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Bearing Capacity of Sand Beds Reinforced with Bamboo Baskets

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ABSTRACT: The Cellular confinement for reinforcing soil has been largely dominated by the use of geosynthetic material even when cheaper and eco-friendly alternatives like bamboo are easily available. Forming a cellular network using the geosynthetic materials termed as geocells, have shown to improve the bearing capacity of foundation beds. However, high cost of geosynthetic materials and focus on sustainable materials has led investigators to search for natural materials as alternative to conventional synthetic materials. This study presents a novel approach of using bamboo basket network for cellular confinement in place of geocells for reinforcing sand. The study quantifies the influence of different parameters like basket diameter, height, and width of bamboo basket network and number of layers on the load bearing capacity of reinforced sand. Results from experiments indicate that use of bamboo baskets effectively increases the load bearing capacity of sand. It is found that smaller diameter baskets with more height are most effective for making bamboo basket networks. Improvement of up to 4.9 times in the bearing capacity of sand reinforced with bamboo baskets network was observed.

Keywords: Bamboo basket, bearing capacity, ground improvement, laboratory model studies, soil reinforcement

Abbreviations: USCS, Unified Soil Classification system; IF, improvement factor.

I. INTRODUCTION

Reinforcing soil foundations with geosynthetics is quite popular as it helps in effectively resisting the stresses and prevents deformations. Forming a cellular network using the geosynthetic materials termed as geocells, have shown to improve bearing capacity of foundation beds [1-4]. These cells are filled with, infill materials generally sand or aggregates and have been found to perform better than other form of geosynthetics such as geogrids, geonets, geotextiles etc. [5, 6]. The geocells made of polymeric materials are used worldwide due to their simplicity and time saving compared to other ground improvement methods. Various mechanism of geocell layer reinforcement such as lateral confinement effect, vertical stress distribution effect and tensioned membrane effect are shown to have greater effect than planar geogrids [7]. Geocells have also been shown to have performed better than other forms of geosynthetics due to their three dimensional nature [5].

High Cost of geosynthetic materials and more focus on sustainable materials has led investigators to search for natural materials as an alternative to conventional synthetic materials. Several researchers have studied the use of natural fibers such as coir fibers [8, 9], sisal fibers [10, 11], palm fibers [12, 4], jute [15, 16], flax fibers [17,18], bamboo [6, 19] etc. for soil reinforcement.

Bamboo being natural and eco-friendly material is a good substitute to synthetic material owing to its high tensile strength. Very few studies are conducted in past for reinforcing soil with bamboo. Mandal and Manjunath [20] utilized bamboo sticks alongside vertical geogrids to improve the bearing capacity of sand beds. Datya and Gore [21] presented several field studies where bamboo grids made from bamboo strips were used to reinforce road base over sandy and clayey subgrades in Orrisa. Toh *et al*., [22] presented various case studies where a combination of geotextile and bamboo fascine mattress was used to reinforce fills over very soft soils in Malaysia. Khatib *et al.,* [23] studied the effect bamboo geotextile composite in reinforcing soft clay beds. The authors reported an increment of 1.27 times in the bearing capacity of clay beds reinforced with network of bamboo poles in a square pattern. Prasad *et al*., [24] carried out cyclic plate load tests on model flexible pavements constructed over expansive soils and reinforced with bitumen coated bamboo mesh. They reported an improvement in the performance of pavement when subgrade was reinforced with Bamboo mesh. The use of bamboo cells similar to geocells was studied by Sitharam and Hegde [25, 26]. They observed that the bearing capacity of soft clay reinforced with bamboo cells and bamboo grids is about 6 times to unreinforced soil. Further it is 1.3 times more than the neoloy geocells. Ahirwar and Mandal [19] studied the effect of aperture shapes on sand bed reinforced with bamboo grids. They observed that bamboo grids of hexagonal shaped aperture performed better than the square shape (bearing capacity increased 3.72 times and 2.78 respectively).

The research and field work on bamboo reinforced soil is mostly restricted to use of bamboo grids and poles both of which are planar form of reinforcement. Very limited research is done on application of bamboo in cellular three dimensional forms. In this study a novel idea of using readymade baskets of bamboo to form a cellular network of bamboo reinforcement is presented. The effect of basket size, diameter, and cell width on the bearing pressure and settlement behavior of sand beds under a square footing is studied with no subheadings.

