Experimental Investigations on Footings supported on soft clay beds reinforced with strength enhanced Jute Geogrids

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ABSTRACT
This manuscript deals with the experimental investigations which were carried out to explore the possibility of enhancing the performance of conventional Jute geogrid, by according a coating of bitumen. Efforts have been made to enhance the potentiality of conventional Jute geogrid in increasing bearing capacity of soil, by coating it with a layer of soft bitumen. On chemical hardening of bitumen, the resulting product of bitumen coated Jute geogrid was found to perform much better than the conventional Jute geogrid and commercial geogrids. Laboratory plate load tests were conducted on soft soil bed reinforced with a) conventional Jute geogrid b) bitumen coated Jute geogrid, and c) Commercial geogrids. A simple trial test series were carried to determine the optimum placement of reinforcement material in the soil bed by placing reinforcement materials at different locations throughout the height of the soil bed. Results from laboratory tests illustrated an increase of bearing capacity by 9 times when single reinforced and 10 times when double reinforced. A substantial reduction in settlement has also been observed with a maximum percentage reduction in settlement of 84%. Results from analytical investigations clearly proved optimum placing of the reinforcement material is towards the top surface of the clay bed to mobilize maximum tensile stresses.

KEYWORDS:Jute Geogrid, Bitumen coating, Bearing capacity, Percentage reduction settlement, Optimum reinforcement placement

1. INTRODUCTION

Emerging needs of the developing countries enforce effective utilization of the available land to satisfy the infrastructural needs of the society. Effective utilization of the sites with soft and loose soil deposits is always been a challenging task to the Civil Engineers. Various ground modification techniques have been adopted by Geotechnical Engineers to make these soil deposits suitable for the construction. The most common and traditional method of ground modification is reinforcing these soil deposits with geosynthetics. Use of geosynthetics is though considered as most effective technique in increasing the bearing capacity of the soil, but on the other side, increases the cost of the project to a considerable extent. Hence, emphasis was given for the search of other alternative materials, which can replace these commercial geosynthetics (Hegde A, Sithara, T.G.; 2013, 2013, 2014, 2014, 2015, 2015). Many researchers had used different materials to replace commercial geosynthetics with sustainable and high tensile polypropylene materials (Venkatesh, Thyagaraj; 2019). Many researchers in the past had tried to use sustainable materials like coir, jute and bamboo for ground modification replacing commercial geosynthetics. An effort has been made to enhance one of these sustainable materials, which can be effectively used to modify soft soil deposits in this study. The current study majorly focuses on the possibility of enhancing the strength of a jute geogrid by according a bitumen coating on it. A conventional jute geogrid is generally used over the slopes of embankments to avoid loss of soil due to precipitation (K. Balan; 2012). Bermuda grass is usually planted in between the apertures of these jute geogrids, for retention of soil from erosion. Use of jute geogrids in reinforcing soil hasn't been studied yet, as the tensile strength of this material is very less. The tensile strength of jute geogrid can be possibly enhanced by providing a coat of bitumen on its surface. Bitumen being visco-elastic in nature, on drying becomes stiff and hard. Results of tests conducted to explore the possibility of the use of bitumen accorded jute geogrid to reinforce the soft soil are discussed in this paper. Tests were also carried out to find possible location for the placement of jute geogrid in the soil bed. Simple trials were made to check the optimum location to place reinforcement material in the soil. Effect of single and double reinforcement in soli was also studied to determine the optimum location to place the reinforcement material.

2. LABORATORY MODELS TESTS

A series of model plate load tests were conducted on a soft soil bed in a tank of size 60cm x 60cm x 60cm under load frame assembly. A circular loading plate of diameter 15cm made of rigid steel is used as the footing in the test. The distance from the centre of the loading plate to the edge of the footing is two times the diameter of the loading plate, and distance from the bottom of the tank to the loading plate is four times the diameter of the loading plate. A mechanical jack consisting of rotating wheel to drive the jack forward and backward on clockwise and anticlockwise rotation correspondingly was mounted on to the load frame to load the footing. The load acting upon the footing was measured using a precalibrated proving ring which is fixed between the mechanical jack and footing with loading plate arrangement as shown in Figure 1.

