Journal of Civil Engineering and Environmental Technology
Print ISSN: 2349-8404; Online ISSN: 2349-879X; Volume 2, Number 3; January-March, 2015 pp. 228-233

http://www.krishisanskriti.org/jceet.html

Influence of Geocell and Fibre Reinforcement on Strength Behaviour of a Sandy Soil

Shivanand Mali[1] and Baleshwar Singh[2]

[1]*Former Post-Graduate Student Department of Civil Engineering Indian Institute of Technology Guwahati, Guwahati-781039, India*
[2]*Professor, Department of Civil Engineering Indian Institute of Technology Guwahati, Guwahati-781039, India*
E-mail: [1]shivanandmali2007@gmail.com, [2]baleshwar@iitg.ernet.in

Abstract—*This paper describes the influence of geocell confinement and randomly distributed glass fibres on the stiffness and strength behaviour of a sandy soil. A series of triaxial compression tests were performed on the soil encased by four different types of geocells fabricated from woven geotextiles. In addition, tests were also conducted on geocell-fibre reinforced sand. In general, it is observed that the granular soil develops a large amount of apparent cohesive strength due to the confinement provided by the geocell. The magnitude of this cohesive strength is noted to vary with the type of geocell. The stiffness of the composite is also found to increase with the provision of geocell reinforcement. The combined effect of geocell-fibre remains the same in terms of stress-strain behaviour and stiffness of reinforced sand. However, the cohesion intercept is enhanced significantly by the combination of geocell-fibre.*

1. INTRODUCTION

The use of geosynthetics in various forms is gaining considerable popularity for mitigation various problems associated with soils encountered at construction sites. The term geocell refers to a cellular form of polymeric material. A network of interconnected geocells filled with soil can provide all-round confinement to the soil, can reduce lateral spreading and can cause the confined composite to behave as a more rigid mattress. They are usable for construction of embankments over soft soils [1], for the construction of flexible retaining wall [2], and for reinforcement of base courses over weak subgrades [3]. The higher stiffness of the geocell-soil system can reduce the stress applied to the supporting soil. As the geocell's cross-sectional shapes and mechanical characteristics can differ along with the type of the soil material, this interaction is expected to vary.

Randomly distributed fibres are also achieving importance in geotechnical applications due to its extensibility, maintenance of strength isotropy and absence of failure plane in the soil mass along the length of the fibres.

Several authors have reported results of laboratory triaxial tests on geocell-reinforced granular soils [4-6]. Many other investigators have conducted tests with the fibres oriented randomly in the soils [7-9]. Several field studies on test sections have been reported to validate the performance of fibre-reinforced soils. It was concluded that the technique showed great potential for military airfield and road applications and that a thick sand-fibre layer was sufficient to support substantial amounts of military truck traffic [10]. Full-scale field tests showed that fibre-stabilized sands were a viable alternative to traditional road construction materials for temporary or low-volume roads [11].

However, the number of reported laboratory studies investigating the interaction between the soil, geocell and fibres is rather limited. The main aim of this study is to determine the improvement in the stiffness and strength properties of a sandy soil reinforced with geocell and geocell-fibre combination through triaxial compression tests.

2. EXPERIMENTAL PROGRAM

2.1. Materials

The sand was collected from the nearby bank of Brahmaputra River. The physical properties of the sand are tabulated in Table 1. According to Indian Soil Classification System, the sand is classified as poorly graded sand (SP). Four different types of woven geosynthetics were used to fabricate geocells, namely GC1, GC2, GC3 and GC4 in increasing thickness and strength, and their properties are presented in Table 2. The geocells were fabricated by stitching the geosynthetics into cylindrical shapes of 38 mm external diameter and 76 mm height. The number of stitches and the thread used were the same throughout. The glass fibres used in this study are shown in Fig. 1. The designations used are: BS for sand, GC for geocell and F for fibre.