The study aims at quantifying the relationship between geometrical parameters of bamboo basket on enhancing the load bearing capacity of sand.

Table 1: Properties of Sand.

S. No.	Property	Value
1.	Specific Gravity	2.67
2.	Effective Particle Size (D_{10}) (mm)	0.22
3.	Coefficient of Uniformity (C_u)	2.13
4.	Coefficient of Curvature (C_c)	1.11
5.	Maximum Dry Density (kN/m^3)	17.55
6.	Minimum Dry Density (kN/m^3)	15.71
7.	Angle of Friction (φ)	40^o
8.	Cohesion (kN/m^2)	0

II. MATERIALS AND METHODS

A. Sand

Locally available river sand is used in the present study. The grain size distribution curve of the sand is shown in Fig. 1 and the properties are listed in Table 1. The soil is classified as poorly graded sand as per Unified Soil Classification system (USCS). The strength parameters of the sand were determined by direct shear test at the relative density of 70% (i.e. at dry unit weight of 16.95 kN/m^3).

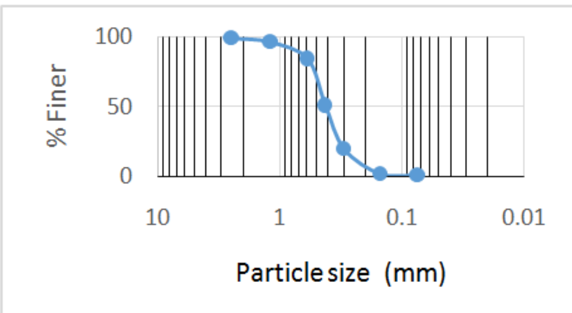

Fig. 1. Grain Size distribution of Sand.

B. Bamboo baskets

Bamboo baskets used in this study were made by local bamboo workers. Weaving of basket is done manually by bamboo workers. Bamboo is divided into strips of different sizes those vary in width, this process done using a sharp knife. The strips are made thinner by peeling top layer and the bamboos are split into flat thin strips. Bamboo artisans arranges these strips in circular manner to make the base of the basket. Strips of bamboo are weaved alternatively and run through the arranged strips. Once the base is completed, the strips are bent slightly to weave the side walls.

Bamboo strips are continuously added and weaved until the required size of bamboo is acquired. These baskets are mainly used for storing grains and supplements and carrying purposes in the fields.

The tensile strength of the strips was determined according to ASTM D 4595-17 [27]. Physical and mechanical properties of the strips are presented in Table 2. The cellular structure is made by connecting these baskets with the help of threads. The basket cell network is shown in Fig. 2. The tensile strength strain curve of the bamboo strip is shown in Fig. 3.

Table 1: Properties of Bamboo Strips.

S. No.	Property	Value
1.	Mass of the Basket (gm/m^2)	850
2.	Ultimate Load (kN/m)	28.54
3.	Failure Strain (%)	3.4
4.	Secant Modulus at 2% strain (kN/m)	769
6.	Thickness (mm)	1.5

Fig. 2. Bamboo Basket network used in the present study.

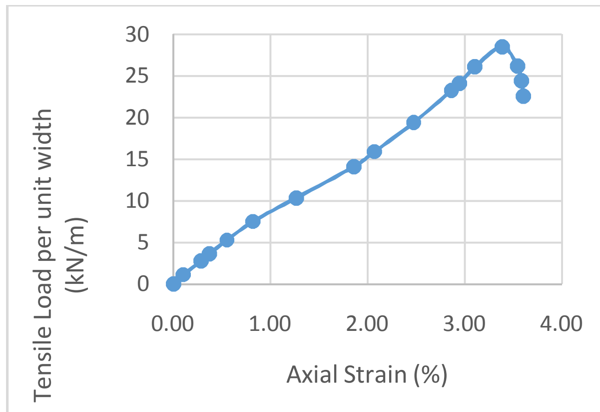

Fig. 3. Tensile strength strain behavior of Bamboo strip as per ASTM D 4595 – 17.

