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Experimental Investigation on Bamboo-made Cellular Mattress Reinforced Fly Ash Beds Overlying Soft Clay

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Abstract. The present study encompassed laboratory model tests on cellular mattress reinforced fly ash beds overlying soft clay. A series of model tests were performed to analyze the influence of mattress width on overall performance of the system in terms of footing pressure applied over the centre of the beds by means of a square rigid steel plate, footing settlement and the adjacent surface deformation (heave/settlement). The study was subjected to the limitation of scale and boundary effects. Laboratory test results indicated around two folds increment in footing capacity for a jute geotextile separator underneath the unreinforced fly ash bed, while around five fold increment in capacity was achieved for the cellular mattress reinforced fly ash bed along with the separator. The surrounding surface deformation of the loaded area over reinforced fly ash bed got diminished with increase in the width of the cellular mattress, while the footing capacity kept on improving. The cellular mattress along with jute separator with basal bamboo grid produced optimum performance. Despite scale and boundary effects, the qualitative results from the present study encourage the use of bamboo-made cellular mattress for soft ground improvement, while it contributes to the solution for disposal of fly ash. Again, bamboo is very fast growing tree and abundantly available in India and other Asian countries. The present study advocates a sustainable, cost-effective, harmless to environment and energy efficient approach for infrastructure development.

Keywords: Cellular Mattress, Fly Ash, Soft Clay, Jute Geotextile.

1 Introduction

Planar 2D reinforcements like geotextiles, geogrids can only provide tensile membrane support. Three-dimensional cellular reinforcement also called as geocell mattress, basically made of interconnected multiple cells, can provide the anchorage support to the loaded area through tensile membrane effect as well as provides the lateral confinement and interface wall shear resistance to the infill material, delivering improved results as compared to the planar form of reinforcements. The footing load applied over geocell mattress reinforced composite bed gets distributed over a wider area, while resulted in reduced settlement as compare to other planar and randomly distributed mesh elements (de Garidel and Morel 1986). Different Geocell systems were successfully used in roads, railways and embankments [Bush et al. 1990; Li 2000; Xie et al. 2004; Dong 2007]. Laboratory model studies were performed by several researchers to optimize the performance of cellular mattress by varying different influencing parameters, like shape and size of cells, tensile strength of cell material, height and width of geocell mattress and infill material (Mhaiskar and Mandal 1996; Sitharam et al. 2007; Moghaddas Tafreshi and Dawson 2012; Dutta and Mandal 2015, 2017; Ravindran et al. 2019).

2 Materials

The model study involves five different materials, bamboo geogrid, bamboo made cellular mattress, jute geotextile, fly ash and marine clay. The bamboo geogrids, used as a basal reinforcement underneath the geocell mattress, were prepared in laboratory. Width of the fabricated well finished individual bamboo stick was 10 mm with thickness of 0.9 mm. The sticks were interwoven orthogonally by maintaining 10 mm x 10 mm square openings to form the geogrids. Mass per unit area of the geogrid evaluated as per ASTM D5261-2010 was 0.5 kg/m^2. Peak tensile strength of the bamboo geogrid determined as per ASTM D4595-2011 was 110 kN/m with tensile stiffness as 2444 kN/m at 4.5% tensile strain. The tensile strength-strain curve for bamboo geogrid is shown in Fig. 1. Cylindrical perforated bamboo cells of 100 mm internal diameter, 150 mm height maintaining average 10 mm square openings were prepared by using the same bamboo sticks. Square cellular mattresses of varying widths were obtained by combining required number of individual cells with the aid of tie wires.

A woven jute geotextile was used as separator between the clay bed and fly ash bed. Thickness of the jute geotextile under 2 kPa normal pressure (ASTM D5199-2012) was 1.3 mm having mass per unit area of 0.7 kg/m^2 (ASTM D5261-2010). Apparent opening size of the geotextile was 135µ (micron) determined as per ASTM D4751-2012. The peak tensile strength of the jute geotextile was 10 kN/m with tensile stiffness as 139 kN/m at 7.2% tensile strain. The tensile strength-strain curve for jute geotextile is shown in Fig. 2.

