A comparative study on the performance of geocells with synthetic and natural fibres

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ABSTRACT: Geocells are three-dimensional, expandable panels made from high-density polyethylene (HDPE), polyester or other polymer material. Cellular confinement systems improve the structural and functional behavior of soils and aggregate infill materials. Coir is abundantly available in Kerala. Coir has got an acceptance as a geotextile material in civil engineering even though it biodegrades. The performance evaluation of natural (coir) and synthetic geocell reinforcement placed over soft clay beds has been studied by small-scale model tests in the laboratory. The test beds were subjected to monotonic loading by a rigid square footing. The influence of natural and synthetic geocell mattress of different cell dimensions on the overall performance of the system has been systematically studied. The fill material used for all these tests are fine to medium sand. The results indicate that the performance improvement is better in synthetic geocell reinforced system compared to natural fibre geocell. The cell size and height of geocell have much influence in bearing pressure. Comparison of the performance of synthetic and coir geocell were made in terms of bearing capacity influence factor. For 10 cm high geocell, the average increas in bearing capacity of synthetic geocell is 1.73 times more than that of coir geocell of similar size and shape. In the case of 20 cm high geocell, the average increase in bearing capacity of synthetic geocell is 2.29 times that of coir. The provision geocell reduced the heaving of the clay layer or prevented the occurrence of heave.

Keywords: *Geocell, Geosynthetics, Coir, Natural geotextiles*

1 INTRODUCTION

Geocell reinforcement is a three dimensional, polymeric, honeycomb-like structure of cells interconnected at joints. The reinforcing mechanism in the geocells is by all-round confinement of soil within its pockets that completely arrests the lateral spreading of soil. Consequently, a better composite material is formed and the geocell layer behaves as a stiffer mattress that redistributes the footing load over a wider area. Typical configurations of geocell reinforcing elements can be divided into three cases; handmade geocells with perforations, perforated geocell and non-perforated flexible geocell. Handmade geocells prepared by cutting geogrids to the required length and height from full rolls and placing them in transverse and diagonal directions, on the bed, with bodkin joints inserted at the connections. The two different patterns used to form geocell mattress are diamond and chevron. Perforated elements prepared as a cellular honeycomb-like structure with an open top and bottom. Non-perforated geocells are made by thermo - welding or gluing of sheet elements into a framed structure.

Chang et al. 2007 reported that as the height of geocell increases, the performance was also increased. The results of laboratory model tests on geocell supported earth embankment constructed over a soft clay foundation were described by Krishnaswamy et al. 2000. The results showed that the provision of geocell layer at the base of embankment improved the load carrying capacity and deformation response of the embankment. Laboratory model tests on a strip footing supported by sand bed reinforced with geocell mattress was conducted by Dash et al. 2001. The parameters varied in the testing program included pattern of geocell formation, pocket size, height and width of geocell mattress, depth of placement of geocell mattress and the relative density of the sand. It is reported that with the provision of geocell reinforcement, failure was not observed even at a settlement equal to 50% of the footing width and a load as high as 8 times the ultimate bearing capacity of the unreinforced sand. The load carrying capacity of soft clay foundations can be improved by a factor of 4.8 times that of unreinforced soil by providing geocell reinforcement according to Sitharam et al. 2005. Madhavi Latha et al. 2006 studied the advantage of geocell reinforcement on the performance of earth embankments constructed over weak foundation soil through laboratory tests and proposed a simple method for the design of geocell supported embankments. Madhavi Latha and Amit Somwanshi 2009 investigated the effect of reinforcement form on the bearing capacity of square footings on sand. Both the experimental and numerical studies demonstrated that geocell is the most advantageous form of soil reinforcement technique of those investigated, provided there was no rupture of the material during loading.

Coir is abundantly available in Kerala, India. Coir has got acceptance as a geotextile material in civil engineering even though it biodegrades. The potential of coir as a geocell material, especially to improve the bearing capacity of soft subsoil is evaluated in this study by comparing the performance with existing synthetic geocells of various dimensions.