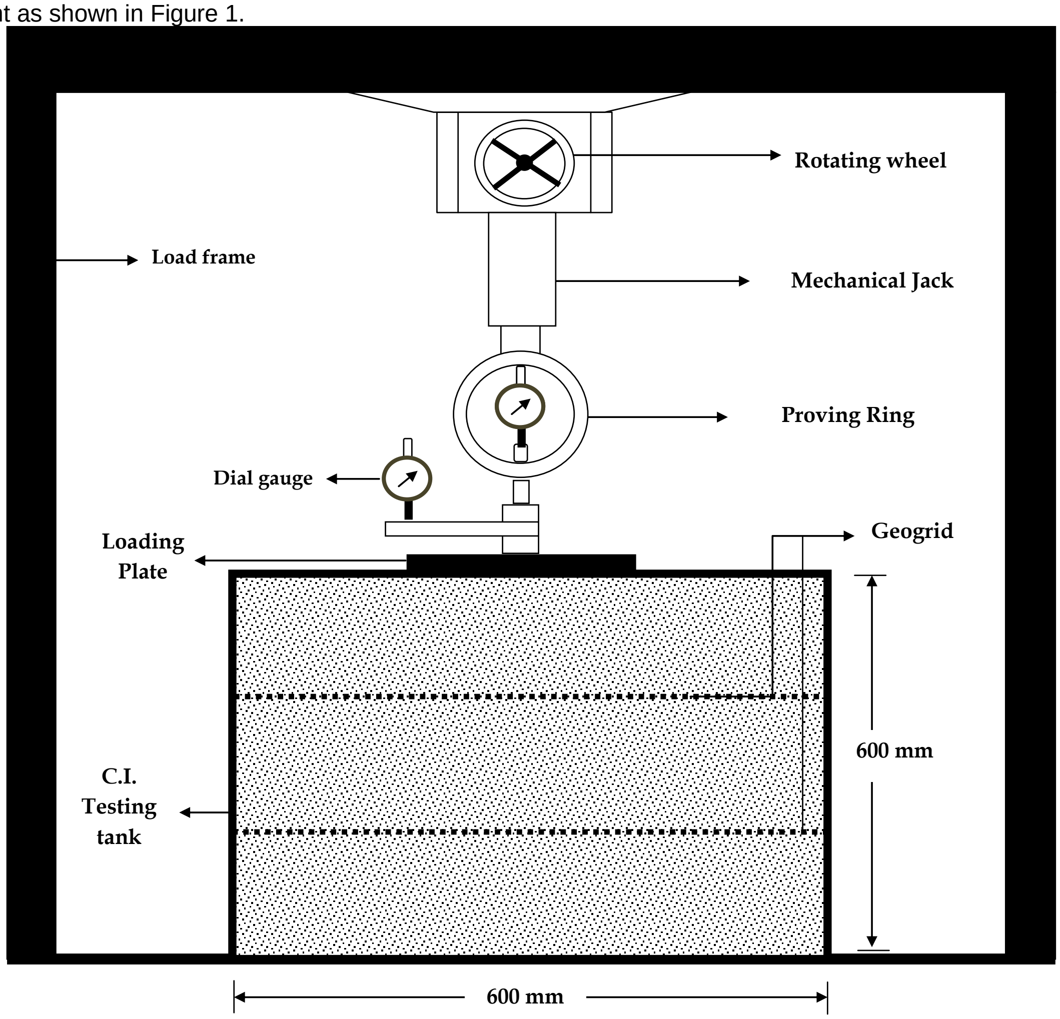


Figure 1. Schematic view of the test setup

2.1 Materials used

The soil which was used to construct the foundation bed was clay with low compressibility (CL). The soil was procured from beds of bhadrakali lake, Warangal, Telangana state, India. The properties of the soil are listed in Table 1. Commercially available geogrid to reinforce the foundation bed was purchased from a certified seller from Hyderabad,Telanagana state, India. The geogrids are manufactured from a high-density polyethylene (HDPE) and are designed for sustain sufficient amount of tensile moduli. Whereas the jute geogrids were procured from M/s. Ballyfab International Ltd., Chennai, Tamilnadu state, India, which is a National Jute Board (NJB) approved company.

