The International Journal Of Engineering And Science (IJES)
|| Volume || 3 || Issue || 7 || Pages || 72-83 || 2014 ||
ISSN (e): 2319 – 1813 ISSN (p): 2319 – 1805

Behaviour of Square footings on Prestressed Geosynthetic Reinforced Sand

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ABSTRACT

The technique of reinforcing the soil below shallow foundations with geosynthetic reinforcement is one of the fastest growing techniques in the field of geotechnical engineering. Therefore, laboratory physical model tests and numerical analyses were conducted to study the behaviour of prestressed geotextile-reinforced sand bed supporting a loaded square footing. In each case, reinforcement depth, prestressing force, prestress directions are varied of the geogrid for the purposes of knowing improvement in load bearing capacity of footing. The study revel that addition of prestress to the geotextile reinforcement results in significant improvement to the settlement and the load-bearing capacity of the foundation. For a surface footing, the load-carrying capacity at reinforcement depth B/4 gives maximum improvement in load bearing capacity and minimum settlement for biaxial prestressing force case (with prestress equal to 3% of the allowable tensile strength of the geotextile) is approximately double that of the geogrid reinforced sand without prestress.

KEYWORDS: *Model footing test, Prestress reinforced bed, Ultimate bearing capacity, Geotextile, Sand bed.*

Date of Submission: 10 July 2014 | Date of Publication: 30 July 2014

I. INTRODUCTION

The concept of soil reinforcement is extensively used in many geotechnical structures including retaining walls, embankments, foundations, slopes, highway and airport pavements, and railway tracks. The scope of this work will focus to study the experimentally the effects of prestressing to single and double layer reinforced sand bed on the load-bearing capacity and settlement at different size of footings, varying depth of reinforcement, varying prestressing magnitude and direction. The addition of prestress to geogrid reinforcement results in improvement in the load carrying capacity and reduction in settlement of the prestressed geogrid sand bed.Many experimental and analytical studies have been performed to investigate the behaviour of reinforced granular beds for different soil types. Binquet and Lee [1] conducted tests on sand reinforced with metal strips. Kurian et al. [8] simulated reinforced soil systems with horizontal layers of reinforcement using a 3D nonlinear finite element programme. The results of numerical analysis were in good agreement with those obtained from model tests. Deb et al. [10] presented a model for the analysis of granular foundation beds reinforced with several geosynthetic layers.

Alamshahi and Hataf [2] studied the effect of providing grid anchors to geogrid in a reinforced sand slope. They conducted a series of laboratory model tests and finite element analysis of a strip footing resting on a reinforced sand slope. They found that the bearing capacity of rigid strip footings resting on reinforced slopes can be significantly increased by adding grid anchors to the reinforcement. Madhavilatha and Somwanshi [8, 9] conducted laboratory model tests and numerical simulations on square footing resting on sand bed reinforced with different types of geosynthetics. The parameters studied were the type and tensile strength of reinforcement, depth of reinforced zone, spacing of geosynthetic layers, and the width of reinforcing layers. They found that, apart from the tensile strength of reinforcement, its layout and configuration play a vital role in improving the bearing capacity. Sharma et al. [10] examined the existing analytical methods for the determination of bearing capacity of reinforced soil foundations. They conducted extensive laboratory and field tests on reinforced soil foundations resting over sandy and silty soils. They also conducted theoretical analysis and proposed the failure mechanism and equations for determination of bearing capacity considering also the tension developed in the reinforcement. Vinod et al. [12] conducted laboratory model tests to determine the improvement in bearing capacity and reduction in settlement of loose sand due to the addition of braided coir rope reinforcement. The results of their model tests indicated that bearing capacity can be increased by up to six times and settlement can be reduced by 90% by the introduction of coir rope reinforcement. Thus there is a need for a technique which will allow the geosynthetic to increase the load bearing capacity of soil without the occurrence of large settlements. The settlements of a reinforced granular bed can be considerably reduced by prestressing the geosynthetic reinforcement. Lovisa et al. [13] conducted laboratory model studies and finite element analysis on a circular footing resting on sand reinforced with geotextile. The improvement in bearing capacity due to prestressing the reinforcement was studied. It was found that the addition of prestress resulted in significant improvement in the load bearing capacity and reduction in settlement of foundation.

II. EXPERIMENTAL MODEL

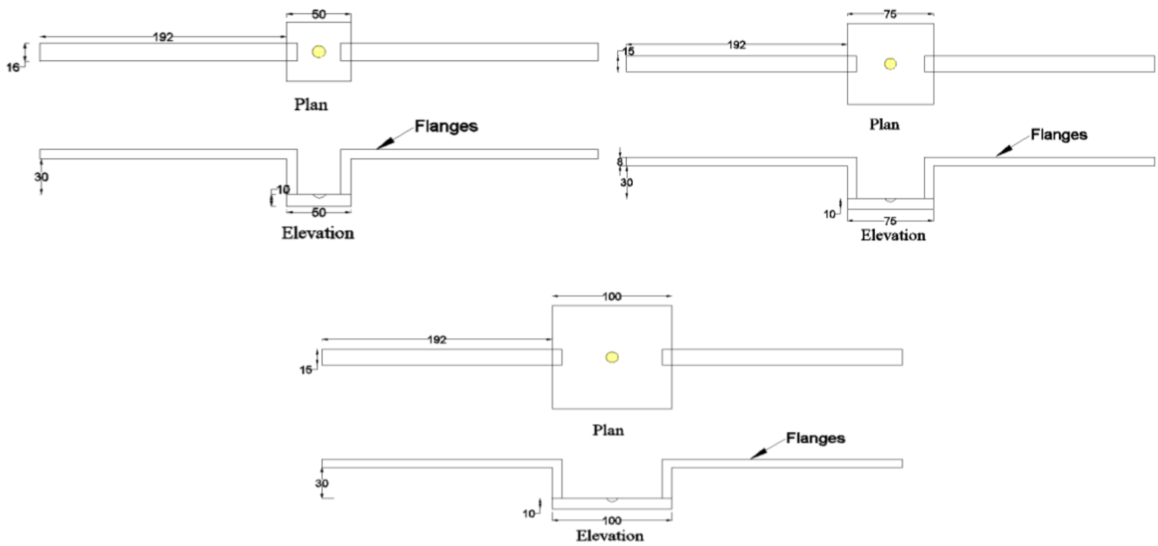
The experimental programme mainly involved a series of laboratory scale bearing capacity tests conducted on a model footings resting on a prestressed reinforced sand bed.