2 MATERIALS USED IN THE STUDY

Synthetics geocells (Strataweb) having different dimensions and designated as SW330, SW356 and SW445 with different cell heights of 10 cm and 20 cm, available in market, were used in this study. The numbers designate the weld spacing and thereby the cell dimensions are also increasing. Coir geocell of the same size and shape as that of synthetic geocell is made from woven coir geotextiles. Kaolinite clay is used as soft soil. Fine to medium sand is used as fill material above the soft soil. The properties of materials used for the study are presented in Tables 1 and 2 (Kaolinite clay, Sand and Geocell).

Table 1. Properties of materials used

Description	**Value**	**Description**	**Value**
Properties of kaolinite clay		**Properties of sand**	
Specific gravity	2.43	Specific gravity	2.61
Soil Classification	MH	Coeft. of uniformity (Cu)	1.80
Liquid limit (%)	54.5	Coeft. of curvature (Cc)	1.04
Plastic limit (%)	44	Effective particle size, D_{10} (mm)	0.28
Plasticity index (%)	10.5	**Properties of coir geotextiles**	
Percentage of clay	74.5	Thickness	7.77
Maximum dry density (g/cc)	1.302	Mass per unit area (gsm)	1267
Optimum moisture content (%)	34	Opening size (mm x mm)	5.38 x 2.8
Coeft. of Consolidation (cm2/sec)	$1.034\text{x}10^{-3}$	Tensile Strength (kN/m)	11.28
Compression index	0.23		

3 LABORATORY MODEL TEST

Model tests were conducted in a test bed-cum-loading frame assembly in the laboratory. The soil beds were prepared in a test tank with inside dimensions of 1000 mm x 1000 mm x 1000 mm. The model footing used was made of rigid square steel plate and measured 200 mm size (LxB) and 20 mm thickness. The footing was loaded with a hydraulic jack supported against the reaction frame. A schematic diagram of the test set up is shown in Figure 1. Coir geocell above the soft clay bed is presented in Figure 2.

Table 2. Cell/ Section properties of geocells

Synthetic/coir cell/Section Properties					
Property		Unit	SW330	SW356	SW445
Cells			3 x 3	3 x 3	2 x 2
Weld Spacing		mm	330	356	445
Cell Depth		mm	100 and 200		
Expanded Cell Dimensions	Width	mm	244	259	320
	Length	mm	210	224	287
Overall Dimension	Width	mm	732	777	640
	Length	mm	630	672	574

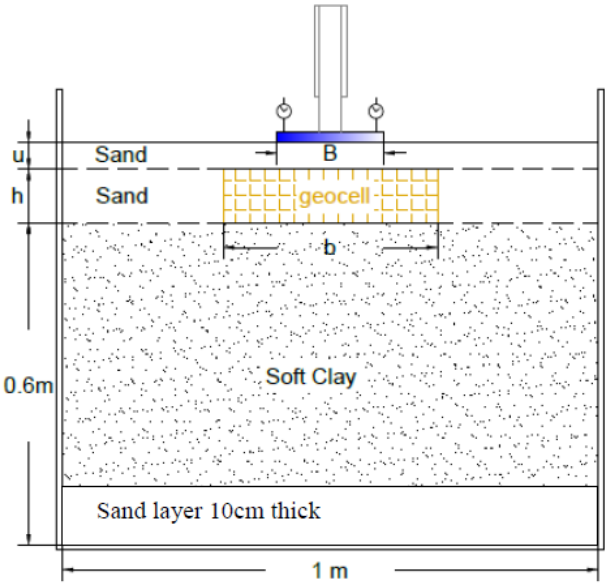


Figure 1. Schematic diagram of test set up

Figure 2. Coir geocell above soft clay bed

3.1 *Preparation of clay bed*

For the entire experiment programme the height of soft soil bed is kept constant at 60 cm. Sand layer of 10 cm thickness was formed at the bottom of the tank for allowing drainage from the clay bed above. Clayey soil was first pulverized and then mixed with water. The water content was kept near to the liquid limit so that the soil is used in soft condition. Soil mixed with water was placed in the tank in layers. For each layer, the required amount of soil to produce the calculated density was found out and compacted up to the required height. By carefully controlling the water content and compaction, a fairly uniform test condition was achieved throughout the test programme.