Table 1: Physical Properties of Sand

Property / Size range	Value
Specific gravity	2.67
Gravel size fraction (%)	0

Coarse sand size fraction (%)	1.2
Medium sand size fraction (%)	16.1
Fine sand size fraction (%)	81.2
Silt size fraction (%)	1.5
Uniformity coefficient, C_u	1.68
Coefficient of curvature, C_c	0.024
Soil classification	SP

Table 2: Properties of Geosynthetics

Type of Geosynthetics	GC1	GC2	GC3	GC4
Thickness (mm)	0.29	0.3	0.32	0.58
Mass per unit area (g/mm^2)	102	114	232	344
Tensile strength (kN/m)	2.5	2.9	11	12.9
Secant modulus at 5% strain (kN/m^2)	15.2	20.2	31	58

Fig. 1: Glass Fibres

2.2. Methods

For preparing geocell reinforced specimen, the geocell is initially kept inside a rubber membrane which is attached to the pedestal of triaxial cell, and is subsequently filled with the measured amount of sand based on the relative density along with 6% moisture content. The sand is filled in three layers and then compacted using a rod having circular disc at its bottom to achieve uniform compaction of the specimen. Specimens were prepared at soil relative densities of 50%, 65% and 82% corresponding to medium, dense and very dense states.

For preparing geocell-fibre specimen, the sand-fibre mix is prepared by adding 3% fibre content with 6% moisture content for uniform mixing of fibre. The prepared sand-fibre mix is filled into the geocell in three layers and compacted. The geocell with sand-fibre mix is encapsulated in a rubber membrane to avoid entry of water into the specimen.

Consolidated drained triaxial compression tests on the specimens were carried out in accordance with Indian standard procedure [12]. The tests were performed at confining stresses of 100, 200, 300 and 400kPa in order to completely define the shear strength parameters. The tests were continued up to 20% strain. Each test was repeated at least twice to ensure reproducibility.

3. RESULTS AND DISCUSSION

The analysis of the test results has been carried out to bring out the separate effects of geocell reinforcement and geocell-fibre reinforcement on the stress-strain behaviour and shear strength parameters of the sand.

3.1. Stress-Strain Behaviour of Geocell Reinforced Sand

The stress-strain response for the geocell reinforced sand specimens at 50% & 82% relative densities and confining pressures of 100 & 400 kPa is presented in Figs. 2 to 5. From Figs. 2 & 3, it is observed that with geocell reinforcement, stress-strain response of sandy soil has been modified. In the unreinforced case, the stress remains constant after reaching peak value while in the reinforced case, the stress is increasing gradually with increase in deformation with no post-peak strength loss.

This behaviour is due to the confinement provided by geocell encasement. Moreover, the increase in strength (maximum deviatoric stress) of reinforced sand is found to be double as that of unreinforced sand. For the same relative density, the strength of geocell reinforced specimen is varying with the type of geocell. The variation of deviatoric stress for different geocells is mainly due to the stiffness of geocell material. As the material is stiffer, more stress will be carried by the geocell-soil assembly. It is also observed that GC4-reinforced sand has showed more stiffness and strength than that of other geocell types. Hence, the strength and stiffness is dependent on the properties of the material used to make the geocell.

Also with increase in confinement pressure, the strength of geocell reinforced sand increases. The increase in confinement pressure brings the sand particles closer to each other and increases the lateral stability and density of the specimen, due to which at higher confining pressure more resistance will be offered by the specimens.

At low confining pressure of 100 kPa (Figs. 2 & 4), it can be seen that the stress-strain response of geocell reinforced sandy soil remains similar for both the relative densities (50% and 82%), with the strength values also being similar. However, at high confining pressure of 400 kPa (Figs. 3 & 5), it can be observed that the stiffness and strength of the geocell reinforced sand for the higher relative density (82%) is greater than that of the lower relative density (50%).

Fig. 6 shows a typical geocell reinforced sand specimen before and after testing. It can be observed that the specimen has failed by bursting of the geocell seam. Hence, seam strength is to be taken into consideration while designing the geocell. The observed failure pattern is found to be more or less similar in all geocell & geocell-fibre specimens tested in the present study.