2.1Test sand

For the model tests, cohesionless, dry, clean and wash kanan sand was used as the foundation material. This sand is available in Nagpur region of Vidharabha, Maharashtra. The particle size of sand decided for the test was passing through IS sieving 2mm and retaining on 450 micron IS sieve.

2.2 Model footing

The model footings of three different sizes were fabricated by using cast iron material. The model footing used was square plates of dimensions 5 x 5, 7.5x7.5 and 10 x 10 cm and 1 cm thick. The plan and elevation of model footing is as shown in Figure 1.Every footing has a little groove at the center to facilitate the application of load. The footings were provided with the two flanges on two sides of footings to measure the settlement of footing under the action of load with the help of dial gauges.



(a) Square Footing 50 x50mm (b) Square Footing 75 x75mm
(c) Square Footing 100 x100mm
Fig.1 Different Sizes of Footings

2.3 Geogrid

The Biaxial geogrid (SG3030) was used to reinforce the sand bed. These high performance geogrids are constructed of high molecular weight and high tenacity knitted polyester yarns with a proprietary coating. The physical and mechanical properties, provided by the manufacturer, **Strata Geosystems (India) Private Limited** is a joint venture company in India with Strata Systems Inc., U.S.A. Table 2 presents the properties of geosynthetics.

Table 2: Mechanical and Geometric Properties of Geosynthetics

Sr. No.	Tests	values
1	Tensile Strength	30 kN/m
2	Creep Reduction Factor (ASTM D 5262, ASTM D 6992)	1.51 kN/m
3	Creep Limited Strength	19.9 kN/m
4	Partial Factor-Installation Damage In clay, silt or sand In sandy gravel In gravel	1.07 1.07 1.30
5	Partial Factor-Environmental Effects GRI-GG7, GRI-GG8)	1.10
Geometric Properties		
6	Grid Aperture Sizes MD CD	18 (mm) 18 (mm)

III. Experimental set up

To study the load settlement characteristics of the footings under given parameters, the plate load test required to be conducted. The tests are conducted on the model footings similar to the prototype under the standard conditions. The various laboratory tests performed to decide the different geotechnical properties of sand and laboratory plate load test conducted on the model footing similar to the prototype under the standard conditions are as discuss below.

3.1 Laboratory tests

The various laboratory tests were performed to decide the different geotechnical and engineering properties of sand such as grade of sand, specific gravity, density of sand, relative density, height of fall and angle of internal friction of sand. Sieve analysis was then performed on the sand in accordance with IS: 2720- part IV-1985 and the particle size distribution curve for sand. The relative density test was also conducted as per IS: 2720- part XIV. The specific gravity of the soil sample was determined by Pycnometer method as per IS: 2720 part III-1964.The properties of sand used are as shown in Table 3.

Table 3: Properties of Sand Used

Sr. No.	Properties	values
1	Specific gravity	2.59
2	emax	0.72
3	emin	0.52
4	γmax	17.04 kN/m3
5	γmin	14.6 kN/m3
6	Relative density (%)	60%
7	Angle of internal friction φ	39.5°
8	Average grain size (D60)	0.72
9	Effective grain size (D10)	0.32
10	Coefficient of uniformity (Cu)	2.25
11	Coefficient of curvature (Cc)	0.625
12	I. S. Classification	Medium sand, SP grade

3.2. Laboratory plate load test

For the experimental investigations, the model plate load tests were conducted in accordance with (IS: 1888-1982) laboratory plate load test on soil and to evaluate the bearing capacity and settlement. In the laboratory it was maintained by refilling the tank after each test by sand raining technique by funnel method to same density. The apparatus required for this test are bearing plates, loading equipments and an instrument to measure the applied load and resulting settlement.

3.3. Laboratory Set-up

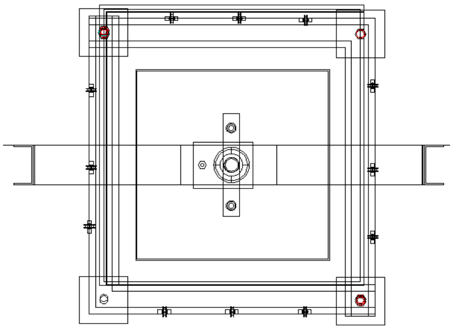
Laboratory set-up consisted of a tank, a reaction frame, a model footing, and hydraulic jack, pulleys, proving ring, dial gauges and biaxial geogrid as reinforcement. These are described in following sections.

3.3.1Tank

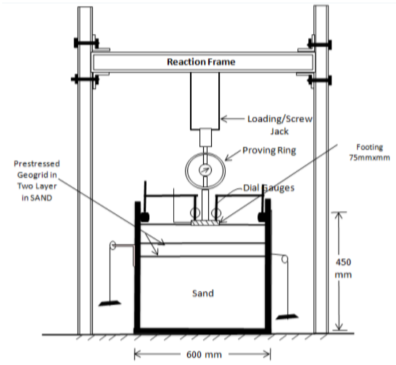
The test tank is made of 2 mm thick having internal dimensions 600mm ×600mm in plan and 450 mm high. The minimum tank size required to be 5 times the width or breadth of footing whichever is more. The bulging effect counteracts by providing sufficient horizontal and vertical bracings at sufficient intervals.