Table 1. Properties of Clay

Parameters	Quantity
Specific gravity	2.70
Liquid limit (%)	42
Plastic limit (%)	19
Plasticity index (%)	23
Maximum dry density (kN/m^3)	16.5
Otimum moisture content (%)	18

USCS classification symbol	CL

Table 2. Properties of commercial and jute geogrids

Parameters	**Quantity**
Commercial geogrid	
Polymer	Polypropylene
Aperture size (mm)	32 x 31
Ultimate tensile strength (kN/m)	20
Shape of aperture opening	Square
Jute geogrid	
Polymer	Jute
Aperture size (mm)	35 x 35
Ultimate tensile strength (kN/m)	9
Shape of aperture opening	Square

The properties of commercial and jute geogrids are listed in Table 2.To compare the load elongation behaviour of both commercial geogrid and jute geogrid, multi-rib tensile strength tests were conducted as per ASTM D 6637. The results of the tests are shown in Figure 2 and Figure 3.

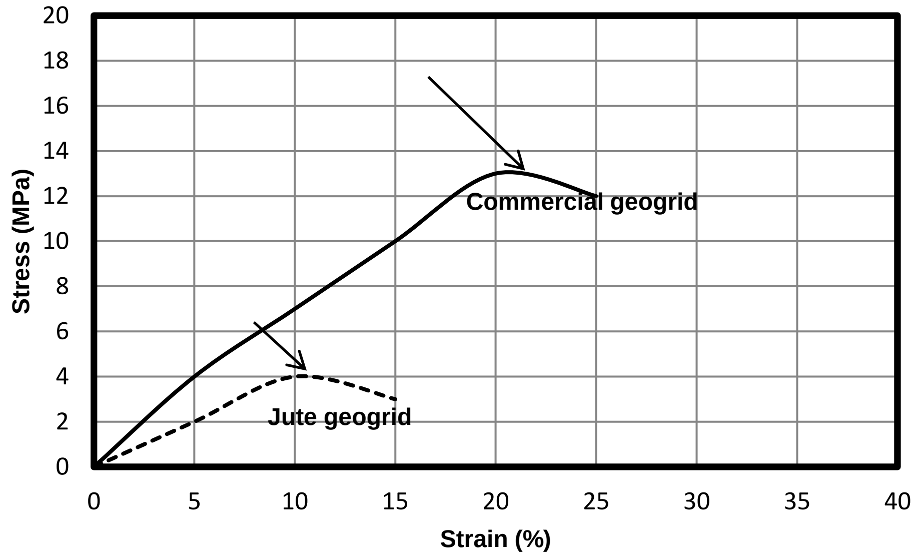


Figure 2. Load elongation behaviour of commercial and jute geogrid

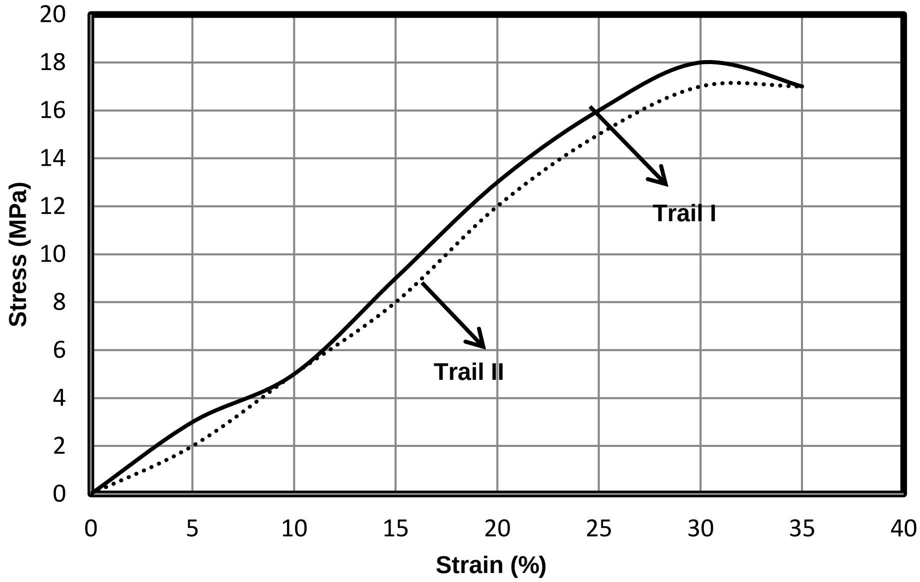


Figure 3. Load elongation behaviour of jute geogrid coated with bitumen

From the figure it is very clear that the tensile strength of the jute geogrid is very less when compared to that of the commercial geogrids. Commercial geogrids mobilizes its full tensile strength upto a strain rate of 20%, whereas the jute geogrid mobilizes its tensile strength upto a rate of 10%, which is half of to that compared with commercial geogrids. It is also acknowledged that jute geogrid got failed within no time, while conducting the test. Hence, it was resolved to enhance the strength of the jute geogrid, such that it can sustain larger tensile moduli. This was done by according a bitumen coating on the surface of jute geogrid. Bitumen on drying turns the jute geogrid into a stiffer material which can resist larger loads. Bitumen was heated initially to make it workable and apply as a coating onto the jute geogrid. The properties of bitumen used are listed in Table 3. A paint brush was used to apply coating of bitumen onto the jute geogrid. After coating bitumen, the jute geogrid was allowed to dry in a temperature controlled room for 72 hours.