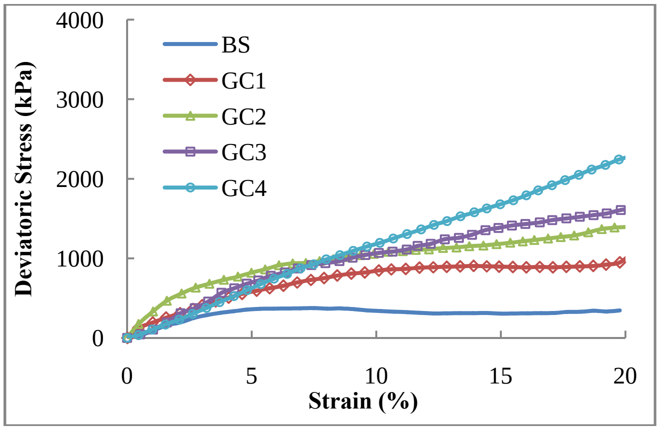

Fig. 2. Stress-strain response of geocell reinforced sand (50% relative density, 100 kPa confining pressure)

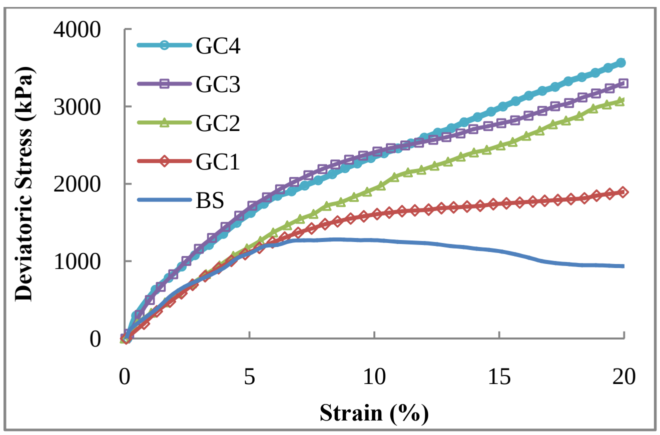

Fig. 3. Stress-strain response of geocell reinforced sand (50% relative density, 400 kPa confining pressure)

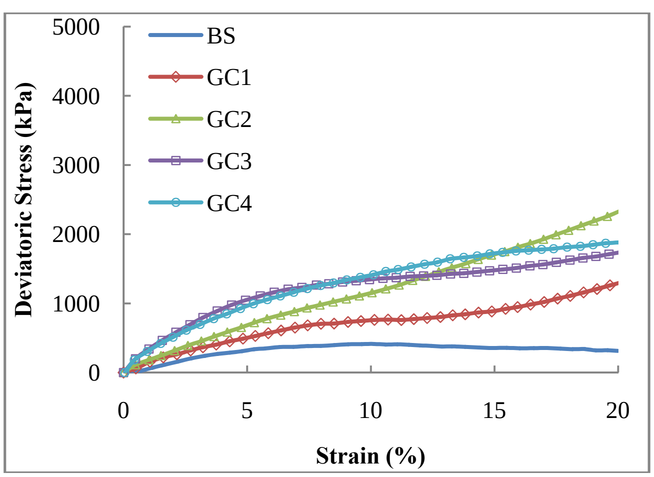

Fig. 4. Stress-strain response of geocell reinforced sand (82% relative density, 100 kPa confining pressure)

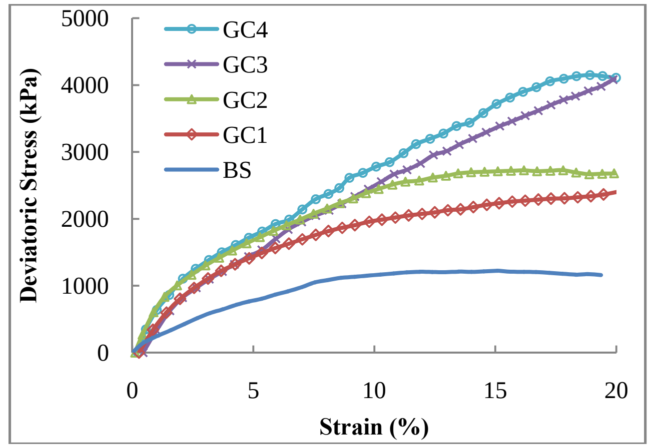

Fig. 5. Stress-strain response of geocell reinforced sand (82% relative density, 400 kPa confining pressure)

a) b)

