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Performance of Square Footing on Sandy Soil Prestressed With Geogrid Reinforcement

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***Abstract*—This paper mainly investigates a series of laboratory scale bearing capacity tests carried out on multiple prestrssed reinforcement layer on model square footing. The investigation parameters are the bearing capacity improvement, magnitude and direction of prestressing force. The addition of prestress to geogrid reinforcement results in significant improvement in the load carrying capacity and settlement response of the prestressed reinforced geogrid sand. Improvement in load bearing capacity is found to be more with biaxial prestressing than uniaxial prestressing. The prestressing of geogrid contributes a tremendous increase in load carrying capacity of footing with reduction in settlement compared to that of unreinforced and reinforced conditions**

Keywords— Model footing test, Prestress reinforced bed, ultimate bearing capacity, Geotextile, Sand bed.

I. INTRODUCTION

The technique of reinforcing soil using tensile resisting elements is widely used in geotechnical engineering practice and is a proven technique to the conventional ground improvement technique under appropriate conditions. Over the past three decades the beneficial use of reinforcement materials like metal strips and geosynthetics to increase the bearing capacity of footing has been clearly established by various researches and it has been proven to be cost effective foundation system. Binquet and Lee [4] conducted tests on sand reinforced with metal strips. Shivashankar et al. [1] proposed that the improvement in bearing capacity of a reinforced granular bed is comprised of three components, namely, shear layer effect, confinement effect and surcharge effect. They proposed equations for computing the effect of each of these components. Kurian et al. [10] 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. Alamshahi and Hataf [14] 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 [2,3] 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.

Vinod et al. [11] 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. It is now well established that geosynthetics demonstrate their beneficial effects only after considerable settlements, since the strains occurring during initial settlements are insufficient to mobilize significant tensile load in the geosynthetic. Lovisa et al. [6] 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.

J. Jayamohan et al. [5] conducted laboratory model studies and finite element analysis on square footing on prestressed reinforced granular beds overlying weak soil. The improvement in bearing capacity due to prestressing the reinforcement was studied and found that addition of prestress to geonet reinforcement significantly improves the bearing capacity and settlement behaviour of the soil. The improvement in bearing capacity depends on the thickness of granular bed, magnitude of prestress, and the direction of prestress. The improvement in bearing capacity is found to be more with biaxial prestressing than uniaxial prestressing. Results show that the percentage increase in load carrying capacity is around 100% when the reinforcement layer is provided at a depth of 0.3times the width of footing for single layer of reinforcement. The prestressing of geogrid contributes a tremendous increase in load carrying capacity of footing with reduction in settlement compared to that of unreinforced and reinforced conditions.

M.Balamaheswari et al. [9] evaluated for bearing capacity of strip footing on geogrid reinforced sand. They also studied the effect of parameters like depth of reinforcement, width of reinforcement and magnitude of prestressing force. The

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prestressing of geogrid contributes a tremendous increase in load carrying capacity of footing with reduction in settlement compared to that of unreinforced and reinforced conditions.

The purpose of this paper is to study experimentally the effects of prestressing the reinforcement on the load-bearing capacity of reinforced sand. The study involved laboratory scale model test on a square footing of size 75x75x10 mm thick. The parameters studied are the effects of the strength at various depths of reinforcement, magnitude and direction of prestressing force for multiple reinforcement layers.

II. EXPERIMENTAL PROGRAMME

In this experimental study we have studied the effects of prestressing on single and double layer reinforcement on the load-bearing capacity of reinforced sand having square footing, at different depth. The study involved laboratory scale model tests on 75 x75 ×10 mm square footing.

A. MATERIAL

The materials used for the experimental work is Biaxial Geogrid, Kanan sand and footing made up of cast iron.

TEST SAND

For the model tests, cohesionless, dry, clean and wash sand was used as the foundation material. The study was carried out on Kanan Sand as 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.

MODEL FOOTING

The model footing used was square plates of dimension75 x75mm and 10mm thick as the plan and elevation of model footing is as shown in Fig.1. Footing has a little groove at the center to facilitate the application of load.