C. Experimental Test Setup

The tests setup consists of a steel tank of dimension 1000mm ×1000mm × 1000mm. A circular shaped steel plate of 20mm thickness and having sides of 200mm was used as the model footing. The dimension of the test tank is selected as five times the width of the test plate based on IS: 1888-1982 [28] to reduce the scaling effects. The footing is to be loaded by a hydraulic jack supported against the reaction frame. Settlement of model footing was measured with the help of three dial gauges of sensitivity 0.01mm placed diagonally the footing. A removable strainer made of perforated steel wires is used for sand raining which is removed after preparation of sand bed.

D. Bamboo Reinforcement layout

The layout of bamboo basket reinforcement is shown in Fig. 4. This study is carried out study the effect of diameter, height of bamboo baskets and width of network made from these baskets. Also effect of multilayers is studied. The nomenclature used in the study is given.

u = distance from the base of footing to the first layer of reinforcement
ur = distance between layers of bamboo basket network
d = diameter of bamboo baskets
h = height of geocell
b = width of Bamboo basket network
B = Width of the footing
All the parameters are standardized with foundation width as d/B, h/B, b/B. It is to be noted that for all tests under planar reinforcement ur/B was kept equal to u/B = 0.1 which is found to be optimum in case of geocell [5, 29].

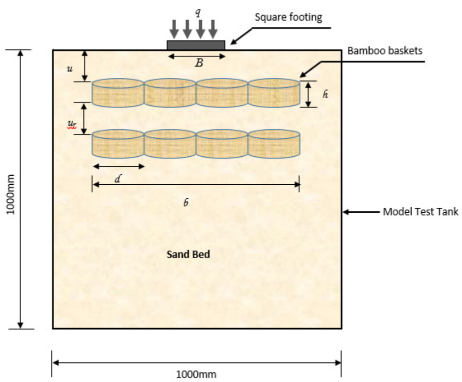

Fig. 4. Bamboo basket network layout.

E. Preparation of test bed

To achieve uniform density of soil in the foundation beds, a sand raining technique was used. Sand raining is done with the help of steel strainer. The height of fall of sand is determined by plotting a curve of density of sand at different height of fall. The sand is filled in tank a total of 10 layers of 10 cm each. Each layers is levelled after it reaches a mark of 10cm. The accuracy of sand placement and the consistency of the placement density were checked during raining by placing small aluminum cans with known volumes at different locations in the test tank. The difference in the densities measured at various locations in the test tank was found to be less than 1%. When the tank was filled up to desired depth, the raining of sand was stopped and the bamboo basket network was placed on the surface of the prepared sand bed. After this, the sand raining is continued to fill these baskets and it is continued till the tank is full. The surface of the soil is levelled and the plate is placed on top of soil surface at the center.

F. Testing Procedure

The footing is placed at the center of the tank after levelling the top of the soil surface. It is to be loaded by a hydraulic jack supported against the reaction frame. The load is to be applied incrementally. The magnitude of each load increment was 0.40 kN and it was equal to 20kPa in terms of footing pressure. Each load increment is maintained constant until the footing settlement stabilized and there is no significant change in settlement (i.e., <0.02mm/min). Settlement of model footing was measured with the help of three dial gauges of sensitivity 0.01mm placed diagonally the footing.

G. Testing Program

Five different series of tests were conducted and their respective summaries are listed in Table 3. Test series A was conducted on unreinforced sand to quantify the improvement with the provision of reinforcement. Test series B–E was done on Bamboo basket network reinforced sand to study the effect of diameter, height of bamboo baskets, the width of bamboo basket network and multilayer network of bamboo baskets. All tests were repeated twice to check the precision of test results. The variance in the results obtained was around 4% and can hence be ignored.

Table 2: Experimental Test Schedule.

Test series	Reinforcement	h/B	d/B	b/B	Objective of tests
A	Unreinforced Sand	—	—	—	To quantify the improvements due to reinforcements
B	Bamboo Baskets	0.5	0.5,0.6,0.75,1,1.25	5	To study the effect of bamboo basket diameter
C	Bamboo Baskets	0.25, 0.5, 0.75, 1	0.5	5	To study the effect of bamboo basket height
D	Bamboo Baskets	0.5	0.5	1,2,3,4,5	To study the effect of bamboo basket network width
E	Bamboo Baskets	0.25 (2 layers and 3 layers) 0.5 (2 layers and 3 layers)	0.5	5	To study the effect of bamboo basket network layers

III. RESULTS AND DISCUSSION

To evaluate the performance of bamboo basket reinforced foundation bed a non-dimensional quantity, the Improvement Factor (IF) is introduced. It is defined as the ratio of bearing capacity of geocell reinforced sand at a given footing settlement to the bearing capacity of unreinforced sand for the same settlement.