Fig. 6: Geocell reinforced sand specimen: (a) Before test, (b) After testing to failure

3.2. Shear Strength Parameters of Geocell Reinforced Sand

Modified failure envelopes (p-q plots) have been generated to analyze the shear strength parameters for different geoocell reinforced specimens. Figs. 7 & 8 show the p-q plots for various specimens at 50% & 82% relative density respectively, and the shear strength parameters are tabulated in Table 3.

From Figs. 7 & 8, it is observed that shear strength parameters are dependent on the type of material used to make the geocell. As the relative density of sand is increased, the strength parameters are also observed to have increased. Apparent cohesion is manifested due to the provision of geocell. The increase in cohesion is more significant than that of friction angle.

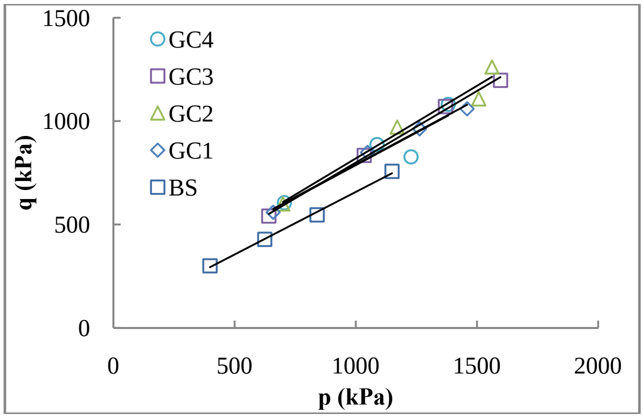

Fig. 7. Modified failure envelopes of geocell reinforced sand (50% relative density)

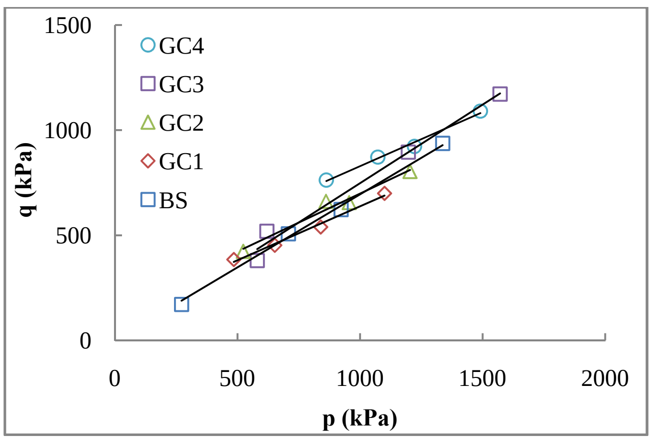

Fig. 8. Modified failure envelopes of geocell reinforced sand (82% relative density)

It can be noted form Table 3 that, the values of shear strength parameters have changed significantly with geocell confinement. It is interesting to note that the values of apparent cohesion of the geocell reinforced sand are approximately 100-200 times as that of unreinforced sand. The geocell has provided passive resistance against shearing and has increased the strength and stability of the reinforced soil.