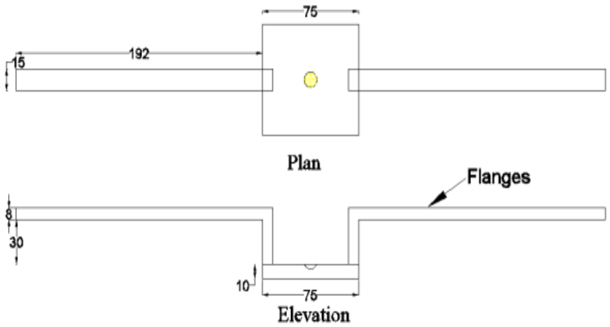

Fig.1. Size of Square Footing 75 x75mm Footings

GEOGRID

In whole experimental work Biaxal Geogrid (SG3030) are used to reinforce sand bed in the model tests. The size of biaxial geogrid reinforcement used was five times the size of the footing. The biaxial geogrid reinforcement were placed at the location of the desired layer of reinforcement i.e. B, B/2 and B/4 from bottom of footing. The top surface of the sand was leveled and the biaxial geogrid reinforcement was placed. The Biaxial geogrid (SG3030) was used to reinforce the sand bed. These high performance geogrids are constructed of high molecular weight and 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 1 presents the properties of geosynthetics.

Table I. 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 ANALYSIS

The model plate load tests are performed in laboratory on the model footing with different reinforcement depth. The various laboratory tests performed to decide the different geotechnical properties of sand and laboratory plate load test conducted on the model footings similar to the prototype under the standard conditions are as discuss below.

A.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.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 2

Table II. 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

B.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. 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.

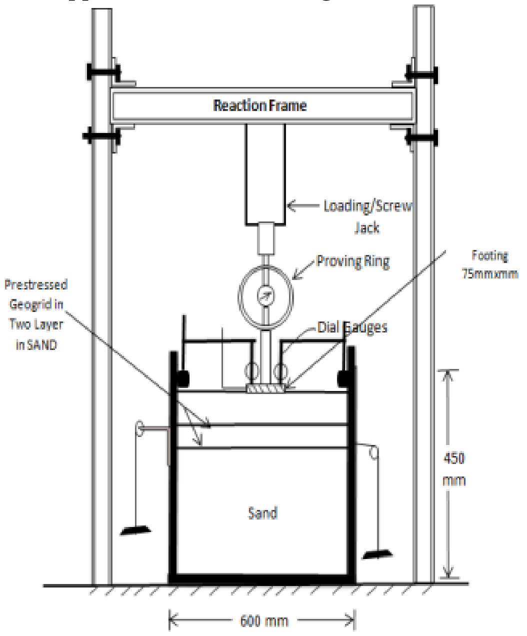

Fig.2. A Schematic Diagram of the Loading Frame and Test set-up

C FILLING OF TANK AND LAYING OF GEOGRID REINFORCEMENT

The tank of 600mm x 600mm x 450mm was filled with the dry sand of 2mm passing and retaining on 450μ sieve up to a depth of 0.25m was prepared in the steel test tank using the sand raining technique using (hopper method), as discussed above. 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 rainfall technique keeping the height of fall as 35 cm to maintain the constant relative density 60% and 15.68 kN/m^3 bulk density throughout all tests. 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.

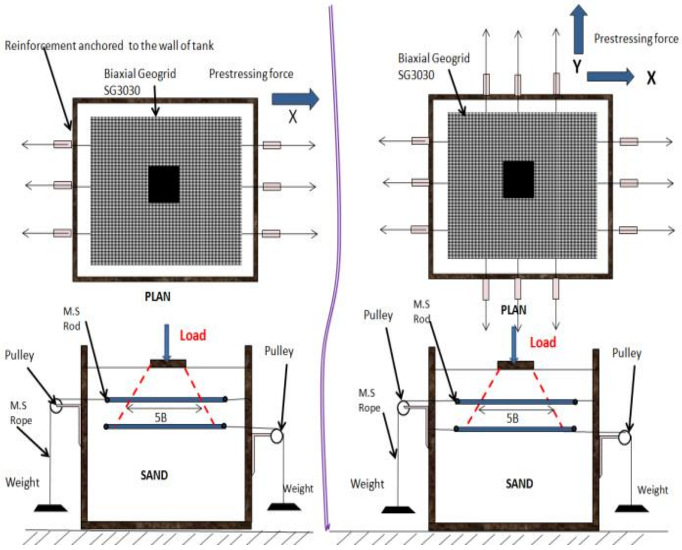

Fig.3. Reinforcement Layout and Configuration

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 depth 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. In center of footing plate a plunger accommodate, 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 are measured through dial gauges (D1, and D2), whose locations are shown in Fig.2.