Table 3. Properties of Bitumen

Parameters	**Quantity**
Flash and Fire point	260°c and 280°c
Ductility value (cm)	72
Softening point	43°c

To determine the tensile strength of bitumen coated jute geogrid multi-rib tensile strength tests were conducted as per ASTM D 6637. Figure 3. Shows the load elongation behaviour of the jute geogrid coated with bitumen. From the figure, it is clear that the tensile strength of jute geogrid was increased by 4.5 times on according a coat of bitumen on it. Infact, the tensile strength of jute geogrid coated with bitumen is 1.4 times to that of commercial geogrids. One more sample was tested to verify the tensile strength behaviour of bitumen coated jute geogrid. The results of second trial test had showed a good justification to the test conducted earlier, with a deviation of less than 5%. The average thickness of bitumen coated jute geogrid was measured using thickness gauge and was found to be 5.91mm. Hence, same thickness was maintained for all the specimens for all the tests.

2.2 Reinforced clay beds

In this study the clay beds were reinforced with commercial geogrids, jute geogrids and bitumen coated jute geogrids. Studies on single and double reinforced beds are conducted here. To find the optimum position of placing the reinforcement material in the clay bed with both single and double reinforcement, a series of trial tests were conducted placing the reinforcing material at different locations. Table 4. represents the details of tests conducted on clay beds with single and double reinforcement with varying locations of reinforcement material. Different locations along the height of the tank (H) were targeted to place the reinforcing material. Depending upon the value of H/3, H/2 and 2H/3, the reinforcing material was placed in the clay bed. In case of double reinforcement reinforcing material was placed twice at different locations. Reinforcement material of required dimensions, i.e. dimensions of the tank 60cm x 60cm is been trimmed to place into the tank.

Table 4. Locations of reinforcing material in soil bed

Trial	**Position of reinforcing material**	**Remarks**
Trial I	H/3	Single reinforcement
Trial II	H/2	Single reinforcement
Trial III	2H/3	Single reinforcement
Trial IV	H/3 and H/2	Double reinforcement
Trial V	H/2 and 2H/3	Double reinforcement
Trial VI	H/3 and 2H/3	Double reinforcement

3. TEST PROCEDURE

The clayey soil was pulverized before adding the predetermined water content in it. Presence of water content in the soil is determined and then the additional water content was added in the soil to achieve optimum moisture content. After adding the water in the soil and mixing uniformly, soil was placed in the plastic container for 48 hours to ensure uniform distribution of water content in the soil. Clay bed was prepared by compacting the soil uniformly in 25mm thick layers achieving the desired height of the foundation. Each layer of the soil was compacted for 25 blows using a rammer with a base of size 15cm x 15cm and weight of 10kgs, made of steel and falling from a height of 20cm evenly onto the surface of the soil. The walls of the tank were coated with a thin layer of lubricant to reduce the friction between the walls of the tank and the soil. A uniform test bed was maintained in all the tests by controlling the water content and compaction. After forming the bed, undisturbed soil samples were collected from the test bed to determine water content and undrained shear strength. The properties of the sample collected from the bed showed a good correspondence with the natural properties of the soil with a deviation of less than 3%. The final surface of the clay bed was leveled and trimmed properly to have a uniform surface in all the tests.

After constructing the clay bed, surface was leveled and the excess soil was trimmed off. A circular loading plate of diameter 15cm was placed at the center of the clay bed. Load is applied by driving the jack forward towards the surface of the clay bed on to the loading plate. A precalibrated proving ring of capacity 200kN was used to measure the load, which is fixed with a ball bearing arrangement. A calibrated dial gauge of 50mm capacity was placed on the plunger which is fixed to the proving ring as shown in Figure 1 to measure the settlement. Load was applied in equal increments uniformly with a constant displacement rate of 1mm/min. The loading for all the tests were continued to a displacement of 50mm.

