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Experimental Studies on Load Settlement Behavior of Cohesionless Soil using Bamboo Grid

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Abstract. Ground improvement is a must in present world where there is lack of land available for construction. Soil improvement can be done in various ways to increase the strength of soil. Soil reinforcement is one of the techniques available to enhance the quality of soil. Various tested techniques are available for this purpose. In this study, bamboo grids have been applied in horizontal layers like geo grids in a test tank to study the increase in bearing capacity under vertical loading. Easy availability, low cost, strong tensile strength, environment friendly behavior are some of the reasons for selecting it. The study is conducted on a steel test tank with locally available Zone III sand. Load tests are conducted on a model circular footing with 0.18m diameter (B) resting on sand with and without bamboo grids to compare the improvement factor for bearing capacity. The reinforcements are inserted in bed of sand with varying depths (B, 0.25B, 0.5B, B 1.5B) and in single and multiple layers. Depth to diameter ratio, number of grid layers, and shape of the aperture plays an important role in performance of model circular footing. At first, model circular footing without bamboo grid is tested and experimental results are compared with various analytical equations available viz Terzaghi (1943), Meyerhof (1963), Hansen (1957, 1970), Vesic (1973), IS: 6403-1981 code. The proximity in the experimental results with Terzaghi establishes the reliability of the test setup. The models are tried with PLAXIS 2D® also.

Keywords: Bearing capacity; bamboo reinforcement improvement factor; model footing; settlement.

1 Introduction

The advent of construction industry has lead to various mega constructions but due to lack of good quality of soil it has become a headache for the engineers. There are many techniques to improvise all the types of soil and reduce the unfavorable ground condition. Many soil improvement processes are available. Various experiments are conducted on reinforced soil to improve bearing capacity of soil and reduce settlement (Binquet and Lee 1975, Fragaszy and Lawton 1984; Guido, Chang and Sweeny 1986; Mandal and Sah 1992; Omar et al 1993a, 1993b; Das and Omar 1994; Shin and

Das 2000; Dash, Abu-Farsakh et al 2013). The high cost of synthetic polymer and durability of natural ones have made the scholars to explore more in this field. The cost of geosynthetic material is one of the deciding factors in its selection. (Akinmusuru and Akinbolade 1981; Dixit 1985; Mandal and Manjunath 1994; Datye and Gore 1994; Sitharam and Hedge 2015; Dutta and Mandal 2016; Lal et al 2017; Dong et al 2010) are few scholars experimented with the natural geomaterials for bearing capacity of soil. Installing bamboo grid reinforced soil system which increases the frictional resistance hereby enhancing the bearing capacity of soil. In this study the effect of various parameters such as the location of the top grid layer, number of grid layers and aperture shape of the bamboo grid on bearing capacity and settlement are studied extensively. In this study, bearing capacity of soil with and without bamboo mat are compared theoretically, analytically and later validated the results with PLAXIS 2D®.

2 Research Methodology

2.1 Test Set-up

To conduct the plate load tests a model steel tank of size 0.95m x 0.95m x 0.95m is prepared at Jorhat Engineering College, Jorhat, Assam as per IS: 1888-1982. It consists of a loading frame, inverted hydraulic jack of capacity of 20kN, pumping unit, steel plates loaded with concrete cubes. Measurement of the magnitude of applied load pre-calibrated pressure is used. Deflection dial gauges of least count of 0.01mm placed to measure the settlements of plates due to applied load. In this experiment, cohesion less sand is used. Here, the sand bed is prepared with 30cm and pre-calibrated compacting energy is applied to achieve the required loose, medium, dense relative densities. Fig.1 shows the test setup along with schematic used in this study.