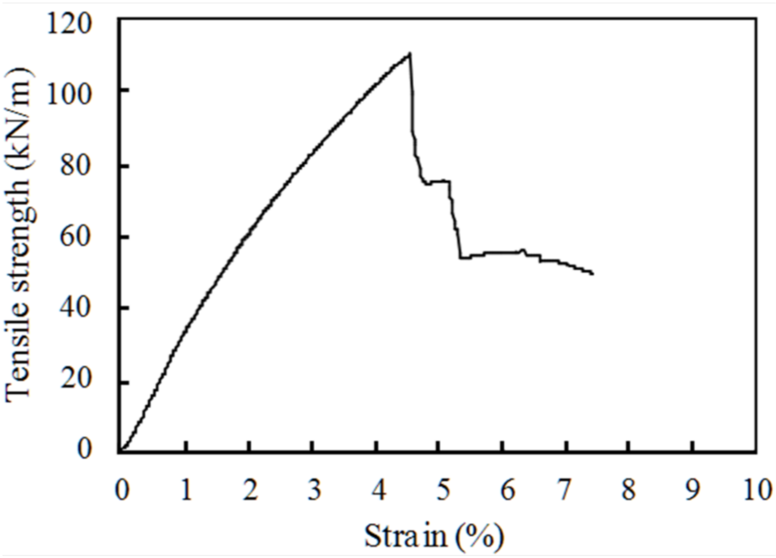

Fig.1. Tensile strength-strain response of bamboo geogrid.

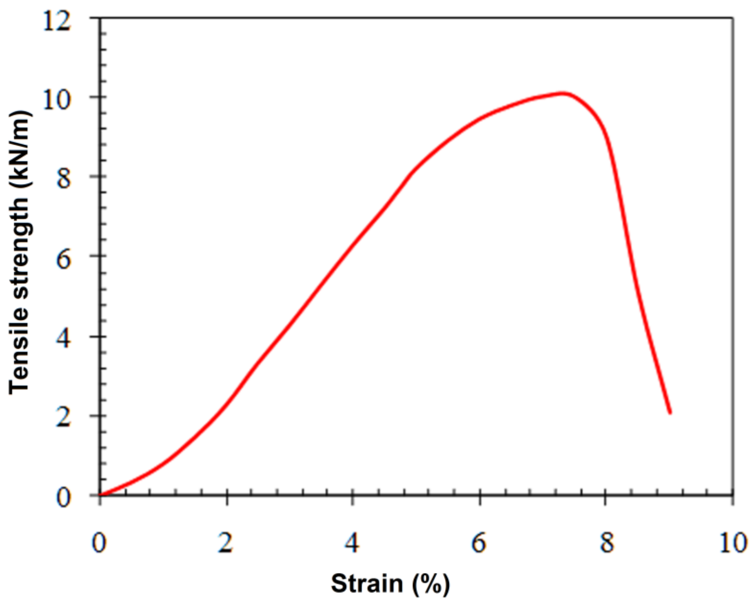

Fig.2. Tensile strength-strain curve of jute geotextile.

Fly ash is a byproduct waste material produced in enormous quantity from coal based thermal power plants. Fly ash, having lower dry unit weight as compared to soil, may produce similar strength and compressibility (Kim et al. 2005). X-Ray Florescence