4. RESULTS AND DISCUSSION

After conduction of each test, the pressure settlement behaviour of the reinforced clay beds was plotted and is compared with that of unreinforced clay beds as shown in Figure 4. A considerable amount of increase in the bearing capacity was observed in all the reinforced beds when compared to that of unreinforced clay bed. In case of unreinforced clay beds, the stresses were mobilized to a pressure of 10 kPa, following onto a vertical curve indicating the failure of the soil bed. Perhaps, sudden failure of the soil bed was not observed. Reinforcing the soil with the conventional jute geogrid showed a slight increase in bearing pressure, i.e. <40% following the same failure pattern of the soil bed as in the case of unreinforced soil. Jute geogrids were placed at different locations in the soil bed, i.e. H/3, H/2 and 2H/3 from top.

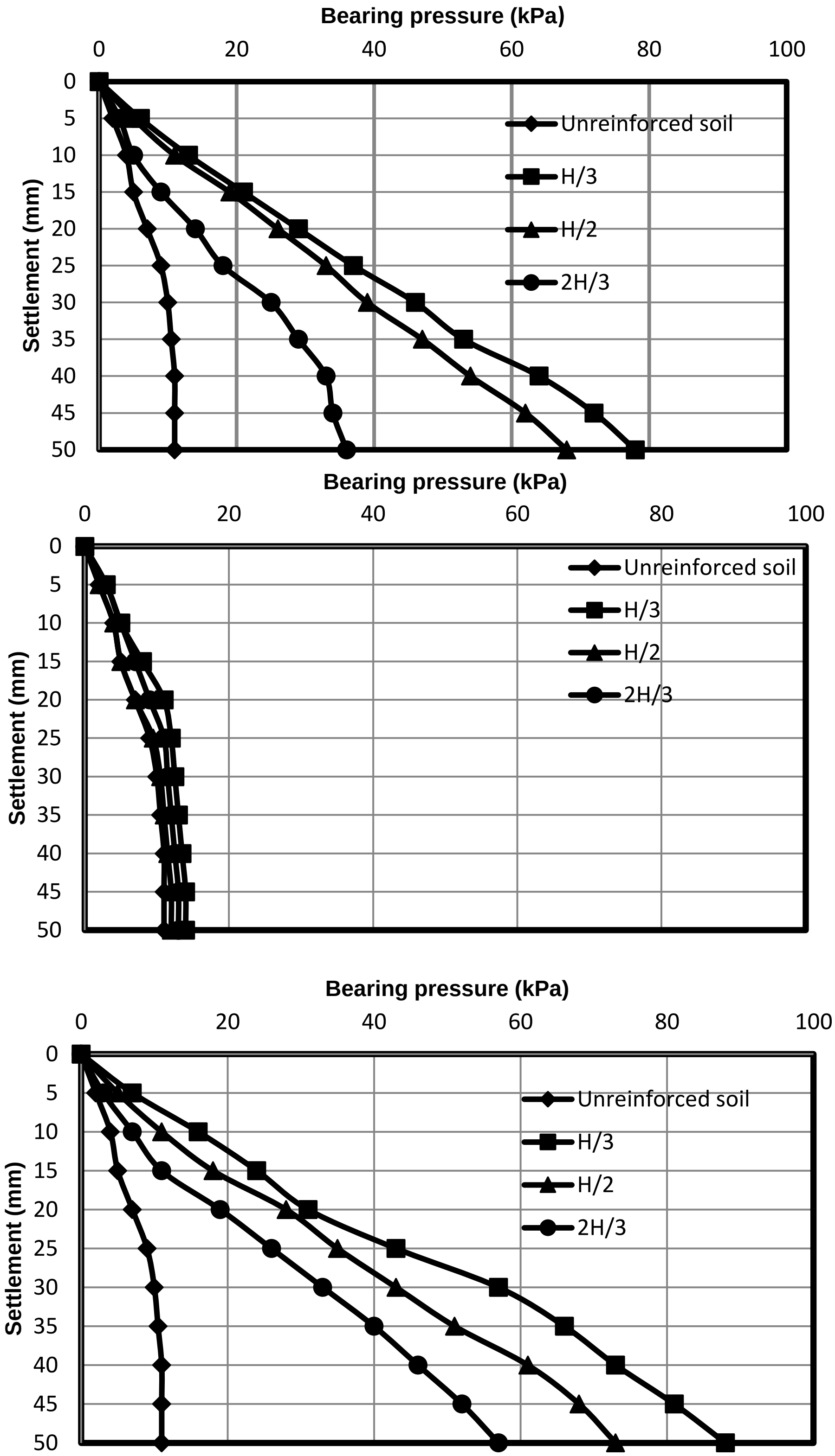
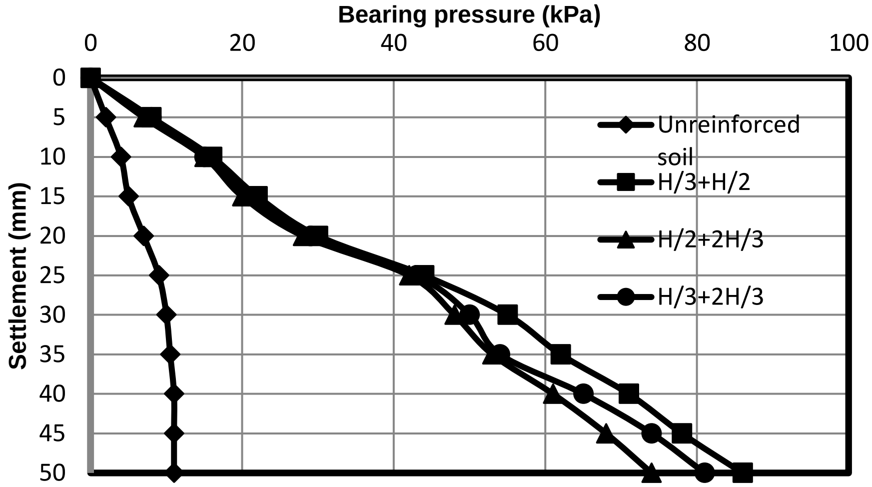
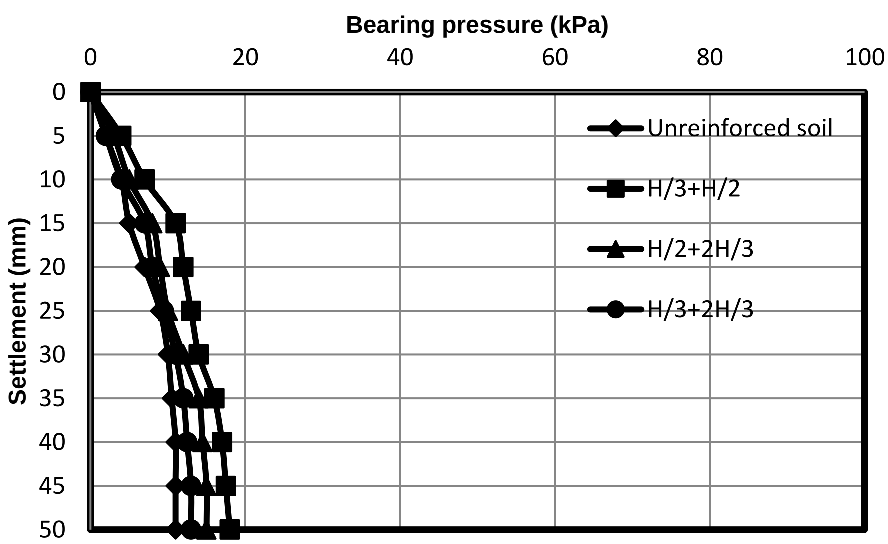