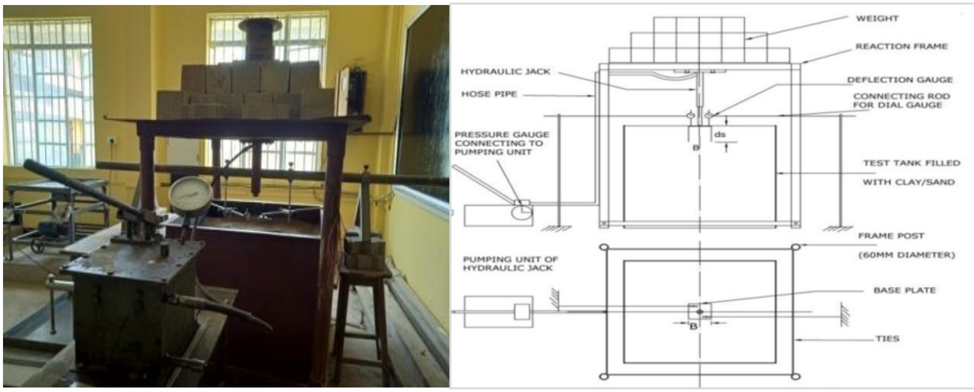


Fig.1. Test Setup with its schematic diagram

2.2 Materials Used

Sand: The material used for this study is sand from Mariani (Bhogdoi River) of Jorhat district, Assam. The sand is cleaned to remove the unwanted materials from it. It is oven dried and sieved through IS sieve size of 4.75mm and portion passing is taken for the experiment. The properties of the sand namely coefficient of curvature (C_c), uniformity coefficient (C_u), Zone of the sand (IS: 383-1970), grading characteristics D_{10}, D_{30}, D_{60} is determined according to the mentioned Indian Standard Codes. The sand is classified as poorly graded sand (SP) with specific gravity 2.65. The grain size distribution is shown in Fig 2 and Table 1 shows the grading characteristics of the sand. Direct shear tests are done according to IS: 2720 (Part 13)-1986 to obtain the internal angle of friction (Φ). The unit weight of soil is 16.04kN/m^3 and average relative density is 59.87%.

Table 1. Properties of Sand Used

Material	D_{60}	D_{30}	D_{10}	C_u	C_c
Sand	0.53	0.37	0.28	1.89	0.92

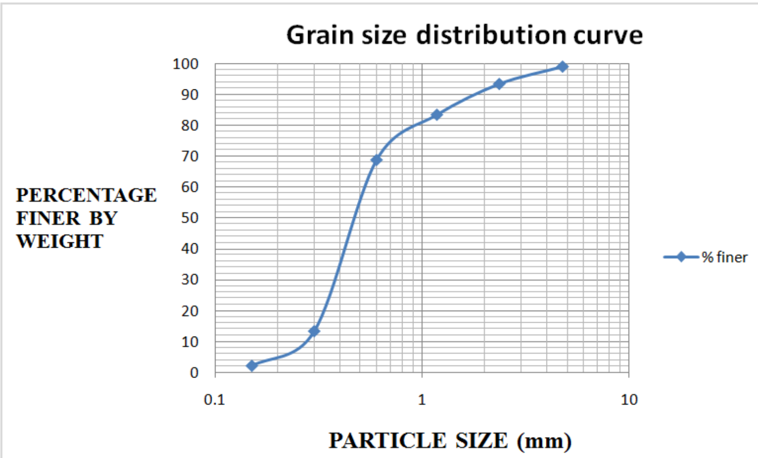
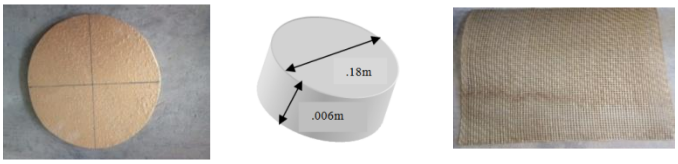


Fig. 2. Particle Size Distribution Curve

Model Footing and Bamboo Grid: Model circular footing (MF) for the tests used in this study is made up of mild steel plate having diameter 0.18m and thickness 0.006 m. Model footing surfaces are smooth. Grids of *Bambusa tulda* (Jati Baah) treated with CCB (copper chrome boron) of length 0.9mx0.9m, splints of width 3mm and thickness of 1mm prepared in Rain Forest Research Institute. Jorhat, Assam is used. The bamboo strips used are configured in planar and orthogonal directional to get Bidirectional and Tridirectional patterns. The photographs of the model footing with its schematic and bamboo mats are given in Fig. 3(a), 3(b), 3(c) respectively.



(a) (b) (c)

Fig. 3 (a) Model Footing (b) Schematic diagram (c) Bamboo Mats

The durability of bamboo in civil engineering projects is a great concern. According to (Gnanaharan 2000) the life cycle of bamboo in wet condition is 5 years. The insects and fungi play an important role in degrading the bamboo and its efficiency. A chemical compound CCB (Copper Chrome Boron) is used to increase its durability by soaking the bamboo strips in it for 24 hours. Moisture content hampers its efficiency as reinforcement as it needs to be coated with bitumen and sun dried for 24 hours (Ghavami 2004).