IF= qr / qo.

where,
qr = bearing pressure of the reinforced soil at the given settlement;
q0 = bearing pressure of unreinforced soil at the same settlement.
In the present study the settlement(s) of footing is normalized with respect to the width of the footing (B) and all the graphs is plotted with respect to this settlement ratio (s/B).

The improvement factor for various cases are reported at s/B ratio of 2.5%, 5%, 10%, 15% and 20%.

A. Effect of bamboo basket diameter

Test series A was conducted to study the load settlement behavior of unreinforced bed and Test series B was conducted to study the effect of bamboo basket diameter on the performance of reinforced sand. For this study bamboo baskets of five different diameters (i.e. 10, 12, 15, 20 and 25cm) were used. The diameter of baskets is normalized with respect to footing width for plotting load settlement behavior. Also the settlement is normalized with respect to footing width (i.e. s/B ratio). The height of these basket is kept constant at 10cm. It is observed that inclusion of bamboo basket network increased the load carrying capacity of sand bed in general.

Fig. 5 shows the pressure settlement behavior of footings on unreinforced sand bed and sand bed reinforced with bamboo basket of different diameter. The maximum increase in bearing capacity is observed for smaller diameter baskets. Fig. 6 shows the variation of improvement factor for different diameter baskets at different settlement levels.

The maximum improvement factor obtained is 3.8 when 10cm diameter baskets were used at a settlement ratio of 20%. For same settlement ratio the improvement factor observed in case of 25cm diameter basket is 2.5. Also for a settlement ratio of 10% the percentage increase in bearing capacity is 196% for a pocket diameter of 10cm where as it is only 81% for a pocket diameter of 25cm. It is found that the smaller the pocket-size, the higher is the load-bearing capacity of geocell-reinforcement. Similar findings were observed [2, 30-32].

Smaller geocell-pockets provide higher confinement to in-filled soil and increases shear and bending rigidity through more number of joints per unit area. Moreover, the smaller the pockets are, the higher is the effective surface area for geocell-soil interfacial resistances. This can derive very high anchorage/frictional resistances through geocell-walls against possible incoming loads. Combining the above, the geocell-soil-composite mattress behaves as a semi-rigid slab which redistribute the load to underlying subgrade more efficiently with lesser intensity to enhance overall performance.

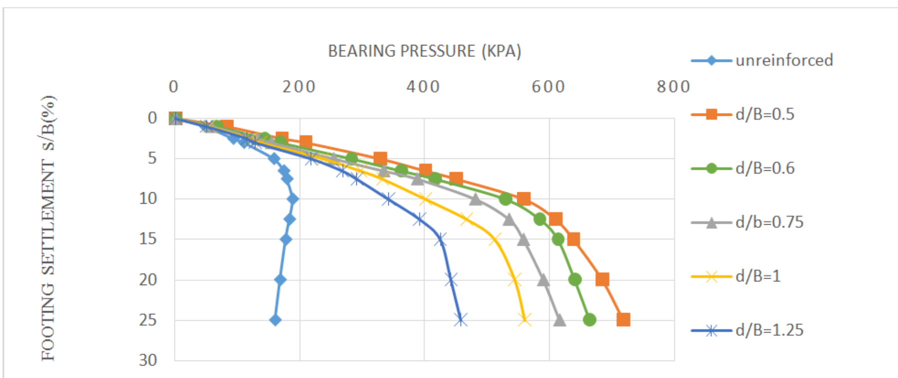

Fig. 5. Variation of bearing pressure with footing settlement for different pocket diameter of bamboo baskets.