3.3.2 Reaction frame

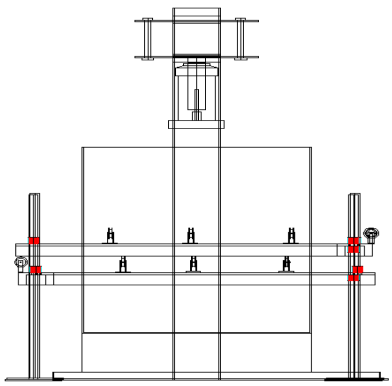
The reaction frame used for applying loads on the model footing, consisted of a horizontal member and two vertical members made of IS channel section.



(a) Plan of Laboratory Test Tank



(b) Elevation of Laboratory Test Tank



(c) Side View of Laboratory Test Tank

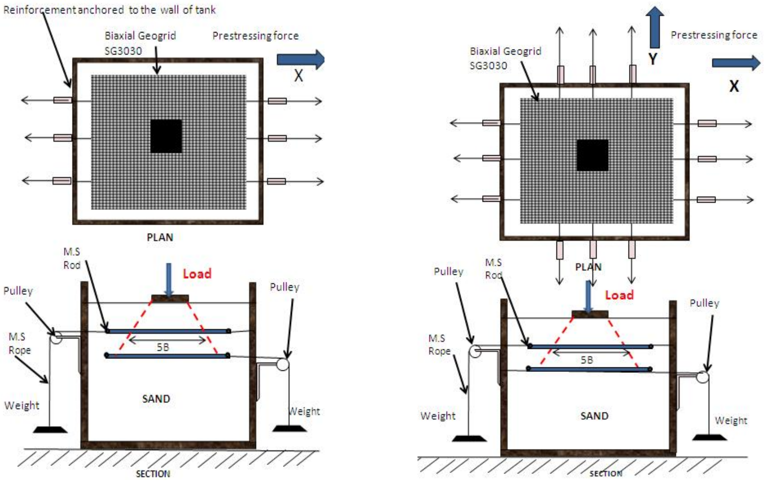
(d) Actual Laboratory Plate load Test Setup

Fig.2 A Schematic Diagram of the Loading Frame and Test set-up

3.4 Filling of tank and laying of geogrid reinforcement

The tank of 60cm x 60cm x 45cm was filled with the dry sand of 2mm passing and retaining on 450µ sieve up to a depth of 35cm tank by using the sand raining technique (hopper method). Prior to that, the side walls of the tank were made smooth by coating with a lubricating gel to reduce the boundary effects. The sand was poured in the tank by sand raining technique keeping the height of fall as 35 cm to maintain the constant relative density 60% and bulk density15.68 kN/m^3 throughout the test. Whenever the sand is deposited up to the location of the desired layer of reinforcement i.e. B, B/2and B/4 from bottom of footing, the top surface of the sand will be leveled and the biaxial geogrid reinforcement will be placed. Again, the sand will be filled over this geogrid reinforcement layer in the tank up to bottom surface of footing. In case of tests with reinforced sand beds, geosynthetic layers were placed at predetermined depths and prestress is applied while preparing the sand bed. The prestress applied is equal to 1%, 2%, 3% and 4% of the tensile strength of the geogrid and is distributed over three pulleys. In uniaxial prestressing, the prestress is applied only in the X-direction, whereas in biaxial prestressing it is applied in both X and Y directions.

After preparing the bed, the surface was leveled, and the footing was placed exactly at the centre of the loading jack to avoid eccentric loading. The footing was loaded by a hand-operated hydraulic jack supported against a reaction frame. A groove was made in the footing plate at its center to accommodate a plunger, through which vertical loads were applied to the footing. A precalibrated proving ring was used to measure the load transferred to the footing. The load was applied in small increments. Each load increment was maintained constant until the footing settlement was stabilized. The footing settlements and surface deformations were measured through dial gauges (D1, and D2), whose locations are shown in Figure 3



a) Uniaxial prestressing **b)Biaxial prestressing**

Fig.3 Reinforcement Layout and Configurations

3.5 Test procedure

The different tests were performed on reinforced sand as per following procedure.

1. The test bed was prepared as per discussed in section 3.4 using geogrid and sand. The footing is placed at the required position on the test sand bed carefully without disturbing the sand bed.
2. The dial gauges were placed on flange carefully i.e. two on footing. The loading unit was then lowered with the help of hydraulic jack through proving ring so that the bottom plunger attached to the proving ring just touches the centre of the footing.
3. After just loading the loading unit, the initial readings of dial gauges were recorded. The required load increments were then applied .On increase of each load, the dial gauge reading were noted at frequent interval of time. After reaching settlement constant, then only next load increment was made. The procedure is then repeated till the failure of the footing occurs.
4. After the failure occurred, the load on footing was release by releasing air valve of hydraulic jack. The footings were removing and the test sand bed was again prepared as discussed in above section and next tests were then performed.

IV. EXPERIMENTAL RESULTS AND DISCUSSION

4.1. Improvement in Bearing Capacity.

Vertical stress (load per unit area) versus normalized settlement curves are shown in Figures 4 to 9.The footing settlement *S* is expressed in mm. It is clearly observed that the addition of prestress significantly improved the settlement behaviour of soil. The load carrying capacity of footing is also significantly improved.