3.2 *Preparation of reinforced bed*

Geocell mattress was placed on top of the compacted clay bed. After placing the geocell mattress in the correct position, the geocells pockets were filled with fine to medium sand at 70% relative density and a unit weightof 15.6 kN/m^3 using sand raining technique. Above the geocell, fill material was provided for a height of 0.1% of the size of the footing (2 cm).

3.3 *Test procedure*

Surface of the fill was leveled and the footing plate was placed at the center of the tank. Loads were applied through a hydraulic jack and the load transferred to the footing was measured using a pre-calibrated proving ring. Footing settlements were measured using two dial gauges placed on either side of the center line of the footing. Three different series of tests were carried out. The details of laboratory model tests are given in Table 3.

Table 3. Details of laboratory model tests

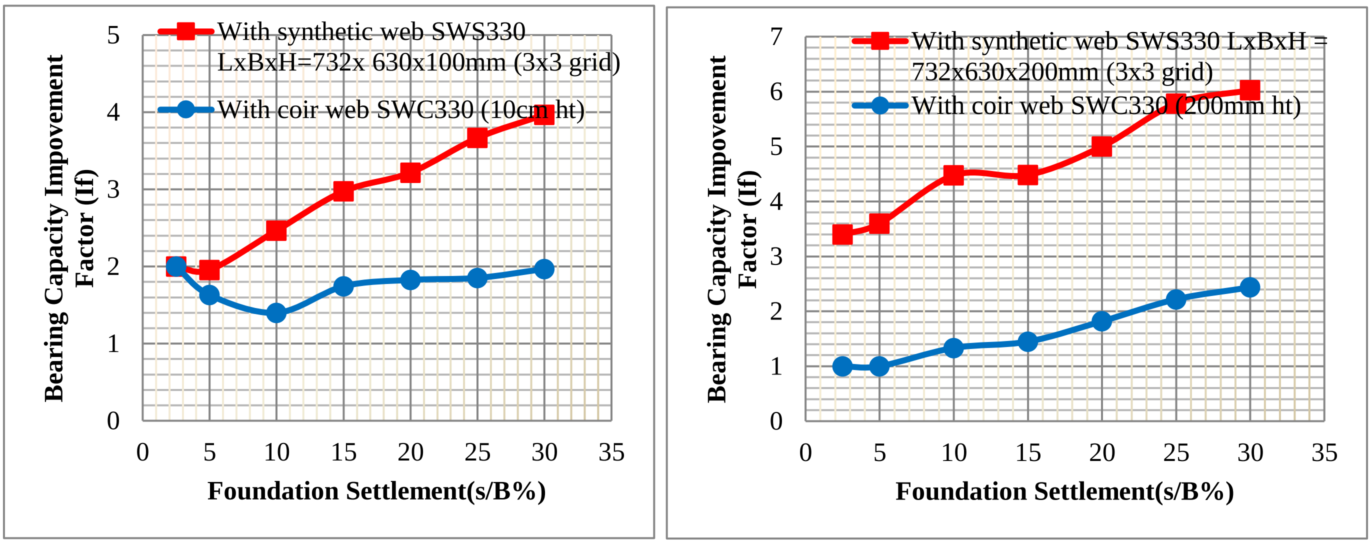
Test Series	Type of reinforcement	Details of test parameters	Remarks
A	Unreinforced	h+u =22cm and h+u=12cm,	Fill material fine to medium sand
B	SW330, SW356 and SW445 of synthetic geocell and with coir geocell of similar dimensions	h+u=12cm (height of geocell h=10cm)	Fill material fine to medium sand
C	SW330, SW356 and SW445 of synthetic geocell and with coir geocell of similar dimensions	h+u=22cm (height of geocell h=20cm)	Fill material fine to medium sand

4 RESULTS AND DISCUSSION

The performance improvement and comparison due to the provision of synthetic and natural fibre geocells are made using a non-dimensional improvement factor (I_f) which is defined as the ratio of footing pressure (q_c) with fill material or geocell at a given settlement to the corresponding pressure on unreinforced soil (q_0) at the same settlement. If the footing on unreinforced soil has reached its ultimate capacity at a certain settlement, the bearing pressure (q_0) is taken as the ultimate value (q_{ult}) while calculating I_f at higher settlements. Since both coir and synthetic geocell are of same size, the side effects of the test tank during loading was neglected.