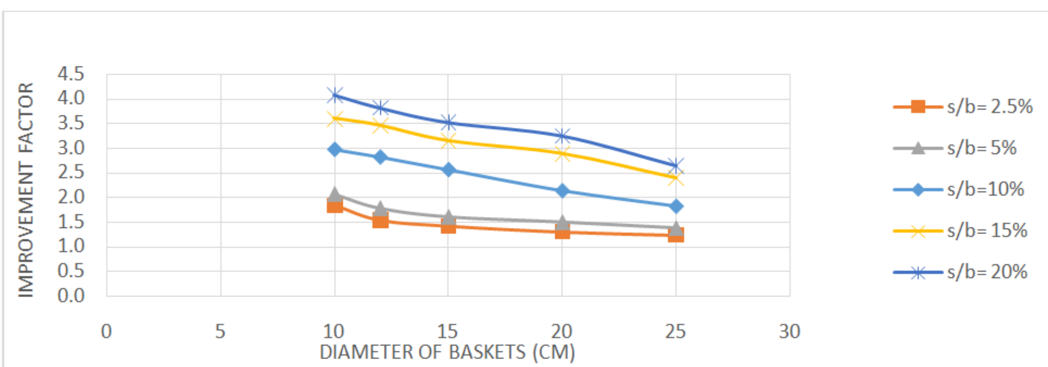

Fig. 6. Variation of improvement factor with diameter of baskets at different settlement levels.

B. Effect of height

Test series C was conducted to study the effect of bamboo basket height in improving the bearing capacity of the reinforced sand bed. For this bamboo baskets of four different heights (i.e. 5cm, 10cm, 15cm, 20cm) were used. The diameter of the baskets used in this series is kept constant as 10cm.

Fig. 7 shows the variation of bearing pressure with footing settlement for different height of bamboo baskets. It is clearly observed from pressure settlement curve that bearing capacity is increasing when the height of basket is increased. The maximum increase in bearing capacity is observed for bamboo baskets of 20cm height. For a settlement ratio of 10 % the percentage increase in bearing capacity is 224% when 20cm basket were used where as it is 124% when 5cm baskets were used. Fig. 8 shows the variation of improvement factor with height of baskets at different settlement. It is observed that an improvement factor of 4.9 is observed for 20cm diameter high basket at 20% settlement level. It is also observed that at smaller settlement level the variation in improvement factor is less compared to large settlement levels. This may be due to catenary shape deformation occurring at higher settlement level which initiates the membrane effect to develop a tensile force in the reinforcement. The vertical component of this force resists the downward movement of the footing and increases the bearing pressure.

By increasing the height of the geocell mattress, the overall frictional resistance on the geocell walls increases because of the increase in the surface area which resists the downward movement of the soil. As a result, the entire geocell mattress behaves as a composite body, thereby giving rise to a better performance improvement. Besides, with increase in the height of the geocell layer, the moment of inertia and the bending rigidity of the geocell mattress increase, which redistributes the footing pressure over a wider area, and therefore increases the performance of the footing. Similar findings were observed [33, 34].

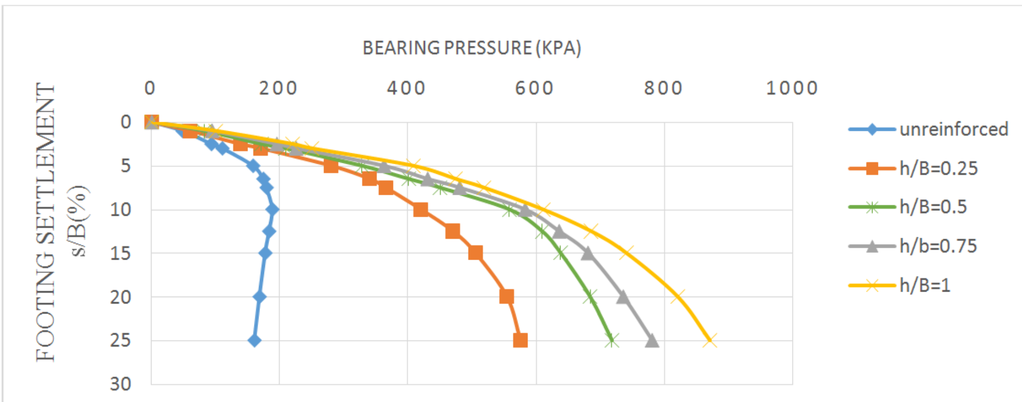

Fig. 7. Variation of bearing pressure with footing settlement for different height of bamboo baskets.