3 Methodology of Load-Settlement Test

Load tests are conducted on the model test tank and test procedure is taken from IS: 1888-1982 for plate load test. Average relative density of 59.87% is maintained for all the tests. The average relative density and unit weight of sand beds are maintained as 59.87% and 16.04 kN/m^3 respectively. The number of drop is selected from the calibrated graph at a required density (59.87%) for all experiments. A sprit level is used to level the surface before placing the footing. It is placed centrally, under spindle of the jack so that the plate, reaction girder and the spindle are coaxial. Dial gauges are used to estimate the settlements. Load is applied in cumulative equal increment of 10kg. Dial gauge readings are measured after the time interval mentioned in IS: 1888-1982. Test is repeated until a high value of settlement is observed. For the further test, reinforcement is placed at the desired depth from the model footing.

3.1 Calculation for ultimate bearing capacity of model footing

The ultimate bearing capacity of shallow circular foundation is determined by load-settlement curves. The comparative load displacement curve of model footing plate in loose, medium, dense sand with corresponding angle of internal friction as 27.5°, 31°, and 35° has been presented in Fig 4. The ultimate bearing capacity for the model footing at different relative densities is calculated numerically by Terzaghi (1943), Meyerhof (1963), Hansen (1957, 1970), Vesic (1973), IS: 6403-1981 is listed in Table 2. The relative densities are 34.8%, 59.87%, 70.24%. Bearing capacity of model footing of diameter 0.18m found out to be 23.80 kN/m^2 experimentally this is extracted from load-settlement graph. Load intensity with respective settlement is plotted on a log-log scale. It matches with the results obtained from Terzaghi equation. Hence it can be concluded that results obtained from the experimental set up is reproducible.

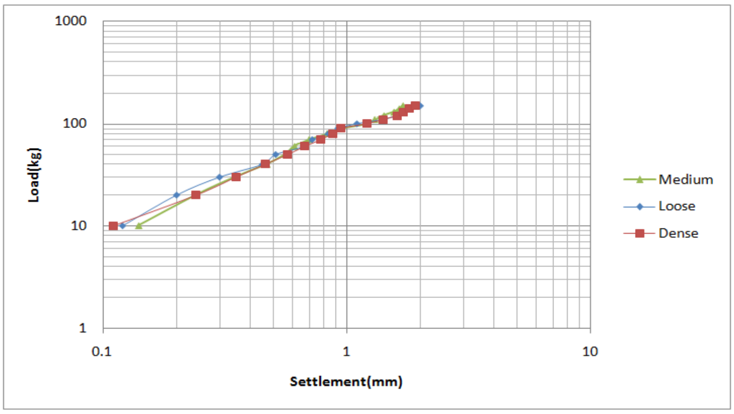


Fig. 4. Comparison of Load-Settlement for circular footing

Table 2. Comparison of Ultimate Bearing Capacity

Method	Ter	Mey	Hansen	Vesic	IS Code	Exp
Loose	14.75	18	10.08	15.37	14.84	12
Medium	25.82	38.26	18.75	26	26.1	23.8
Dense	46.13	81.38	36.26	49	46.6	41

3.2 Effect of bamboo reinforcement at different depths

The bamboo mat used as reinforcement having size 0.9mx0.9m, strips of width 3mm and thickness 1mm which are chemically treated with CCB are configured together for bidirectional (square aperture) and tridirectional (hexagonal) where the connection patterns are inter-woven, orthogonally and diagonally interlocked for maintaining the equal aperture size during the preparation of bamboo grids for the research. These bamboo mats are placed at a depth of 0.25B, 0.5B, B, 1.5B where B is the diameter of the model footing.

Effect of Square aperture Bamboo at different depths. The square aperture bamboo mats of size 0.9mx0.9m are placed at a depth of 0.25B, 0.5B, B, 1.5B where B is the diameter of the model footing. The improvement of bearing capacities due to installation of bamboo layer are represented by a non-dimensional factor called "*Improvement Factor*". The factor is defined as the ratio of ultimate bearing capacity of shallow foundation with bamboo layer to the ultimate bearing capacity of shallow foundation without it. It is clear that the ultimate load and ultimate bearing capacity decreases with the increase in the difference of the between the distance of bamboo layer and the model footing. Same is the case with the failure load. Fig 5 and Fig 6 shows square aperture bamboo grid placed at the required depth and load-settlement graph for model footing with bamboo reinforcement at different depths. Table 3 depicts the values obtained.