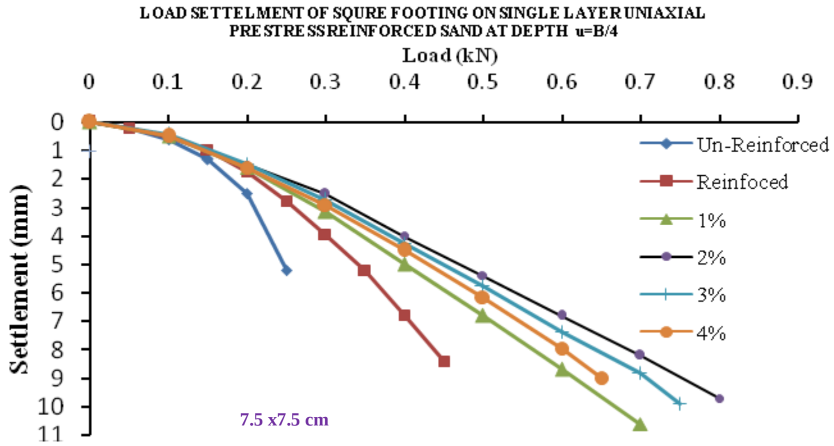


Fig. 4 Load settlement of square footing on single layer uniaxial prestress reinforced sand at depth u=B/4

4.2 Effect of Magnitude of Prestress

From Figure 4 which represents the load settlement curve single layer uniaxial prestressed sand bed at reinforced depth B/4, it can be seen that maximum improvement is observed when the magnitude of prestress was equal to 2% of the tensile strength of reinforcement. Further addition of prestress is not beneficial.

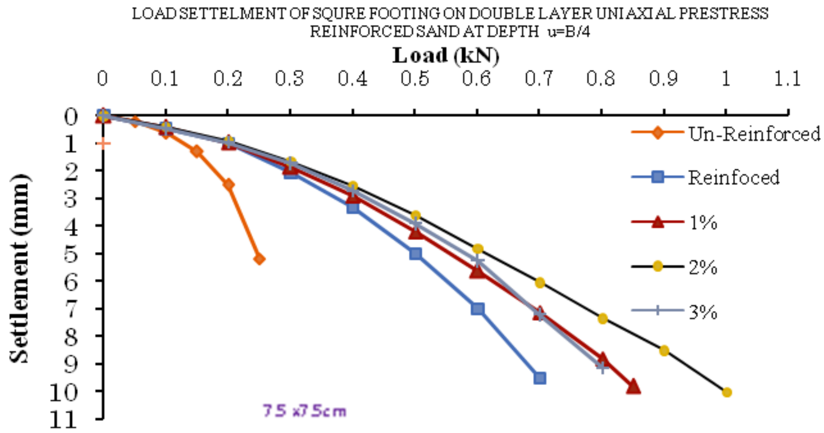


Fig.5 Load settlement of square footing on double layer uniaxial prestress reinforced sand at depth u=B/4

However, for sand bed double layer uniaxial prestress reinforced sand at depth u=B/4, it was observed that the maximum improvement in settlement behaviour occurred when the magnitude of prestress was equal to 2% of the tensile strength of reinforcement. Further increase in prestress is not beneficial (Figure 5). The results obtained from load settlement of square footing on single layer biaxial prestress reinforced sand at depth u=B/4 Figure 6. It is observed that the maximum improvement is when the magnitude of prestress is equal to 3% of the tensile strength of reinforcement.

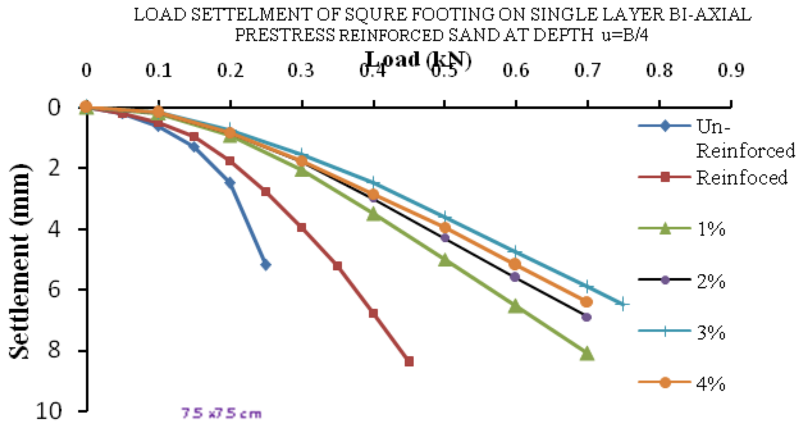


Fig. 6 Load settlement of square footing on single layer biaxial prestress reinforced sand at depth u=B/4

The results obtained from load settlement of square footing on double layer biaxial prestress reinforced sand at depth u=B/4 indicates that maximum improvement is obtained also when the magnitude of prestress is equal to 3% of the tensile strength of reinforcement (Figure 7).