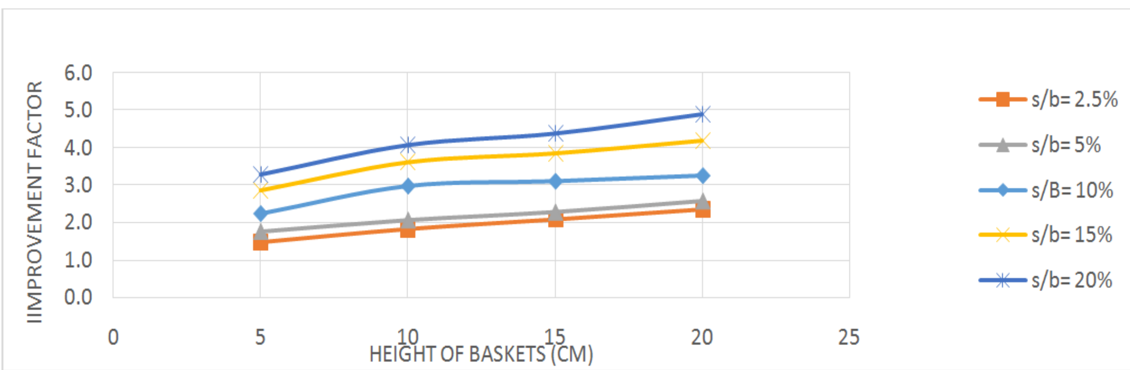

Fig. 8. Variation of improvement factor with height of baskets at different settlement levels for bamboo basket reinforcement.

C. Effect of width

Tests series D are conducted to investigate the influence of width of bamboo basket network on the bearing capacity of reinforced sand beds. To study the effect of the width of bamboo network diameter and height of bamboo basket both were chosen as 10cm, so a total of four baskets were used to create a network of 1B width, similarly 16,36,64 and 100 baskets were used to create a network of 2B, 3B, 4B and 5B respectively.

Fig. 9 shows the variation of bearing pressure with footing settlement for varying width of bamboo basket network. It is observed that bearing capacity increases with increase in the width of bamboo basket network. For a network width of 1B at a settlement ratio of 10% the percentage increase in bearing capacity is only 40%, which increases to 86% for a bamboo width of 2B and goes up to 196% for a network width of 5B covering the whole tank area.

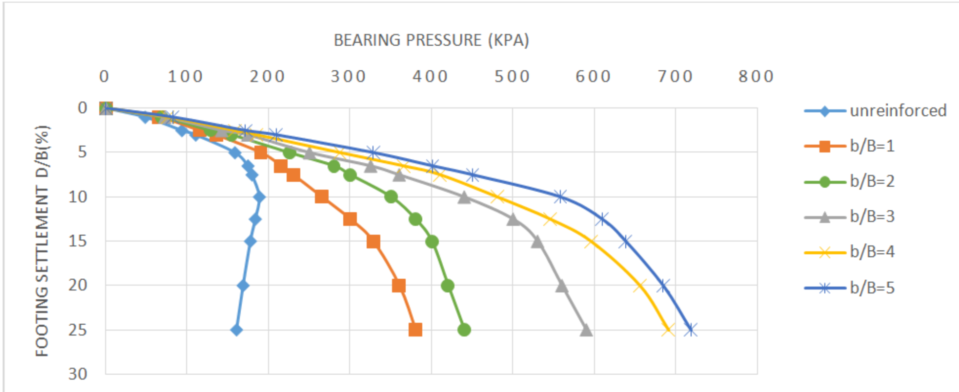

Fig. 9. Variation of bearing pressure with footing settlement for varying width of bamboo basket network.

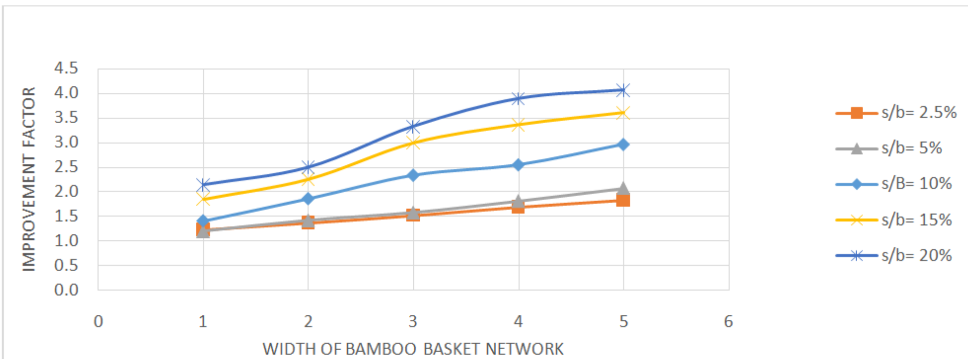

Fig. 10. Variation of improvement factor with width of bamboo basket network at different settlement levels for geocell reinforcement.