Fig. 5. Square aperture bamboo grid at required depth

Table 3. Ultimate bearing capacity of model footing with square aperture bamboo grid at various depths

Depth	Failure load (Kg)	Ultimate bearing capacity (kN/m^2)	IF
0.25B	120	47.15	1.98
0.5B	110	43.22	1.81
B	80	31.4	1.32
1.5B	70	27.5	1.15

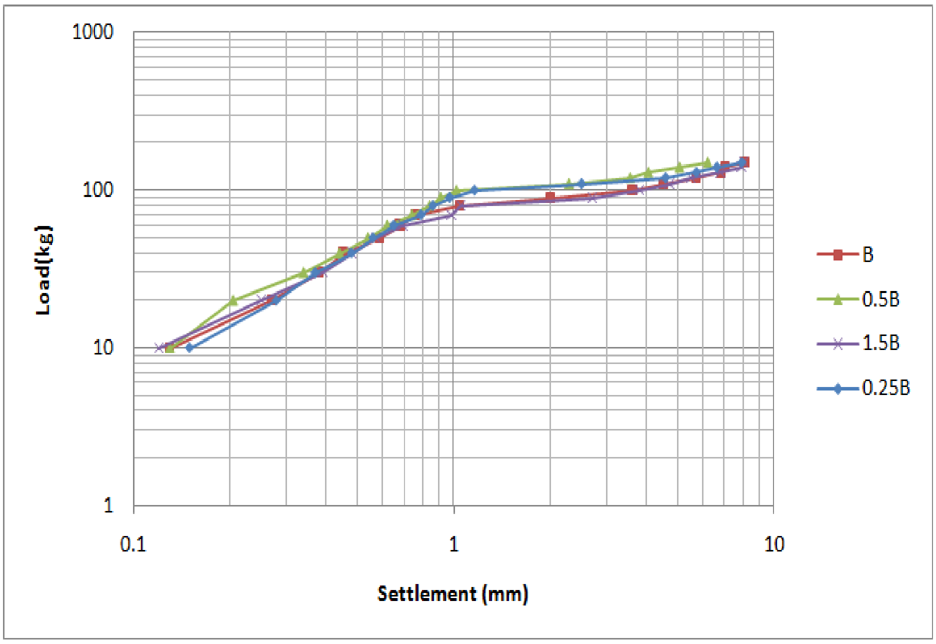


Fig. 6. Load-Settlement graph for model footing with bamboo layer at different depths

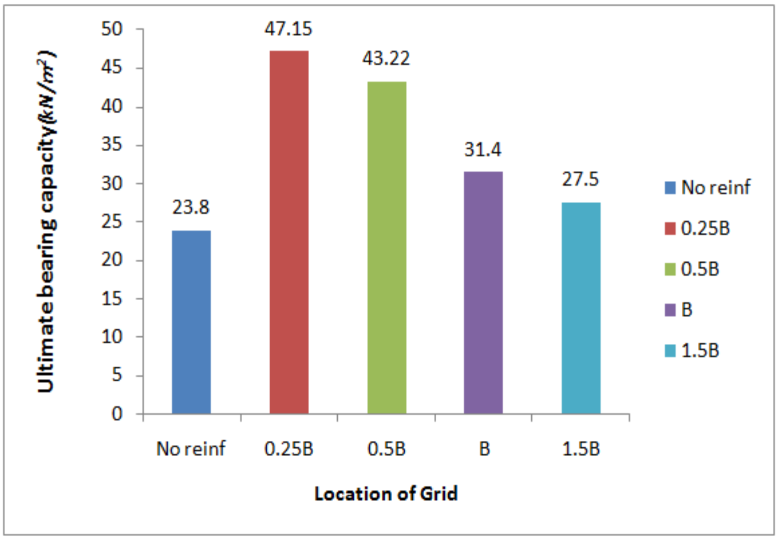


Fig. 7. Comparison of bearing capacity with and without grid

Effect of Hexagonal aperture Bamboo at different depths. The effect of hexagonal bamboo mats of size 0.9mx0.9m when placed at 0.25B, 0.5B, B, 1.5B are discussed in the following Fig 8 and Table 4. A graphically representation is given in Fig 9.