Fig.4. Prestressing Arrangement

D.ASSEMBLY OF TESTING

The laboratory plate load tests were carried out on the square footing. A proving ring is fixed to the hydraulic plunger to transfer the pressure of the fluid to the plunger. The proving ring is provided with bottom plunger that is used to transfer the load to footing. The two dial gauges, each on one footing are provided to measure the average settlement of footing. The footings are rested on the reinforced sand bed which is filled by rain fall method. The assembly of testing is as shown in Fig.5.

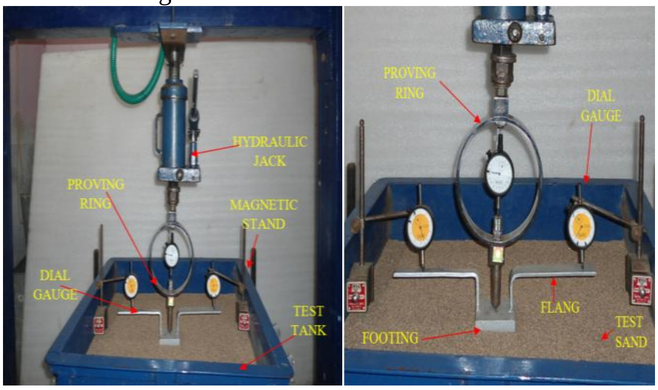

Fig.5. Assembly of Laboratory Plate Load Test

E. TEST PROCEDURE

i. The test bed was prepared as per discussed in section C using geogrid and sand. The footing is placed at the required position on the test sand bed carefully without disturbing the sand bed.

ii. The dial gauges were placed on flanges 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.

iii. 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 deformation or settlement constant, then only next load increment was made. The procedure is then repeated till the failure of the footing occurs.

After the failure occurred, the load on footing was released by releasing valve of hydraulic jack. The footings were removed and the test sand bed was again prepared as discussed in above section and next tests were then performed.

IV EXPERIMENTAL RESULTS AND DISCUSSION

A series of load tests were conducted on the model footing, the primary purpose of which was to evaluate the effect of prestressing the geogrid on the settlement behaviour of footing resting on the geogrid -reinforced sand bed. The parameters investigated include the settlement of the model footing, the bearing capacity ratios.

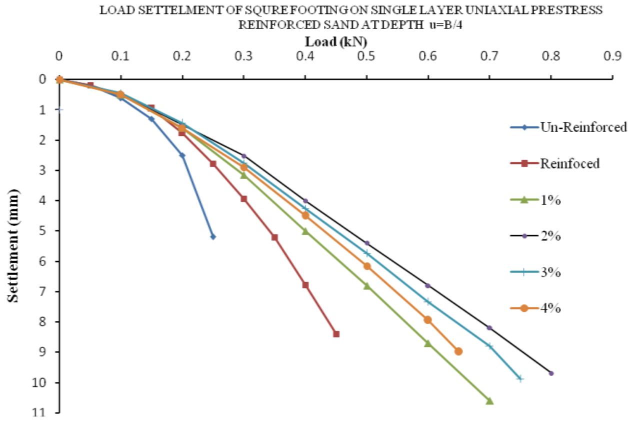

Fig.6. Load intensity versus normalized settlement curves at single layer reinforcement depth B/4 with Uniaxial prestressing force of different magnitude.

The load versus settlement curves were obtained from the load test data. However, for reinforced cases, where the strength of the soil increased, the load capacity of the jack dictated the extent of testing. It can be seen in Figs. 6–14 that the introduction of prestress to the geotextile reinforcement greatly improves the settlement behaviour of the soil. The bearing capacity ratio can be analysed with respect to the ultimate bearing capacity or the allowable bearing capacity at a given settlement level of a foundation.