Fig. 10 shows the variation of improvement factor with width of bamboo basket network at different settlement levels. The improvement factor for is very low less than 2 at settlement ratio of 10% for network of width 1B and 2B as compared to higher width of reinforcing network. As the width of bamboo basket network increases, the load distribution becomes more uniform and the transfers of the incoming load with much lesser intensity to underground soil. Proper load distribution is highly imperative to sustain large pressure. Also a larger network of reinforcement produces significant interfacial resistance through surrounding soil and derives high membrane resistance. Similar findings were observed, [31, 33, 35].

D. Effect of number of layers

Test series E was carried out to study the effect of using multilayers of these bamboo baskets network. To study the effect of layers' bamboo baskets of two heights 5cm and 10cm were taken. The diameter of these baskets is kept constant as 10cm. Two layers and three layers of both the 5cm and 10cm basket network were studied. The spacing between the layers is kept as 2cm.

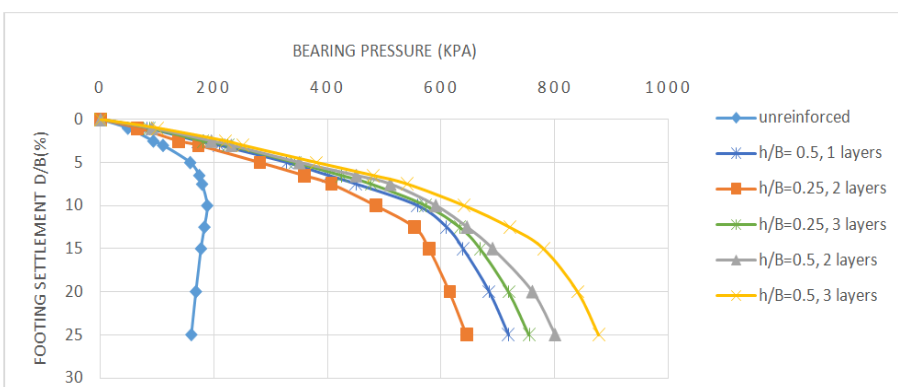

Fig. 11. Variation of bearing pressure with footing settlement for different no. of layers of bamboo baskets network.

Fig. 11 the variation of bearing pressure with footing settlement for different no. of layers of bamboo baskets network. It is observed that the bearing capacity for a single geocell layer of 10cm height is more than a two layered system of 5cm high baskets. This may be due to lesser rigidity offered by less heighted baskets. The percentage increase in bearing capacity for a three layered system of 10cm high baskets is 240% whereas it is 204% for a three layered system of 5cm high baskets. Overall it may be clearly observed that, as the number of geocell layers increased both stiffness and bearing pressure at a specified settlement increase substantially. Likewise, at a given bearing pressure, the value of the settlement decreased as the number of geocell layers increased. Similar findings were observed [36, 37].

IV. CONCLUSION

A detailed study of various geometrical parameters was carried out to compare the usefulness of different size bamboo baskets in reinforcing sand beds under square footing. A dimensionless improvement factor was introduced to quantify the improvement in bearing capacity characteristics. The results obtained clearly establishes the fact that bamboo basket network is very effective in reinforcing sand beds. The optimum diameter of basket was found to be 10cm and bearing capacity improvement is lesser for large diameter baskets. The optimum height of the bamboo basket was 20cm. When a basket of 10cm diameter and 20 cm height was used to make bamboo network, the percentage improvement in bearing capacity was around 224% which is very encouraging. The bearing capacity of sand was also seen to be increasing with increasing width and no layers of bamboo basket network. Overall the study presents a novel technique of using bamboo baskets and may be of great use in reinforcing shallow foundations.

V. FUTURE SCOPE

To develop the better understanding regarding bamboo cells and their applications in field, various durability studies and load tests on large scale with varying soil type must be carried out. Design codes for application of bamboo cells can be developed only after extensive research in this area.

Conflict of Interest. No conflict of interest.

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