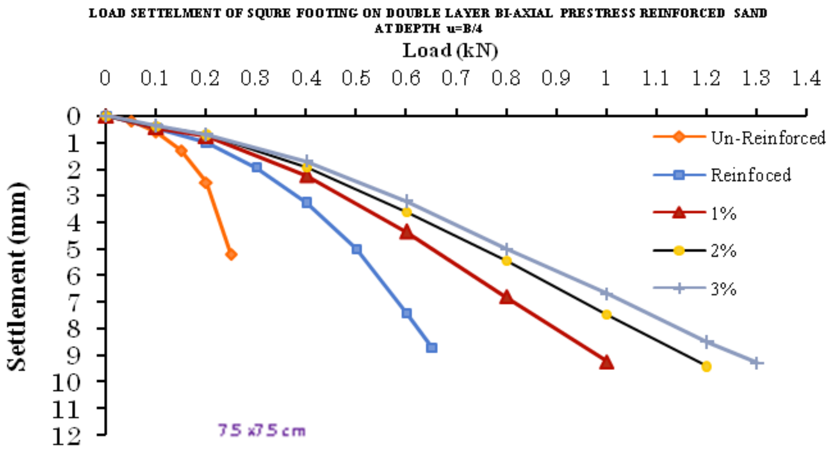


Fig. 7 Load settlement of square footing on double layer biaxial prestress reinforced sand at depth u=B/4

Uniaxial Prestress Reinforced Sand at Depth u=B/2

Figure 8 presents the variation of load settlement of square footing on single layer uniaxial prestress reinforced sand at depth u=B/2. It can be seen that maximum improvement is observed when the magnitude of prestress is equal to 2% of the tensile strength of reinforcement. Further addition of prestress is found to be not beneficial.

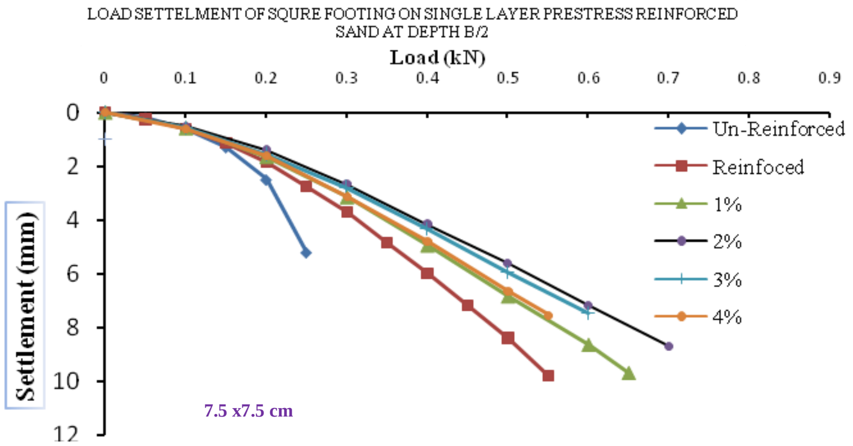


Fig.8 load settlement of square footing on single layer uniaxial prestress reinforced sand at depth u=B/2

In case of load settlement of square footing on double layer uniaxial prestress reinforced sand at depth u=B/2, from Figure 9, it is observed that the maximum improvement in settlement behaviour occurs when the magnitude of prestress is equal to 2% of the tensile strength of reinforcement.

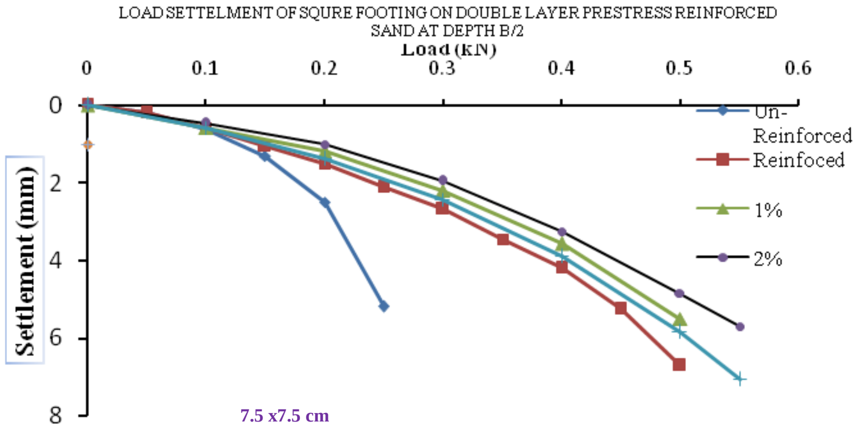


Fig. 9 Load Settlement of Square Footing on Double Layer Uniaxial Prestress Reinforced Sand at Depth u=B/2

Further increase in prestress caused a reduction in the improvement in bearing capacity. It is also observed that the improvement in bearing capacity when the prestress was increased from 1% to 2% was only marginal.

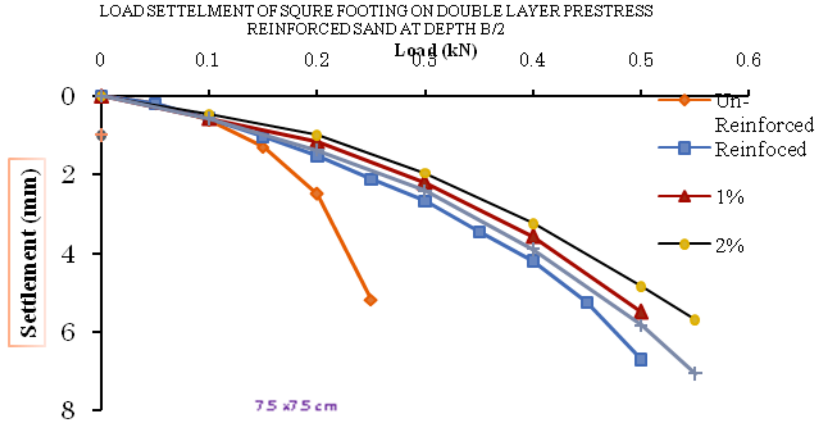


Fig.10 Load settlement of square footing on double layer uniaxial prestress reinforced sand at depth u=B/2

With the results obtained from a square footing on double layer uniaxial prestress reinforced sand at depth u=B/2, it is observed that the improvement in settlement behavior with 3% prestress is less than that with 1% and 2% (Figure 10). The improvement in settlement behavior with a prestress of 1% and 2% was almost marginable; the improvement in settlement behavior was more with a prestress of 2%.