Figure 4. Pressure settlement behaviour of soil with single reinforcement at various location of H/3, H/2 and 2H/3 a) Commercial geogrid b) Jute geogrid c) Bitumen coated jute geogrid

The load settlement behaviour in all the cases was found to be similar with slight variation i.e. H/3 being the maximum and 2H/3 being the minimum. In all the three cases, the curves tend to vertical, indicating failure of the soil bed. In case of commercial geogrids, bearing pressure increased to a substantial extent. Commercial geogrid when placed at a depth of 2H/3 from the top surface, bearing pressure increased up to 3.6 times when compared to that of an unreinforced clay beds. Whereas when placed at H/3 and H/2 it was 7.8 and 6.8 correspondingly and didn't show any sign of failure of clay beds for the measured displacements. The bitumen coated jute geogrid performed better than the conventional jute geogrids and also commercial geogrids. Increase in bearing pressure was observed continuously for the measured displacement. The maximum bearing pressure was observed when bitumen coated jute geogrid was placed at a depth of H/3 from the top surface, which was around 9 times when compared to that of unreinforced clay, 5 times when compared to that of maximum bearing pressure when reinforced with conventional jute geogrids and around 1.2 times when compared to that of maximum pressure when reinforced with commercial geogrids. In all the cases the hierarchy can be given as H/3 followed by H/2 and then 2H/3. This is because of locating the reinforcement layer more closely to the top surface of the clay bed, where loads are acted upon. The reinforcement material was damaged to a greater extent, when it was placed at a depth of H/3, representing effective utilization of the reinforcing material to mobilize tensile stresses. For double reinforcement of the clay beds, reinforcing materials were placed twice at three different locations. I) one at a distance of H/3 and the other at a distance of H/2 from the top surface (H/3+H/2) ii) one at a distance of H/2 and the other at a distance of 2H/3 from the top surface (H/2+2H/3) iii) one at a distance of H/3 and the other at a distance of 2H/3 from the top surface (H/3+2H/3). Bearing pressure of the double reinforced clay beds substantially increased when compared to that of single reinforced and unreinforced beds as shown in Figure 5.





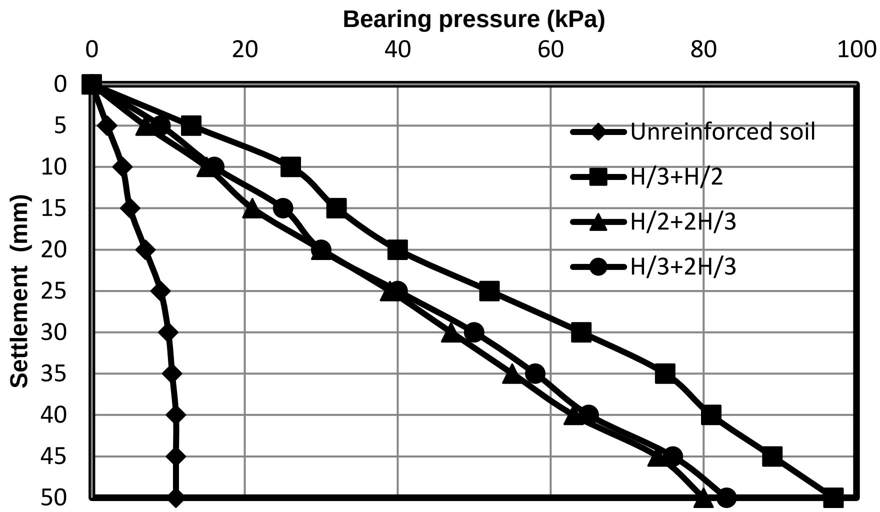


Figure 5. Pressure settlement behaviour of soil with double reinforcement at various location of H/3, H/2 and 2H/3 a) Commercial geogrid b) Jute geogrid c) Bitumen coated jute geogrid

Better performance of the clay bed was observed when reinforcement material was placed at H/3+H/2 and H/3+2H/3. Placing reinforcement material at a depth of H/2+2H/3 gave similar performance of that placing single reinforcement at a depth of H/3, which was optimum location to place a single reinforcement layer. Placing of reinforcement material at a depth of 2H/3 in all the cases didn't prove effective as the clay bed failed before the reinforcement material which shows the tensile strength of the reinforcement material was not effectively mobilized for the applied stress. When two reinforcement materials are placed at a depth of H/3 and H/2 (H/3+H/2), it was observed that the reinforcement material at H/3 didn't got damaged to a greater extent, as observed in the case of the single reinforcement at H/3. Reinforcement materials at H/2 accorded a good support to the material placed at H/3, which exhibits effective utilization of the reinforcement materials for the increased stresses. Performance of reinforced soil bed can also be assessed based on reduction of settlement of the footing using Percentage reduction settlement (%RS) factor, which is defined as

$$\%RS = \left(\frac{S_o - S_r}{S_o}\right) x\ 100$$

Where, S_o is settlement corresponding to ultimate bearing capacity of an unreinforced foundation bed. To estimate the ultimate load bearing capacity of an unreinforced clay bed double tangent method suggested by Vesic was used. As per this method, two tangents T_1 and $T_2$are extended from the earlier and later parts of the curve. The intersection point of these two tangents is projected onto axes to know the ultimate load bearing capacity and its corresponding settlement. Whereas S_r is the settlement recorded for the reinforced beds corresponding to the ultimate load bearing capacity of unreinforced bed.