Due to the high strength developed in the soil from the addition of prestress, the ultimate bearing capacity for all the cases reached during physical model testing. The pressure versus settlement curves generated for each footing depth. The double tangent method was adopted for estimating the ultimate load-bearing capacity, which was defined as the pressure corresponding to the intersection of the two tangents

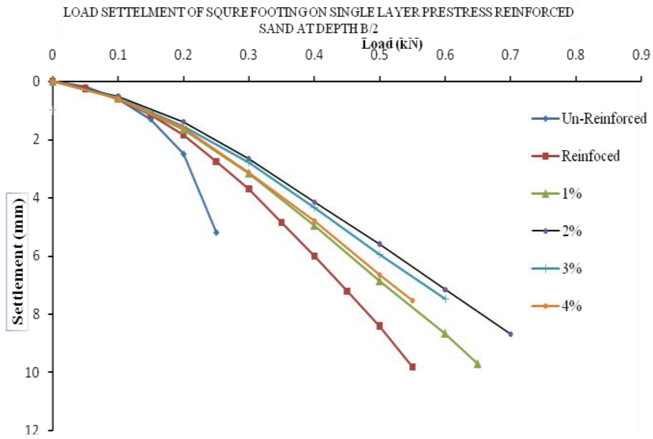

Fig.7. Load intensity versus normalized settlement curves at single layer reinforcement depth B/2 with Uniaxial prestressing force of different magnitude.

It can be seen that the introduction of prestress generally doubles the load-bearing capacity of the unreinforced soil, in comparison to reinforcement alone, which results in only 1.3–2.5 times the load bearing capacity of the soil. Therefore, the addition of prestress is considered a worthwhile method of reinforcement.

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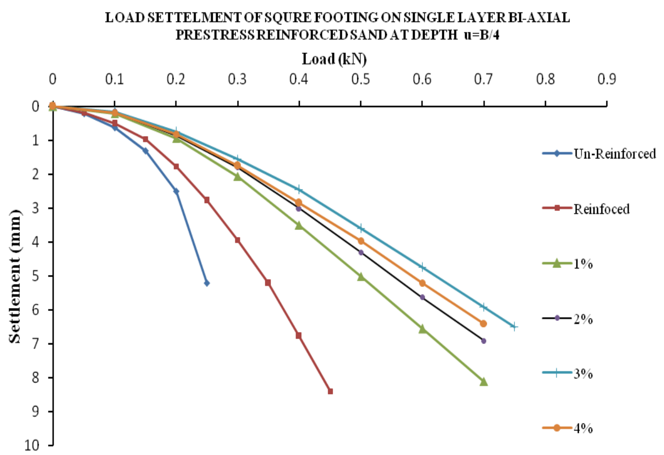

Fig.8. Load intensity versus normalized settlement curves at reinforcement depth B/4 with Biaxial prestressing force of different magnitude.

It is also observed that the bearing capcity of unreinforced soil is greatly improved by providing reinforcement at depth B/4.Where as further increase in reinforcement depth up to B have not significantly improve the bearing capacity of soil.

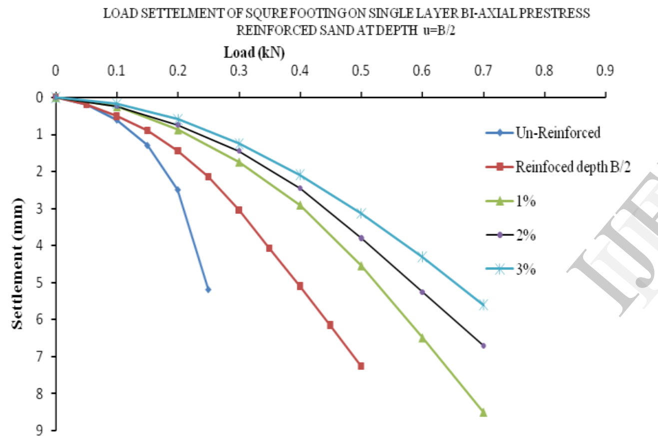

Fig.9. Load intensity versus normalized settlement curves at reinforcement depth B/2 with Biaxial prestressing force of different magnitude.

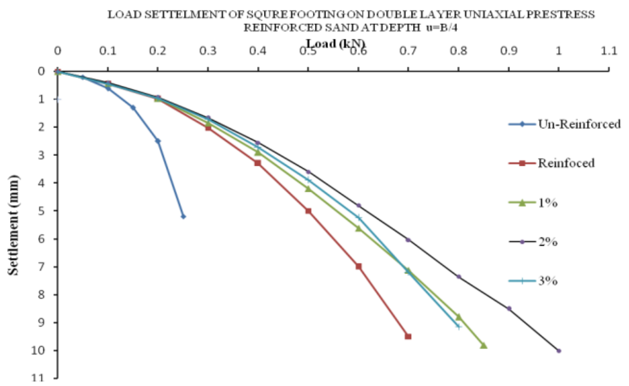

Fig.11. Load Intensity versus Normalized Settlement Curves at Double layer Reinforcement Depth B/4 with Uniaxial prestressing force of different magnitude.