Fig. 8. Hexagonal aperture bamboo mat at required depth

Table 4. Ultimate bearing capacity of model footing with hexagonal aperture bamboo grid at various depths

Depth	Failure load (Kg)	Ultimate bearing capacity (kN/m^2)	IF
0.25B	170	66.8	2.81
0.5B	150	58.9	2.47
B	130	51.08	2.13
1.5B	80	31.4	1.32

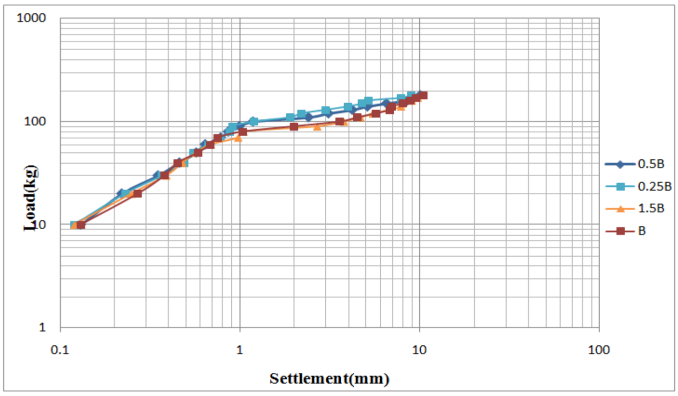


Fig .9. Load-Settlement graph for model footing with bamboo layer at different depths

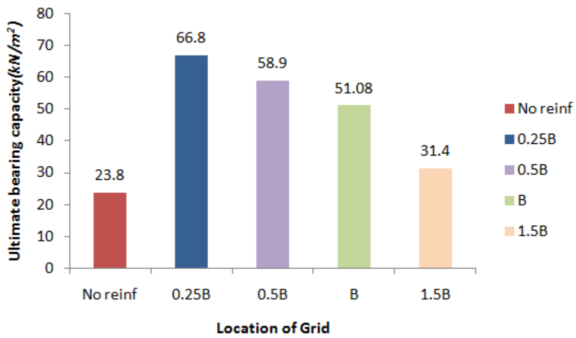


Fig. 10. Comparison of bearing capacity with and without grid

From the above discussion it is clear that for the same size and aperture the TBG which is hexagonal aperture gives better performance compared to BBG of square aperture. The reason may be, due to its geometry, TBG is capable to transfer stresses in all direction, giving more bearing resistance compared to that BBG.

4 Numerical Analysis

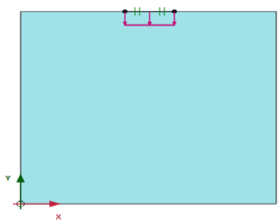
The geometry of the finite element soil model adopted for the analysis is 0.95mx0.95m with the identical dimension of the model footing mentioned above. Comparison has been drawn for bearing capacity with and without bamboo mats. Later, bamboo mats placed at the required depth is shown with the results obtained. Here, ground water condition is neglected. Superstructure is replaced by an equivalent amount of loading and that equivalent amount of vertical pressure is applied. The various properties used in the study are given in Table 5. In this study more emphasis is given to Medium density sand. In this analysis Mohr Coulomb analysis is used. Analysis is carried out in PLAXIS 2D® where the load-displacement curve is obtained.

Table 5. Properties used in PLAXIS 2D®

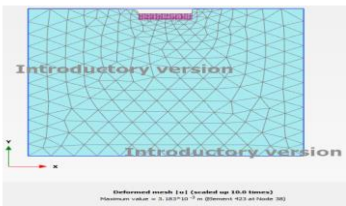
Properties	Value
Type of soil	Sand
Soil Model	Mohr-Coulomb
Void Ratio	0.5
Foundation thickness (m)	0.006
Foundation diameter (m)	0.18
EA (kN/m)	5089380.1
EI (kNm^2)	10306
w (kN/m/m)	0.5
Name of the geogrid	Bamboo
Pattern	Square Hexagonal
EA (kNm^2)	700 900

4.1 Model Footing without bamboo mat

Following geometrics are obtained when pressure is applied to the model footing during analysis. Fig 11 (a, b, c) show the model, displacement and stress distribution of the soil bin respectively. Fig 11d shows the load-displacement behavior of the foundation without bamboo mat under vertical loading. From this curve, ultimate bearing capacity is measured.