Biaxial Prestress Reinforced Sand at Depth u=B/2

Figure 11 presents the load settlement of square footing on single layer baxial prestress reinforced sand at depth u=B/2. It can be seen that maximum improvement is observed when the magnitude of prestress is equal to 3% of the tensile strength of reinforcement.

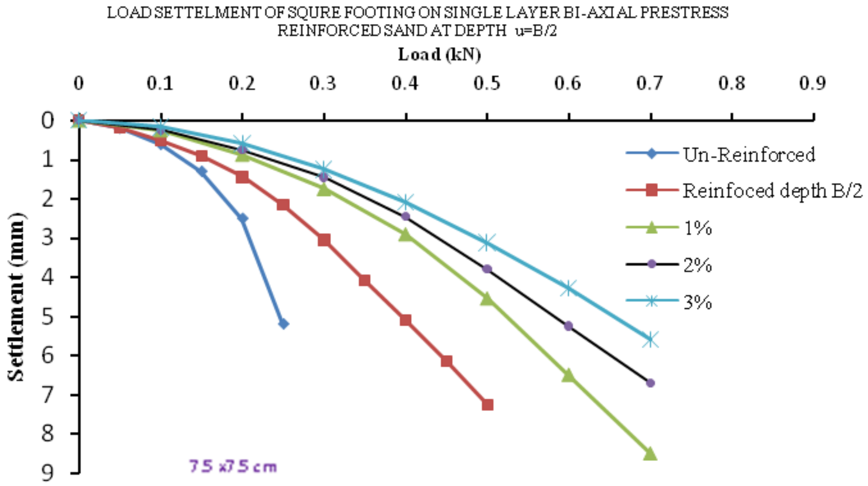


Fig.11 load settlement of square footing on single layer biaxial prestress reinforced sand at depth u=B/2

In case of load settlement of square footing on double layer biaxial prestress reinforced sand at depth u=B/2, from Figure 12, it is observed that the maximum improvement in settlement behaviour occurs when the magnitude of prestress is equal to 3% of the tensile strength of reinforcement.

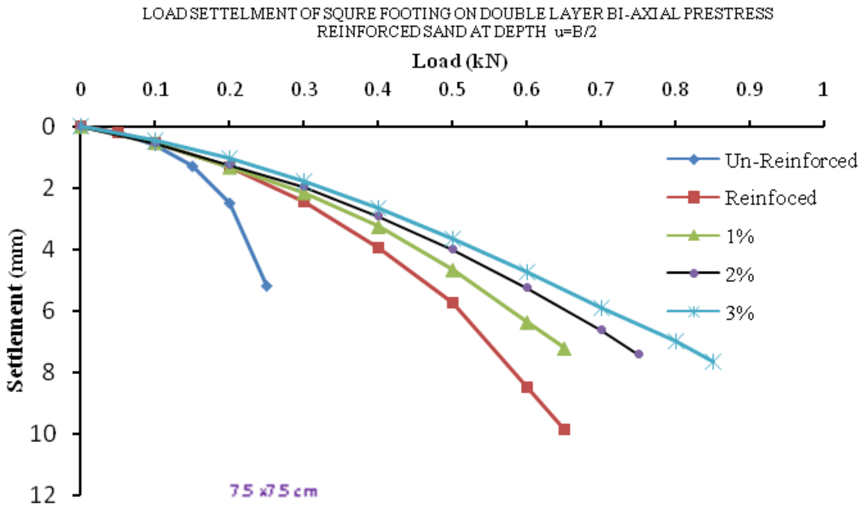


Fig. 12 Load settlement of square footing on double layer biaxial prestress reinforced sand at depth u=B/2

It is also observed that the improvement in bearing capacity when the prestress was increased from 2% to 3% was only marginal. The improvement in settlement behaviour with a prestress of 2% and 3% was almost marginable; the improvement in settlement behaviour was more with a prestress of 3% (Figure 12).

Square Footing (50mm) for optimum depth and prestressing force

Figure 13 shows a experimentally observed improvements in settlement behaviour, due to uniaxial and biaxial prestressing. In this case, also the general improvement in settlement behaviour is more when prestress is biaxial. Maximum improvement is observed when the prestress is equal to 3% of the tensile strength of reinforcement for single and double layer. It is also observed that when the magnitude of prestress is equal to 2%, the improvements attained due to uniaxial prestressing for single and double layer.

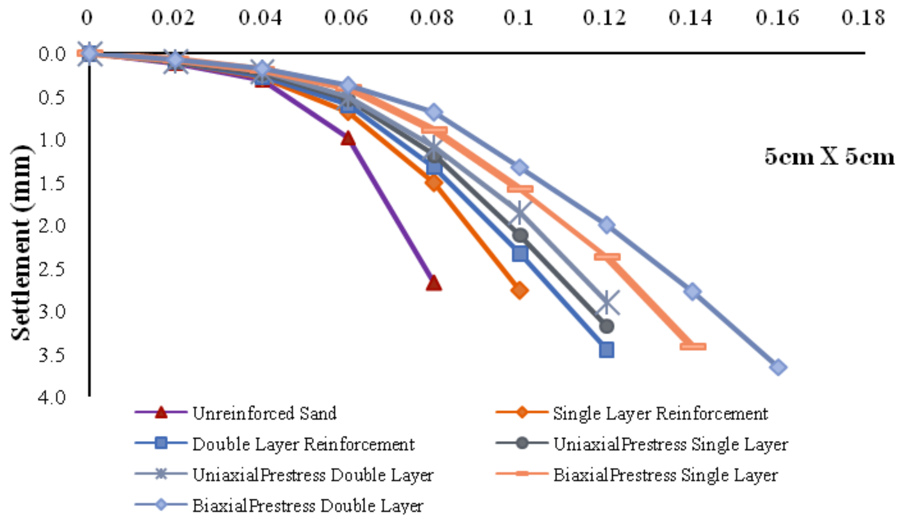


Fig.13 load settlement of square footing on prestress reinforced sand at depth u=B/4

Square Footing (100mm) for optimum depth and prestressing force

Figure 14 shows experimentally observed improvements in settlement behaviour, due to uniaxial and biaxial prestressing. In this case, also the general improvement in settlement behaviour is more when prestress is biaxial. Maximum improvement is observed when the prestress is equal to 3% of the tensile strength of reinforcement for single and double layer. It is also observed that when the magnitude of prestress is equal to 2%, the improvements attained due to uniaxial prestressing for single and double layer.