4.1 *Performance evaluation of SW330 geocells having 100 mm and 200 mm high*

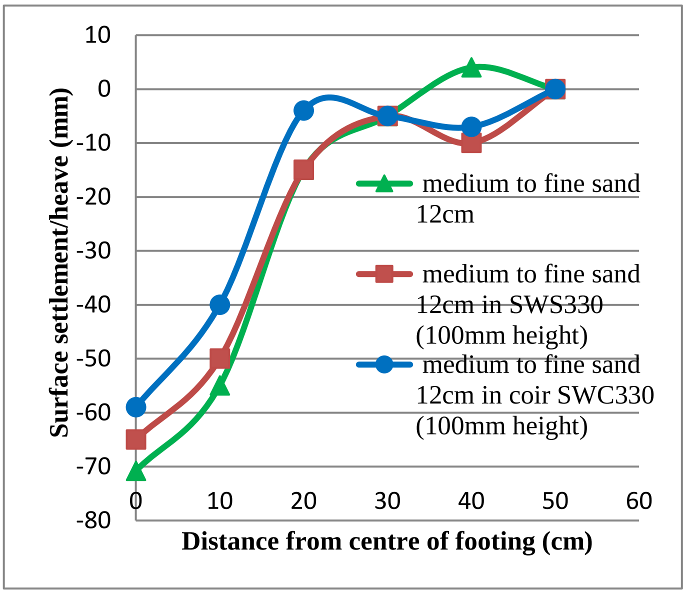
Geocell of SW330 has 3 x 3 cell and having an overall size of 732 mm (L) x 630 mm (B). Cell size was 244 mm x 210 mm. Height of the geocell was 100 mm and 200 mm. Bearing Capacity Improvement Factor (I_f) for fill material reinforced with geocell SW330 with respect to fill material is shown in Figures 3 (a) and 3 (b). Settlement and heave at the surface of the clay layer after the test is presented in Figures 4 (a) and 4 (b)



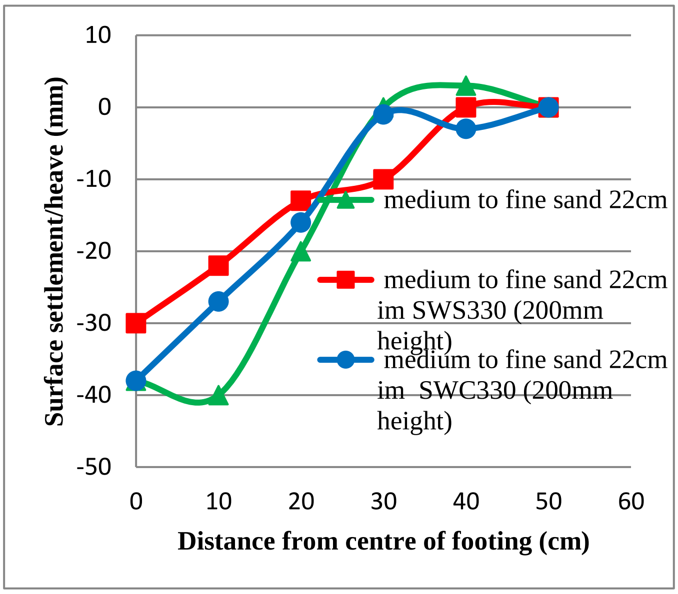
(a) (b)

Figure 3. BCIF Vs Foundation settlement for web SW330 (a) for 100 mm height and (b) for 200 mm height

From Figure 3, it can be seen that synthetic geocell has a higher bearing capacity factor with respect to coir geocell. The bearing capacity improvement factor was found to be 2 and 4 for coir and synthetic geocells respectively for 100 mm height, whereas it was 2.44 and 6 times that of unreinforced fill material for coir and synthetic geocell of 200 mm height. Geocell with synthetic will carry 2 and 2.46 timess load than that with coir for a height of cell 100 mm and 200 mm respectively. The effect of increasing the height of geocell on bearing capacity is marginal in the case of coir geocell compared to synthetic geocell.



