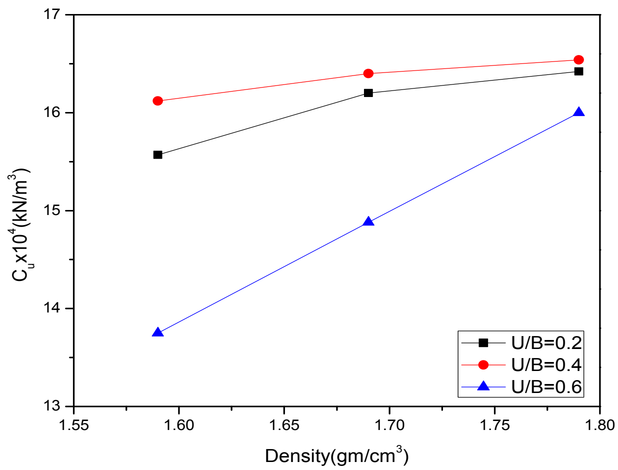

Fig -21: Variation of C_u with densities for different U/B ratios

4.12. Determination of the Dynamic Soil Properties

The coefficient of elastic uniform compression (C_u), the coefficient of elastic shear ($C\tau$), the coefficient of elastic non-uniform shear ($C\psi$) and the coefficient of elastic non uniform compression $C\varphi$ are then determined by the relations given below as per IS 5249: 1992 [21].

$C_u = P/ S_e$ kN/m^3.

$C_u = 1.5$ to $2\ C\tau$,

$C\varphi = 3.46\ C\tau$,

$C\psi = 1.5\ C\tau$.

Table -4: Values of Cu, Cτ, Cφ, Cψ for unreinforced conditions of sand bed for different densities.

Density (gm/cc)	C_u*10^4 KN/m^3	Cτ*10^4 KN/m^3	Cφ*10^4 KN/m^3	Cψ *10^4 KN/m^3
1.59	6.40	3.65	12.62	5.47
1.69	10.76	6.14	21.24	9.21
1.79	12.67	7.24	25.05	10.89

Table -5: Values of C_u, Cτ, Cφ, Cψ for reinforced conditions of sand bed for different densities and U/B ratios.

U/B ratio	Density (gm/cc)	C_ux10^4 kN/m^3	Cτx10^4 kN/m^3	Cφx10^4 kN/m^3	Cψx10^4 kN/m^3
0.2	1.59	15.57	8.89	30.75	13.33
0.2	1.69	16.20	9.25	32.00	13.87
0.2	1.79	16.42	9.38	32.45	14.07
0.4	1.59	16.12	9.21	31.86	13.81
0.4	1.69	16.40	9.37	32.42	14.05
0.4	1.79	16.54	9.45	32.69	14.17
0.6	1.59	13.75	7.85	27.16	11.77
0.6	1.69	14.88	8.50	29.41	12.75
0.6	1.79	16.00	9.14	31.62	13.71

5. CONCLUSIONS

The load carrying capacity (Q_u) and the value of C_u, Cτ, Cφ and Cψ of the square footing in case of unreinforced sand increases with the increase in the density of the soil medium, it further increases with the inclusion of geo-grid reinforcement. The values of Q_u and C_u, increases up to U/B ratio 0.4 and afterwards decreases. Use of the geo-grid reinforcement leads to better performance from the point of view of C_u improvement as well as settlement reduction. With the increase in the number of cycles of loading, unloading and reloading and density of the foundation medium the permanent plastic settlement of footing goes on reducing.

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