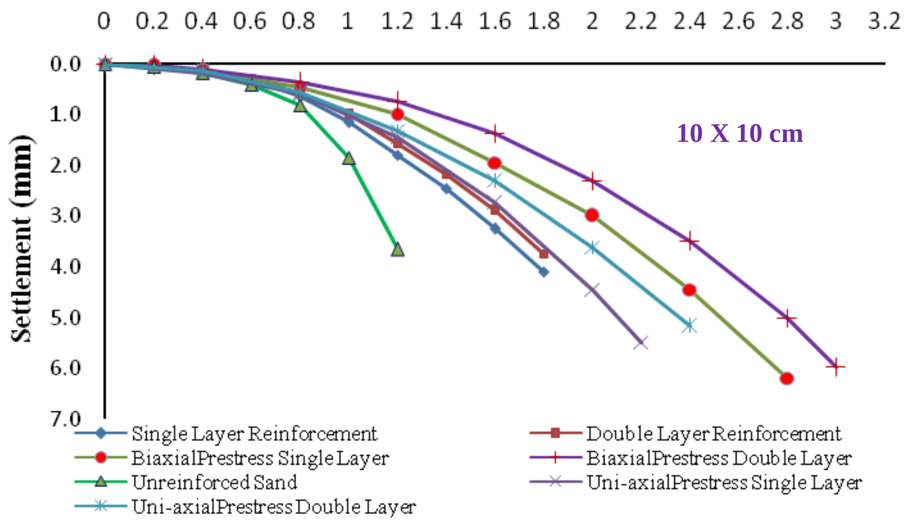


Fig.14 Load settlement of square footing on prestress reinforced sand at depth u=B/4

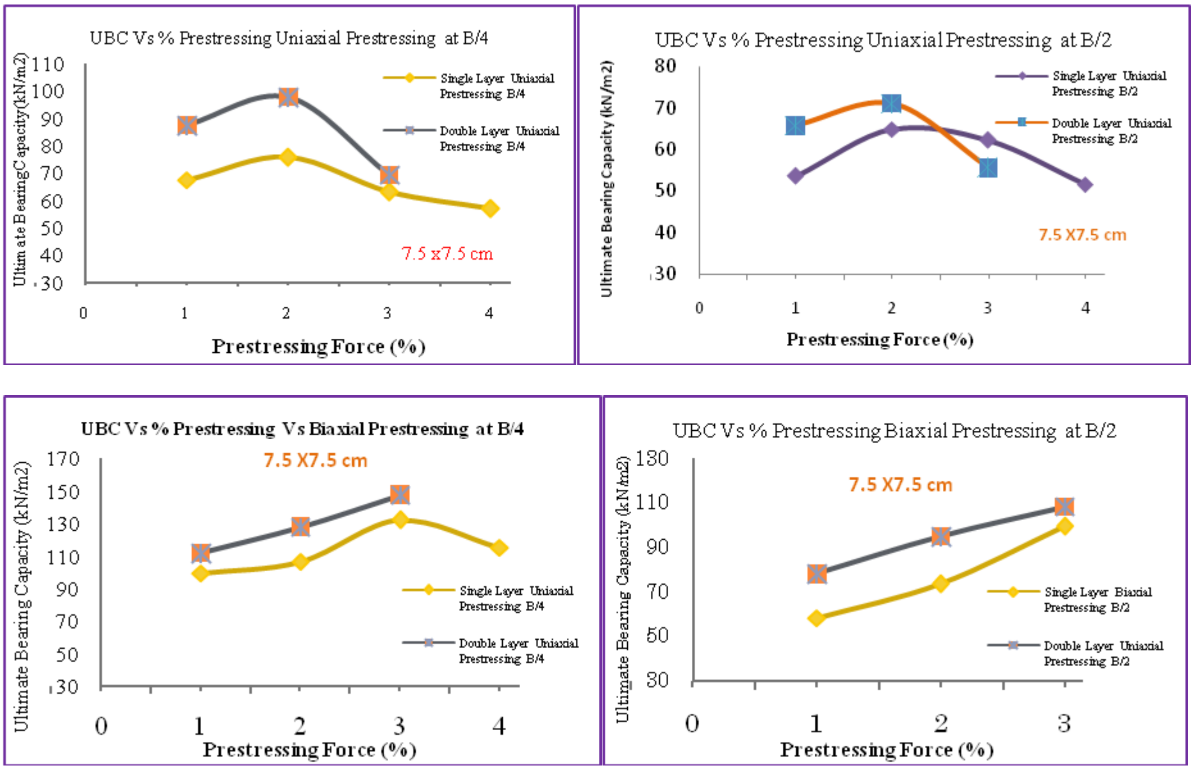


Fig.15 Comparison of UBC Vs prestressing force (75mm footing)

Figure 15 shows a comparison between the ultimate bearing capacities vs. prestressing force for 75mm footing, due to uniaxial and biaxial prestressing. In this case, the general improvement in settlement behaviour is more when prestress is biaxial. Maximum improvement is observed when the biaxial prestress is equal to 3% of the tensile strength of reinforcement. Therein, it is observed that improvement observed up to depth B/4 and B/2 but further increase in depth no improvement effect of reinforcement observed. Maximum improvement in settlement behaviour is observed when the biaxial prestress is equal to 3 % of the tensile strength of reinforcement.