(a)



(b)

Figure 4. Settlement or heave from the centre of footing for SW330 (a) for 100 mm and (b) for 200 mm height

No heaving on the surface of clay bed is observed for both synthetic and coir geocells. Heaving was observed without geocell reinforcement in the fill material. Provision of geocell of both synthetic and coir reduces the settlement compared to that of fill material alone. Settlement was found to be higher in synthetic geocell when the height is 100 mm and it is vice versa in the case of 200 mm heigh geocells when compared with coir geocell. The rigidity of the geocell is getting reduced as height increases in the case of coir geocell. However, increasing the height of geocell by double, reduces the settlement by about 53.8 % and 35% in synthetic and coir geocells respectively.

4.2 *Performance evaluation of SW356 geocells having 100 mm and 200 mm high*

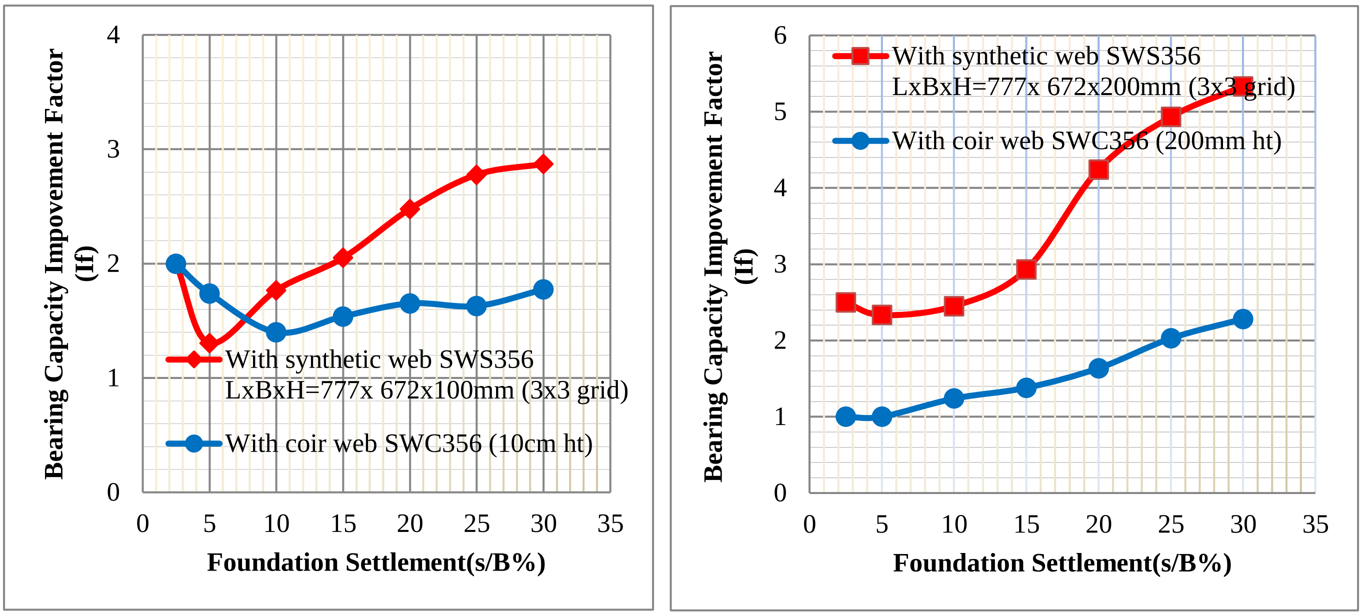
Geocell of SW356 has 3 x 3 cell and having an overall size of 777 mm (L) x 672 mm (B). Overall size of the geocell was higher than SW330. Cell size of 259 mm x 224 mm. i.e., cell size is larger than SW330. Bearing Capacity Improvement Factor (If) against settlement and settlement or heave at the surface of the clay bed are shown in Figures 5 and 6.

As the cell size increases; the bearing capacity improvement factor reduces for both synthetic and coir geocells as established by earlier studies. Upto 15% of footing settlement in coir geocell, bearing capacity improvement factor varies and thereafter it is almost linear increase. For synthetic geocell a steady increase in bearing capacity factor is visible as the settlement increases. Bearing capacity improvement factor is 1.80 and 2.85, i.e., a reduction of 10% and 29% in the improvement factor respectively for coir and synthetic geocells, when the cell size is increased by 6% than that of SW330 for a height of 100 mm. When the height was increased to 200 mm, it was reduced by 6.5% and 11% respectively for coir and synthetic geocells. Though the cell size is higher, increase in height will increase the bearing capacity factor. The increase in improvement factor is predominant in the case of synthetic geocells.