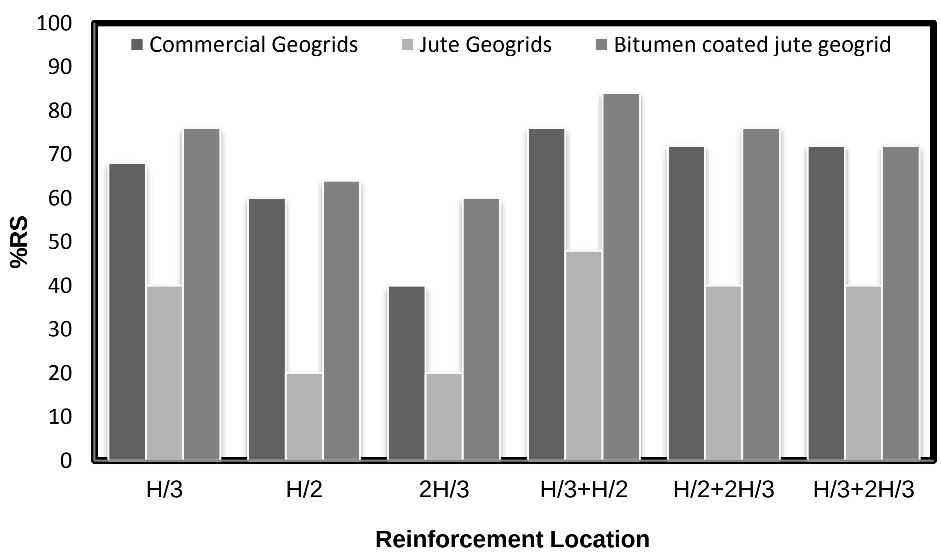


Figure 6 % Reduction in settlement of different reinforcement materials at different locations

Figure 6 shows percentage reduction settlement of the clay beds reinforced with different materials at various locations. A maximum reduction settlement of 84% was observed when clay bed was double reinforced with bitumen coated jute geogrid placed at H/3&H/2. Lowest value of settlement reduction was observed when clay bed was reinforced with jute geogrid at H/2 and 2H/3. No significant reduction in settlement was observed when clay bed was reinforced at 2H/3 with a single reinforcement irrespective of material used for reinforcement.

5. CONCLUSIONS

The performance of strength enhanced jute geogrid by according a coating of bitumen was studied based on the experimental and analytical results. The obtained results were compared with the performance of the clay bed when reinforced with other materials like commercial geogrids and jute geogrids.The following conclusions can be extracted from the obtained results.

i). Jute geogrid being a less tensile resistant material was effectively utilized to reinforce the clay beds, by enhancing its strength by according a bitumen coat to it. Chemical hardening of the bitumen had significantly enhanced the strength of the bitumen coated jute geogrid making it stiffer and suitable to reinforce soil beds.

ii). Performance of clay beds reinforced with single and double reinforcement layers were studied by placing the reinforcement materials at different locations throughout the depth of the clay bed. It was found that double reinforcement of clay bed gave better results when compared to that of single reinforcement. The clay bed resisted better stresses when the reinforcing material was placed at a height of H/3 from the top in case of single reinforcement and at a height of H/3+H/2 in case of double reinforcement.

iii). Bearing capacity of a clay bed was increased by 9 times when compared to that of an unreinforced clay bed when reinforced with strength enhanced jute geogrid at height of H/3 from top surface, when placed alone. Increase in bearing capacity by about 10 times was observed when placed at H/3 and H/2.

iv). Reinforcement material was damaged to a greater extent when placed alone at a height of H/3 from the top surface of the soil bed. An additional support by adding another reinforcement material at a depth of H/2 from top surface avoided damage to the reinforcement material placed at a depth of H/3.

v). Substantial reduction in settlement was observed whenever reinforcement material was placed at a depth of H/3 from the top surface of the soil bed both in case of single and double reinforcement.

vi). It is acknowledged that placing reinforcement material above H/3 towards the top surface could lead to failure of reinforcement material leaving the soil bed unreinforced for the further stresses.

In addition, the strength enhanced jute geogrids are resilient to tensile stresses and have an ability to recover after removal of loads. Strength enhanced jute geogrids are also economical when compared to that of the commercial geosynthetics.

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