Numerical Analysis

The ultimate bearing capacity (q_{ult}) of a shallow foundation on unreinforced sand can be analyzed without a cohesion component. As a result, Meyerhof bearing capacity equation can be adapted as follows:

$$\mathbf{q_{ult} = \gamma\, D_f N_q S_q d_q + 0.5\, \gamma\, B\, N_\gamma\, S_\gamma d_\gamma} \quad \ldots(1)$$

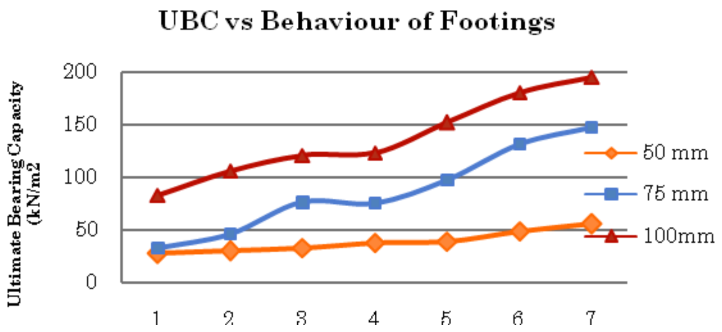
where, B is the footing width, γ is the unit weight of the soil Nγ and Nq are the bearing capacity factors that are functions of the angle of internal friction for unit weight and surcharge, respectively S_q and d_q are the shape and depth factors associated with surcharge S_γ and d_γ are the shape and depth factors associated with unit weight. The calculated friction angle value 39.5° was used in all theoretical calculations, regardless of footing depth or reinforcement arrangement, as adopted by Hansen theory. Although designed for strip foundations, the equation was modified using Hansen's shape factors so that it could be applied to the Square footing studied herein. The ultimate bearing capacity $q_{ult}(R)$ for the square footing underlain by the reinforced foundation soil calculated by below equation.

$$\mathbf{q_{ult}(R) = \gamma D_f N_q S_q d_q + 0.5 \gamma B N_\gamma S_\gamma d_\gamma} \qquad \ldots(2)$$

With

$$\mathbf{\Delta B = 2u\,[0.68 - 2.071(h/B) + 0.743\,(CR) + 0.03(b/B)} \qquad \ldots(3)$$

Where, h is the distance between reinforcing layers, u is the depth of reinforcement below the footing base, b is the width of geotextile and CR is the cover ratio. The cover ratio component was developed for a geogrid-reinforced foundation. For a geotextile-reinforced foundation; however, CR can be assumed unity using Eqs (1) – (3).The theoretical ultimate bearing capacity values for a square foundation resting on unreinforced and reinforced sand beds were calculated. All the above various cases were analysed numerically. It is found that there is 5% difference between the experimental and analytical results. The difference found may be due to experimental or instrumental error.



1	Unreinforced sand foundation			
2	Geotextile-reinforced sand foundation without prestress	Single		
3	Geotextile-reinforced sand foundation without prestress	Double	-	
4	Prestressed Geotextile-reinforced sand bed	Single	Uniaxial	
5	Prestressed Geotextile-reinforced sand bed	Double	Uniaxial	
6	Prestressed Geotextile-reinforced sand bed	Single	Biaxial	
7	Prestressed Geotextile-reinforced sand bed	Double	Biaxial	

Fig.16 Comparison between ultimate bearing capacity vs. depth of footing.

V. CONCLUSIONS

The following conclusions are made based on the results obtained from experimental and numerical studies; on the behaviour of prestressed reinforced sand bed.The improvements in settlement behaviour and load-bearing capacity of a geotextile-reinforced sand foundation were investigated using experimental methods. The physical model test with single and double layer of prestressed geotextile as reinforcement was developed. Based on the test results obtained, the following conclusions can be drawn.

[1] The addition of prestress to the geotextile reinforcement improved the settlement response and load bearing capacity of the soil.

[2] The improvement in bearing capacity depends on the reinforcement depth, magnitude of prestress, and the direction of prestress. The improvement in bearing capacity is found to be more with biaxial prestressing than uniaxial prestressing.

[3] Settlements are also less with biaxial prestressing at reinforcement depth B/4 for single and double layer reinforcement for 3% prestressing force. The improvement in bearing capacity increases with the placement depth of reinforcement.

[4] The uniaxial prestressing at reinforcement depth B/4 for single and double layer reinforcement for 2% prestressing force give good increase in ultimate bearing capacity.

[5] The size of footing play important role in improvement in load bearing capacity due to effect of prestressing force. The footing having greater size gives good result than small size and small size footing become more sensitive during testing but big size footing shows good improvement in load bearing capacity and settlement response.

Future Scope

Further study is required to determine the effects of any losses in prestress due to anchorage slip, stress relaxation in reinforcement, shrinkage of soil, and so forth. The pulling out process may not be easy to simulate in field conditions, especially to have a high prestress in the geosynthetic. However, it is expected that some suitable practical methods of prestressing the geosynthetic in field situations will be developed in future.

ACKNOWLEDGEMENT

I owe my sincere thanks to my dissertation guide Dr. A. I. Dhatrak who has not only helped me, but also gave me the enthusiasm and encouragement in my every step. I am thankful for his help, support, and guidance throughout the completion of the dissertation. I am also thankful to persons who co-operate, helped and encouraged throughout the dissertation work period.

(Farukh Akhter Khan)

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