(a)



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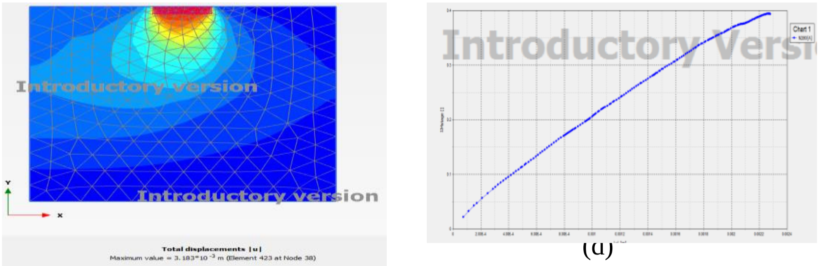
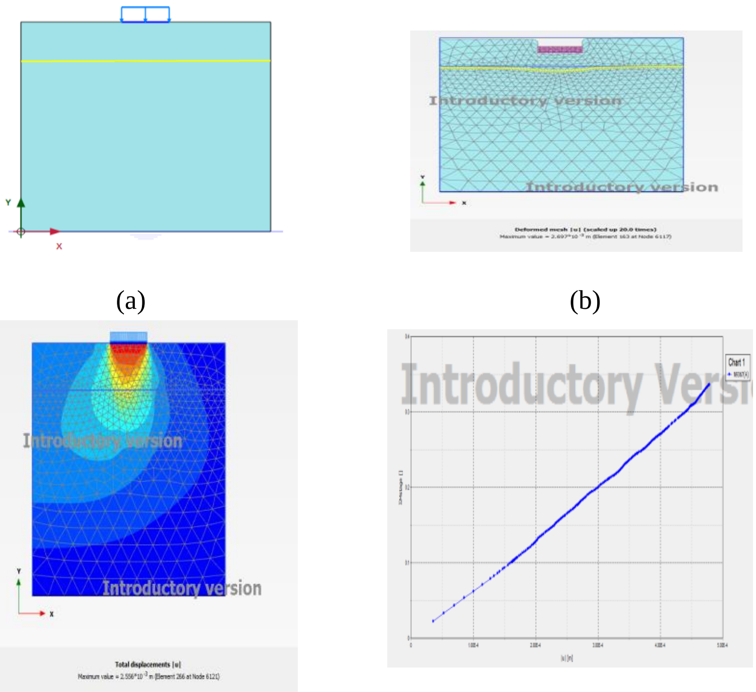


Fig.11.(a) Modeling (b) Displacement (c) Stress Distribution (d) Load-Settlement curve

4.2 Model Footing with square aperture bamboo mat

Following geometrics are obtained when maximum load is applied on the model footing with bamboo mat of size 0.9mx0.9m during analysis. Fig 12 (a,b,c) show the model, displacement and stress distribution of the soil bin with bamboo mat at a depth of B from the footing respectively. Fig 12d depicts the load-settlement curve for the mentioned loading.



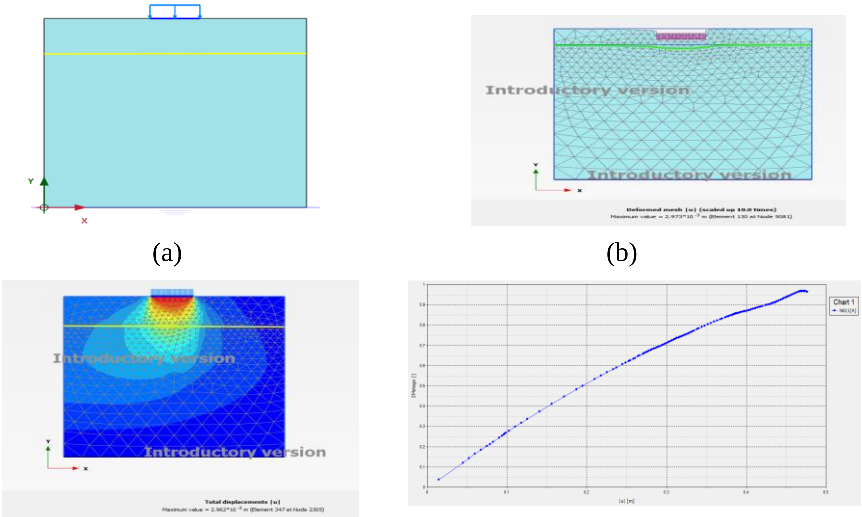
(a) (b)