As the cell size increases, the bearing capacity improvement factor of synthetic geocell was found to be 1.58 and 2.33 times that of coir geocells having 100 mm and 200 mm height respectively. Settlement and heaving behavior was similar to SW330.

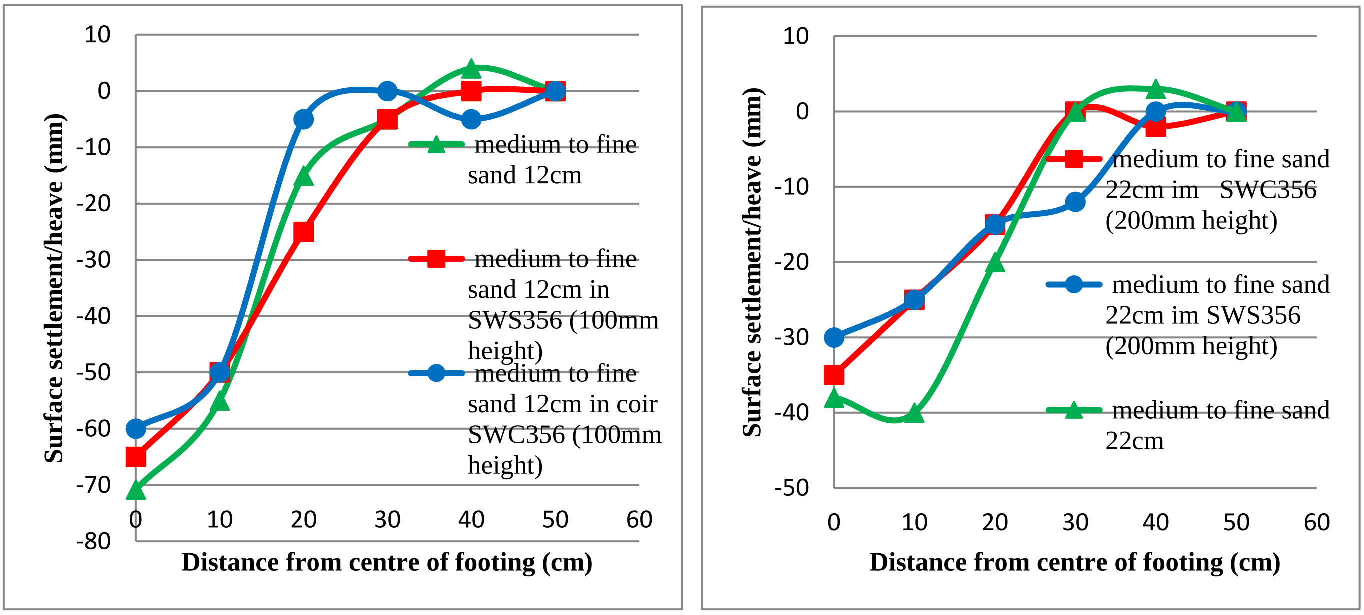
4.3 *Performance evaluation of SW445 geocells having 100 mm and 200 mm high*

Geocell of SW445 has 2 x 2 cell and having an overall size of 640 mm (L) x 574 mm (B). Overall size of the geocell was less than SW330 and SW356. Cell size of 320 mm x 287 mm. i.e., cell size is larger than SW330 and SW356 series. Cell size is about 33% higher than SW330 and 25% with that of SW356. Bearing Capacity Improvement Factor (If) against settlement, and settlement or heave at the surface of the clay bed, are shown in Figures 7 and 8 respectively.