A similar trend was observed for reinforced soil without prestress, the bearing capacity improvement found at reinforcement depths B/4 to B/2.

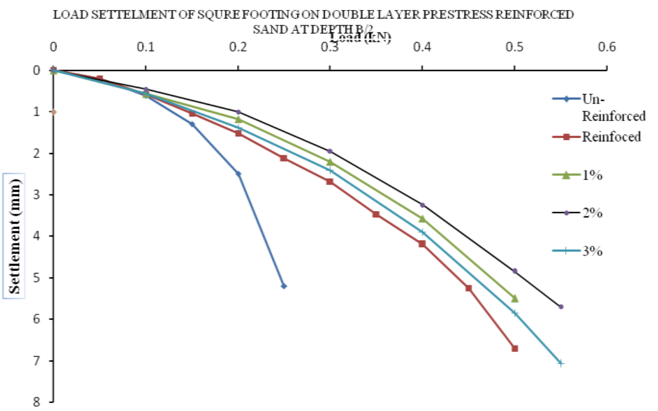

Fig.12. Load Intensity versus Normalized Settlement Curves at Double layer Reinforcement Depth B/2 with Uniaxial prestressing force of different magnitude.

Therefore, the behaviour of unreinforced and reinforced (without prestress) soil for a reinforcement depth B/2 and B/4, is almost identical to that of reinforcement depth. However, the effect of prestress in the geogrid reinforcement is more effective for the reinforcement depth B/4.

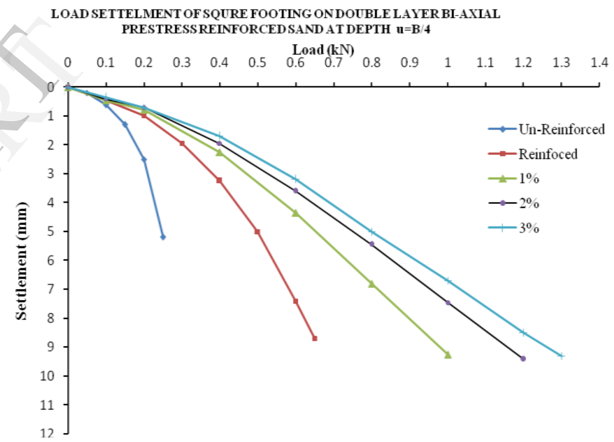

Fig.13. Load intensity versus normalized settlement curves at reinforcement depth B/4 with Biaxial prestressing force of different magnitude.

It is known that the bearing capacity of unreinforced cohesionless soils increases with increase in the size of the footing, and a few relationships have been proposed in the past as reported in many authors.

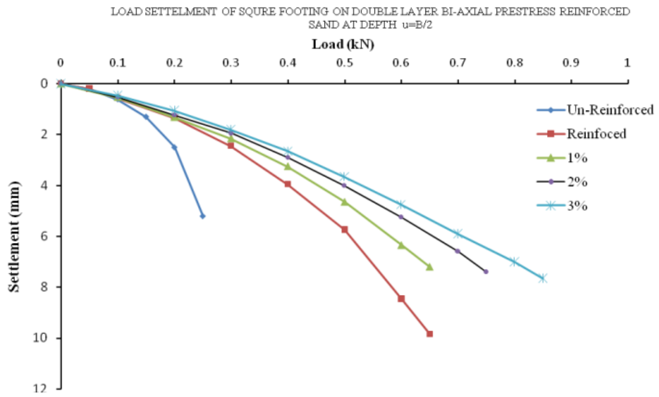

Fig.14. Load intensity versus normalized settlement curves at reinforcement depth B/2 with Biaxial prestressing force of different magnitude

A similar behaviour can be expected in case of reinforced foundation soils with or without prestressing, but detailed research findings are required in future based on large-scale model studies or in-situ testing.

V. Concluding Remarks

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:

i. The addition of prestress to the geotextile reinforcement significantly improved the settlement response and load bearing capacity of the soil.
ii. 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.
iii. 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.
iv. 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.

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