(XRF) test was conducted on fly ash samples to identify its basic chemical composition. It mainly consists of Silicon dioxide (SiO_2) 63.52%, aluminum oxide (Al_2O_3) 26.89%, iron oxide (Fe_2O_3) 5% and calcium oxide (CaO) 1.23%. Sulfur trioxide (SO_3) is 0.072% and total loss on ignition is 1.49%. As per ASTM C618-12, it is Class F fly ash. The specific gravity of fly ash is 2.15. It contains silt sized particles (78%), sand sized particles (15%) and clay sized particles (7%). It is non-plastic with liquid limit 29.54%. The maximum dry unit weight and optimum moisture content (OMC) as obtained from standard Proctor tests according to ASTM D698-2012 are 12.1 kN/m^3 and 24% respectively. Although at dry state fly ash has no cohesion value, it develops apparent cohesion while compacted in presence of water. The cohesion and angle of internal friction of the fly ash at OMC are 26 kPa and 28° respectively as determined from consolidated drained (CD) triaxial tests as per ASTM D7181-2011. The deviator stress-axial strain curves at low confining pressures of 5, 10, 15 and 25 kPa are shown in Fig. 3. The confining pressures were kept low so as to simulate the laboratory test conditions.

Marine clay used in the present study was collected from Dronagiri area near Navi Mumbai, India. Specific gravity of the marine clay is 2.6. It contains clay particles 51%, silt particles 47.55% and sand particles 1.45%. Liquid limit, plastic limit and plasticity index are 82%, 35% and 47% respectively. As per ASTM D2487-11 (Unified Soil Classification System), the soil is classified as inorganic clay of high plasticity (CH). The maximum dry unit weight and optimum moisture content (OMC) obtained from standard Proctor test are 14.2 kN/m^3 and 28% respectively.

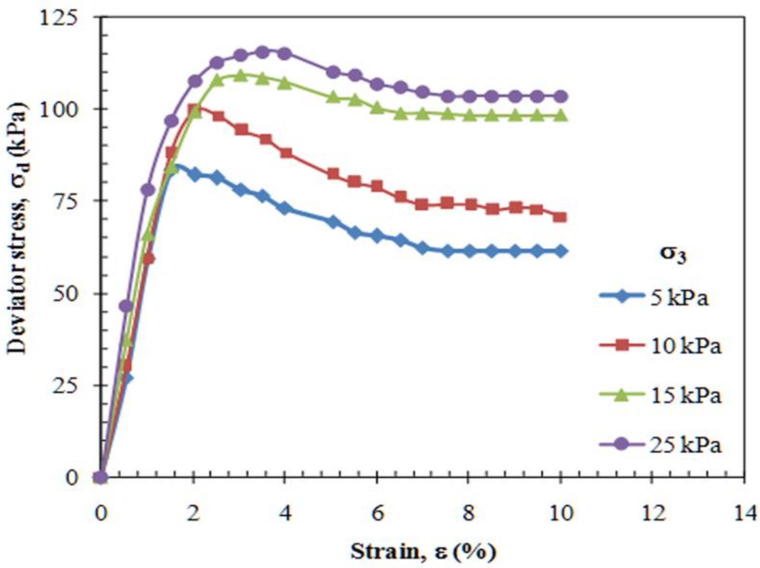

Fig.3. Deviator stress-axial strain curves of fly ash from consolidated drained (CD) triaxial tests.

3 Test Set Up and Procedure

The cellular mattresses with infill compacted fly ash along with a jute geotextile separator without and with a basal bamboo-grid were placed over a 400 mm thick soft clay bed, formed inside a rectangular steel tank of 850 mm x 750 mm x 620 mm inner dimension. Photograph and schematic of the test set up are shown in Figs. 4 and 5, respectively. The test set up Strain controlled loading at a constant rate of 2 mm/min was applied over the centre of prepared different test beds using a rigid steel plate of 10 mm thickness having contact area as 170 mm x 170 mm. A spherical recess was made on the loading plate at its centre to accommodate a steel ball bearing, over which the groove of a 50 kN load cell seated perfectly, while top of the load cell was attached to a strain controlled threaded jack supported against a 100 kN reaction frame. Linear Variable Differential Transformers (LVDTs) were used to measure the footing settlement as well as the surface deformation on the fly ash bed. Rear ends of all the LVDTs were fixed to a slotted angle as fixed rigid datum. Two LVDTs (front movable spindle) were placed at diagonally opposite side of the centerline of the loading plate to measure its vertical settlement during loading. Deformation (heave/ settlement) on the fly ash surface was measured on either side of the loading plate along the center line in the direction of tank length using two LVDTs, while the LVDT spindles were placed on 20 mm length × 20 mm width × 4 mm thick Perspex plates (almost weightless), placed over the fly ash bed at 1.5B distance from the centerline of the loading plate. A small recess was made at the center of the top surface of the Perspex plates so as to accommodate the LVDT spindle avoiding any slippage during model test. As the surface deforms, it will move the Perspex plates upward during heaving or downward during settlement and causes the consequent movement of the LVDT spindles creating data logged as the surface deformation. The loading was continued up to maximum 60 mm footing settlement considering the maximum capacity of the LVDTs. .