(a) (b)

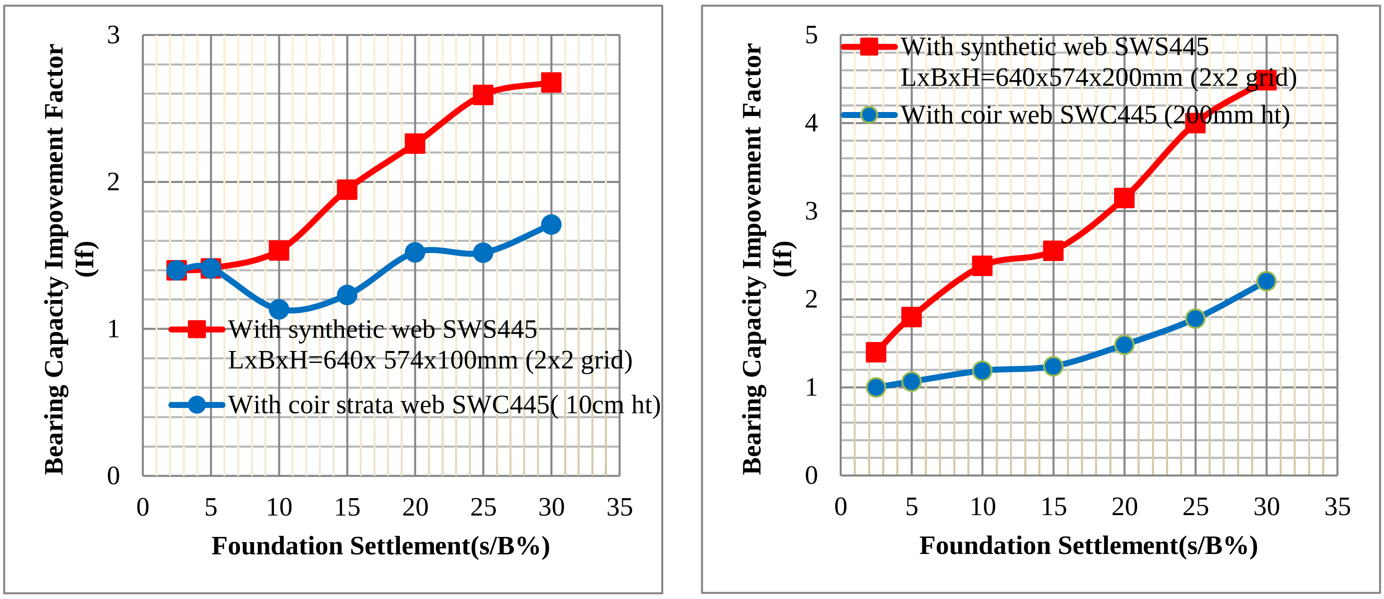
Figure 5. BCIF Vs Foundation settlement for web SW356 (a) for 100 mm height and (b) for 200 mm height



(a) (b)

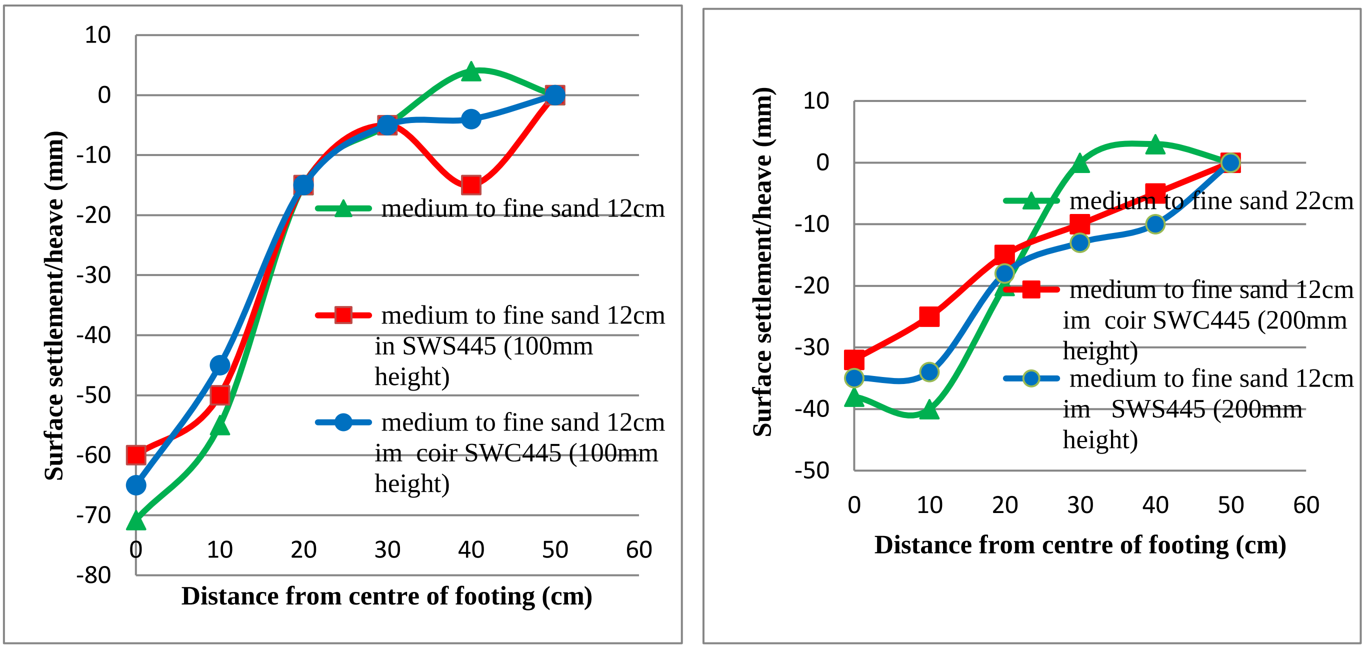
Figure 6. Settlement or heave from the centre of footing for SW356 (a) for 100 mm and (b) for 200 mm height