(c) (d)

Fig .12. (a) Modeling (b) Displacement (c) Stress Distribution (d) Load-Settlement curve

4.3 Model Footing with hexagonal aperture bamboo mat

Following geometrics are obtained when maximum load is applied on the model footing with bamboo mat of size 0.9mx0.9m during analysis. Fig 13 (a,b,c) show the model, displacement and stress distribution of the soil bin with bamboo grid at a depth of B from the footing respectively. Fig 13d is with the load-settlement behavior for hexagonal aperture bamboo grid.



(a) (b)

(c) (d)

Fig. 13.(a) Modeling (b) Displacement (c) Stress Distribution (d) Load-Settlement

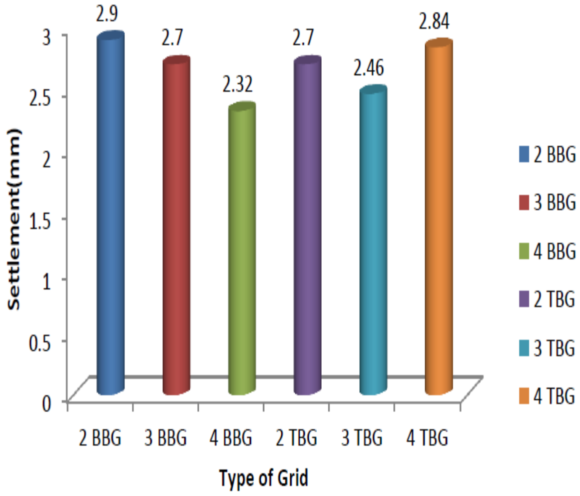
Table 6. Comparison of bearing capacity for medium density soil when bamboo grid placed at B

Type of aperture	Ultimate bearing capacity (kN/m^2)
Bidirectional	40
Tridirectional	62.4

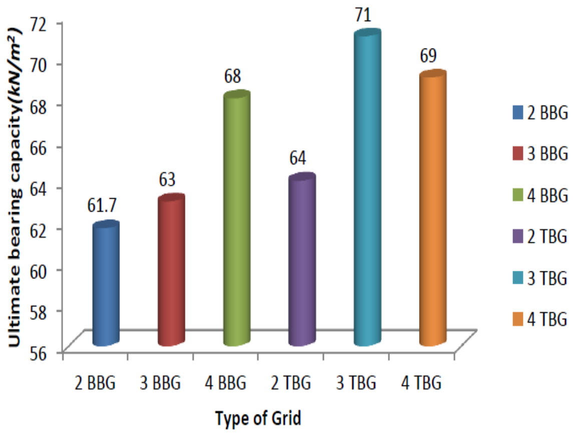
The model being axis symmetric load applied is given in kN/rad. Thus, the total load can be represented in the scale of kN by multiplying the value with 2π.From the output results Table 6 it can be concluded that the TBG offers more bearing capacity when applied at any random depth (here B).

4.4. Effect of number of layers with PLAXIS 2D®

The ultimate bearing capacity and settlement when different number of layers placed at required depths are studied with PLAXIS 2D®. With the above mentioned properties the analysis is observed for various variables.



(a)



(b)

Fig. 14. (a) Comparison between type of grid and settlement (b) Comparison between type of grid and settlement

5 Conclusions

Based on the results from the study the following conclusions can be drawn:

1. The bearing capacity increases with the increase in the relative density of soil and with insertion of bamboo mat.
2. The IF decreases significantly with the increase in the difference of the depth between footing and bamboo layer.
3. Due to the aperture shape the bearing resistance offered by TBG is more compared to that of the BBG for the same size of the reinforcement.
4. The settlement observed on the reinforced sand bed with three layers of TBG is less compared to the same number of layers of BBG. In case of bearing capacity it is more in three layers of TBG. Thus, it can be concluded that (N=3) of TBG is more effective than (N=4) of BBG.

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