Fig. 4. Photograph of the test set up.

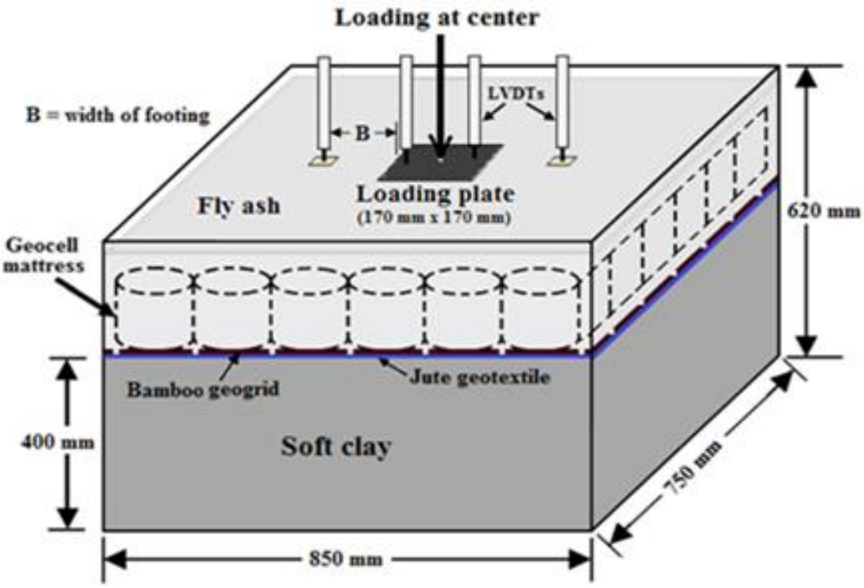

Fig. 5. Schematic of the test set up.

4 Preparation of Clay Bed and Fly Ash Bed

The same compaction procedure as reported by Dutta and Mandal (2015) was adopted to prepare a uniform clay bed inside the model tank. Moisture content of the soft clay beds was maintained around 70%, with undrained shear strength 8-10 kPa and bulk unit weight around 20 kN/m^3.

The unreinforced and bamboo cellular mattress reinforced fly ash beds were prepared by compaction following the same procedure as adopted by Dutta and Mandal (2015) to prepare unreinforced and geocell mattress reinforced fly ash beds. Unreinforced fly ash bed refers to the fly ash beds without geocell mattress, but it may have basal bamboo grid and jute geotextile separator. By compacting fly ash beds over soft clay bed, achieved dry unit weights for unreinforced and mattress reinforced beds were 87% and 84% of the maximum dry unit weight, respectively. Photograph of the preparation of bamboo cellular mattress reinforced fly ash bed is shown in Fig. 6.

A 15 mm fly ash head, almost equal to 10% of the width of loading plate, was always kept over the geocell mattress to avoid any uneven placement of the loading plate, which may occur if it was placed directly over the geocell mattress. Dash et al. (2001, 2003) as well as Moghaddas Tafreshi and Dawson (2010) recommended optimum geocell performance using a top fill cover as 10% of diameter or width of loading plate.