The behavior of both synthetic and coir geocell is same as in the previous cases, with higher bearing capacity improvement factor for synthetic geocell. However, the improvement factor for both the cases was less than that of SW330 and SW356. It was 2.68 and 1.71 for synthetic geocell and coir geocell respectively for a height of 100 mm. With respect to SW330, the decrease in improvement factor was about 33% for an increase in cell size of about 33%, whereas with SW356, it was about 6% for an increase in cell size of 25% for synthetic geocells. For coir geocells, the improvement factor was less by 14% and 5% compared to SW330 and SW356 respectively. Synthetic geocell carries a load of 1.56 and 2.05 times compared to that of coir having 100 mm and 200 mm respectively. Though a general conclusion can be made for the relation between bearing capacity improvement factor and cell size of geocell, a definite relationship could not be established. However, the reduction in bearing capacity improvement factor with increase in cell size, is more predominant in synthetic geocell than coir geocell. Settlement behavior was found to be same as in the previous cases and there was no heaving at the surface of the clay bed.



(a) (b)

Figure 7. BCIF Vs Foundation settlement for web SW445 (a) for 100 mm height and (b) for 200 mm height



(a) (b)

Figure 8. Settlement or heave from the centre of footing for SW445 (a) for 100 mm and (b) for 200 mm height

The bearing capacity improvement factor for SW445 when the height is doubled as in the previous cases. Bearing capacity improvement factor was found to be 4.50 and 2.20 for synthetic and coir geocells respectively when the height of cell is increased to double. The increase was about 68% for synthetic geocell and 27% for coir geocell. As the cell size is increased with 200 mm height, for synthetic geocell, the bearing capacity was reduced by 33 % and 18% with respect to SW330 and SW356 respectively. For coir geocell it was found to be less by 11% with SW330 and almost the same factor for SW356.

5 CONCLUSIONS

Comparative evaluation of the performance of geocells with synthetic and coir were made in model tests using fine to medium sand fill underlain by kaolinite clay. Synthetic geocells of Strata Web was compared with coir geocells having the same dimensions and were developed from woven coir geotextiles. From the model tests, the following conclusions were made;

a. Synthetic geocells improves the bearing capcity by double than that with coir geotextiless for all types of cell sizes and height.
b. As the height of geocell increases to double, coir geocells increases the bearing capacity by 20% for all cell sizes.
c. In synthetic geocells, the increase in height to double increases the bearing capacity by about 60% for all cell sizes.
d. Increase in cell size of the geocell will reduce the bearing capacity of the system as a whole
d. Settlement behaviour is almost same for both synthetic and coir geocells of same cell size and height.
e. No heaving occurs on the surface of clay layer for both synthetic and coir geocells.

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