Fig. 6. Photograph of the preparation of bamboo cellular mattress reinforced fly ash bed.

5 Test Series

Test results reported in this paper have been obtained from the test series reported in Table 1.

Table 1. Test series for the model study

Test series	Fly ash bed	Influencing parameters
A	Absent, i.e. test over clay bed	
B	Unreinforced (F): a) Fly ash bed directly over clay b) J + Fly ash bed	Constant height of fly ash bed: H = 150 mm
C	Reinforced with bamboo cellular mattress: (D = 100 mm; E = 2444 kN/m) J + M + infill fly ash J + BG + M + infill fly ash	Variation in mattress width: b/B = 1.24, 1.85, 2.47, 3.09, 3.71 Constant height: h = 150 mm

F = Unreinforced fly ash bed; J = Jute geotextile; BG = Bamboo geogrid; M = Bamboo geocell mattress; H = Height of unreinforced fly ash bed; h = Height of bamboo cellular mattress; b = Width of mattress; B = Width of footing; D = Diameter of mattress pockets; E = Tensile stiffness of bamboo cell corresponding to the peak tensile strength.

6 Results and Discussions

The pressure-settlement responses of the footing on different test beds are plotted, while the footing pressure (p) as abscissa and settlement (s) as ordinate are expressed in non-dimensional forms as $p/\gamma B$ and s/B(%), respectively. B is the footing width and γ is the bulk unit weight of clay. During settlement of the footing, surface deformation (settlement/heave) was recorded over footing adjacent area. The surface deformation (δ) is expressed in non-dimensional form as δ/B(%) and plotted against s/B(%).

6.1 Effect of Jute Geotextile

The variation of pressure-settlement responses of footing over only clay bed as well as over the unreinforced fly ash beds without and with jute geotextile separator are depicted in Fig. 7. It can be observed that punching failure occurred in the only clay bed. Placement of fly ash over the clay bed increased the footing capacity as fly ash has more modulus of elasticity as compared to clay. In presence of jute geotextile separator, the footing capacity further increased owing to the tensile membrane influence from the jut geotextile.

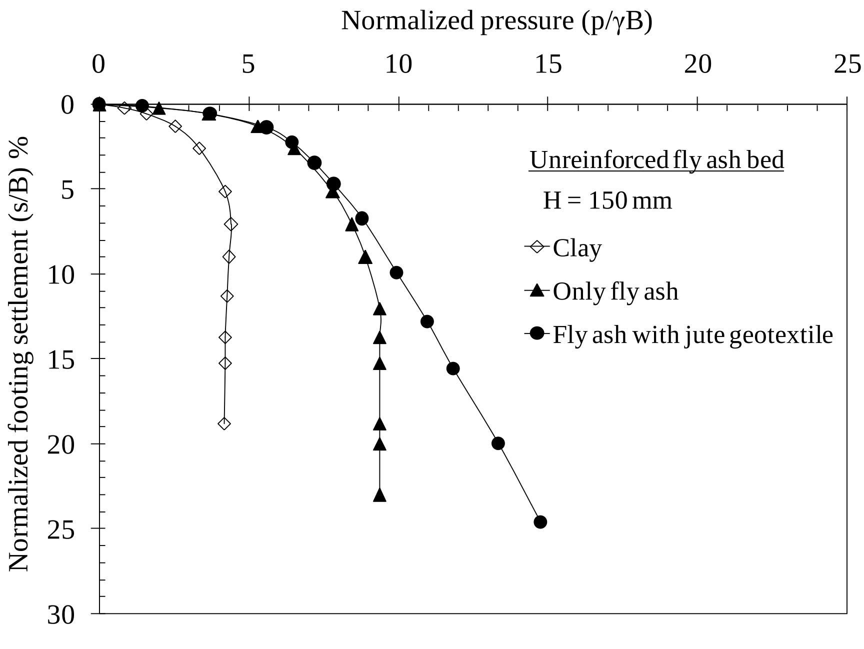

Fig. 7. Variation in footing pressure over only clay and unreinforced fly ash beds.

6.2 Effect of Basal Bamboo Grid

The influence of basal bamboo grid underneath the geocell mattress is illustrated in Fig. 8 for a cellular mattress of height 150 mm and width b/B = 3.09. Placement of a basal bamboo grid along with jute separator underneath the bamboo cellular mattress improved the footing capacity as compared to the footing capacity obtained from placing the mattress along with only jute separator. It may be attributed to the added tensile resistance from the bamboo grid.

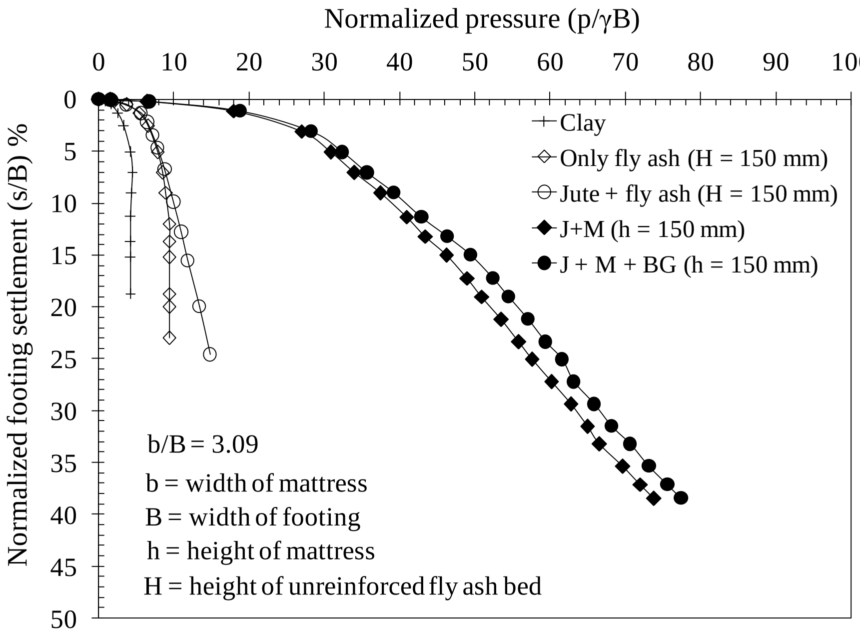

Fig. 8. Variation in footing pressure over geocell mattress without and with basal bamboo grid

6.3 Effect of Width of Cellular Mattress

With increase in the width of cellular mattress, the footing pressure increased as can be observed from Fig. 9 that represents the variation of footing pressure with settlement for different mattress widths (h = 150 mm) along with basal bamboo grid. Geocell mattress supported the footing pressure through mobilization of shear resistance with fly ash at its outer periphery throughout the height of the geocell wall. The mattress with higher plan area intercepted the rupture plane more as well as produced increased anchorage support to the footing settlement and consequently, redistributed the footing pressure over a wider area. These may be the reasons for the improved footing performance with increase in the width of mattress. At b/B = 3.09, the footing capacity improved around 5.5 times as compared to only fly ash bed of same height over the clay bed. The footing adjacent surface heaving decreased with increase in the width of mattress as can be observed from Fig. 10. As the width of mattress increases, resistance to the upward heaving of the footing adjacent cells increased from the cells attached to those adjacent cells.

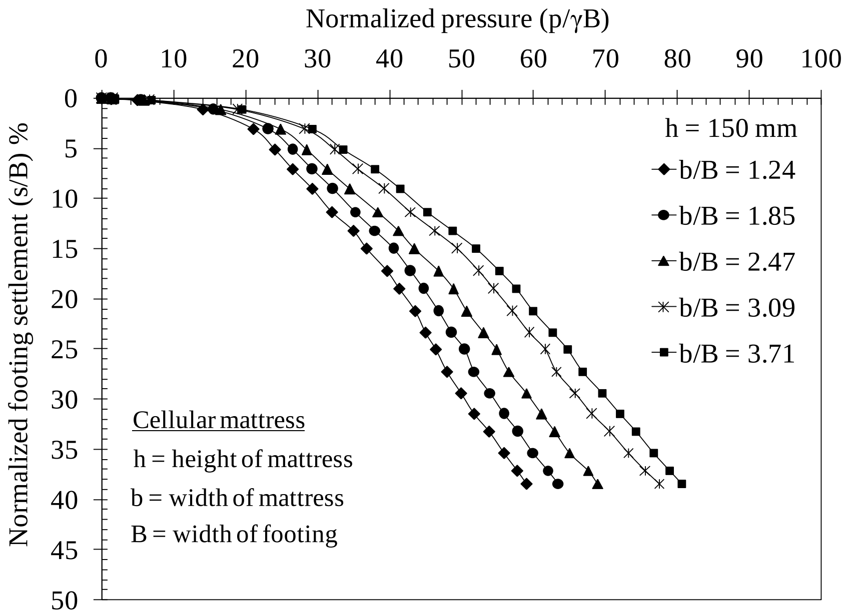

Fig. 9. Variation in footing pressure over geocell mattress of varying widths along with basal bamboo grid

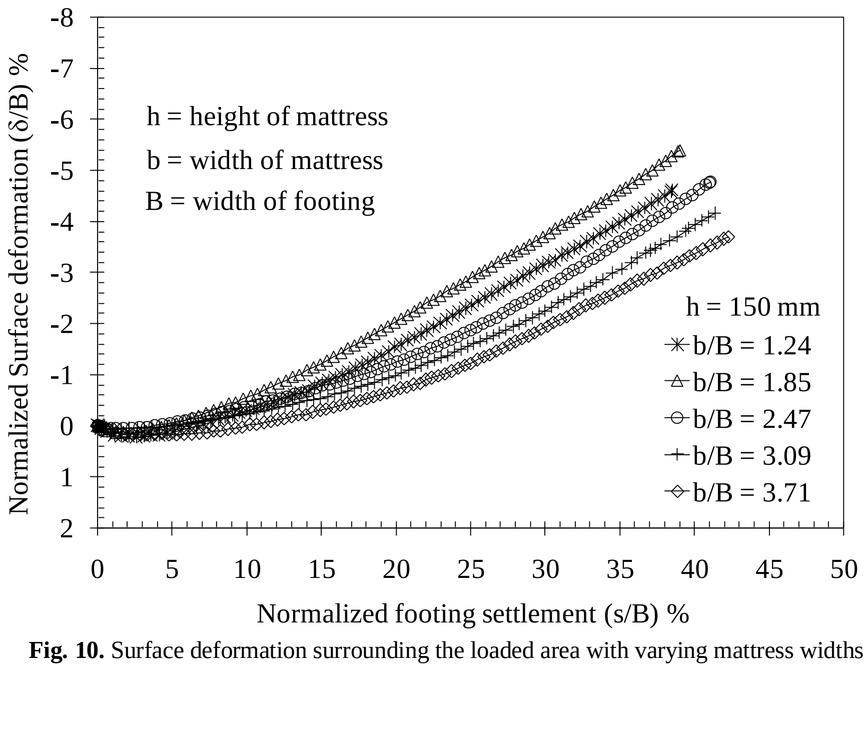

Fig. 10. Surface deformation surrounding the loaded area with varying mattress widths

7 Conclusion

Placement of fly ash bed over only clay increased the footing capacity, which further increased in presence of a jute geotextile separator. Optimum performance of the cellular mattress reinforced fly ash bed was obtained along with jute separator and basal bamboo grid, while the footing capacity improved around 5.5 times. Increase in the width of cellular mattress maintaining a particular cell height increased the footing capacity, while from the present study, the optimum width of cellular mattress was obtained as 3.09times the width of square loading plate.

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