Table 3: Shear strength parameters of geocell reinforced sand

Relative Density	Geocell Type	c (kPa)	φ (degree)
50%	BS	0.17	34.2
	GC1	19.51	34.8
	GC2	108.24	35.2
	GC3	164.15	37.6
	GC4	225.12	39.2
82%	BS	0.19	39.1
	GC1	34.21	39.5
	GC2	142.10	40.4
	GC3	205.2	42.3
	GC4	263.11	42.0

3.3. Stress-Strain Behaviour of Geocell-Fibre Reinforced Sand

The stress-strain response for the combined effect of geocell-fibre reinforcement at 50% & 82% relative densities and at confining pressures of 100 & 400 kPa is presented in Figs. 9 to 12. Similar to geocell reinforced sand (Figs. 2-5), the strength and stiffness of geocell-fibre reinforced sand get influenced by the type of geocell material, relative density of sand, and confining pressure. However, unlike geocell reinforcement, post-peak strength loss is observed with geocell-fibre reinforcement.

At the low confining pressure of 100 kPa (Figs. 2 & 9 and Figs. 4 & 11), it can be concluded that the response of geocell-fibre reinforced sand indicates strength which is greater than that of geocell reinforced sand. Moreover, the stiffness of geocell-fibre reinforced sand is found to improve. The enhancement of strength is due to fibre-sand interfacial friction and additional mobilization of apparent cohesion.

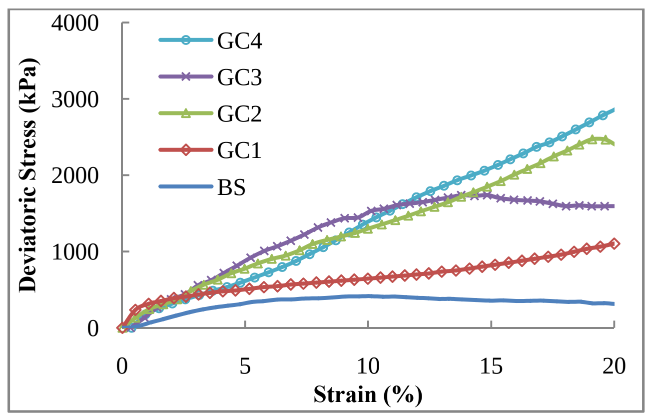

Fig. 9. Stress-strain response of geocell-fibre reinforced sand (50% relative density, 100 kPa confining pressure)

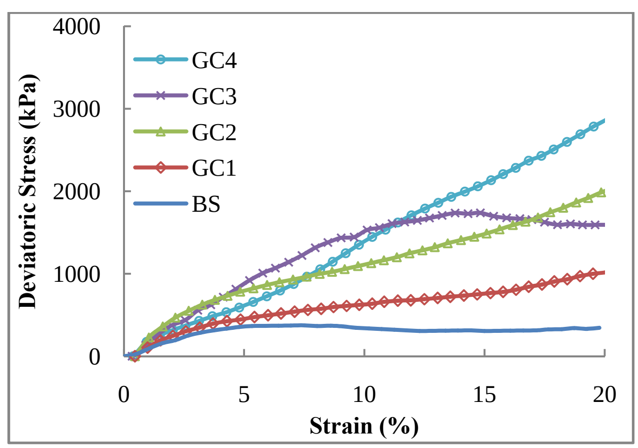

Fig. 10: Stress-strain response of geocell-fibre reinforced sand (50% relative density, 400 kPa confining pressure)

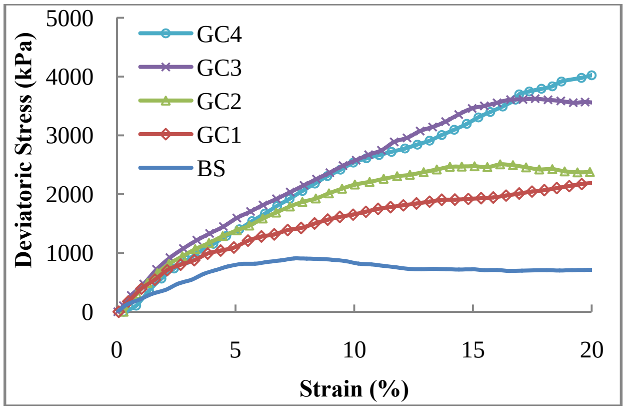

Fig. 11. Stress-strain response of geocell-fibre reinforced sand (82% relative density, 100 kPa confining pressure)

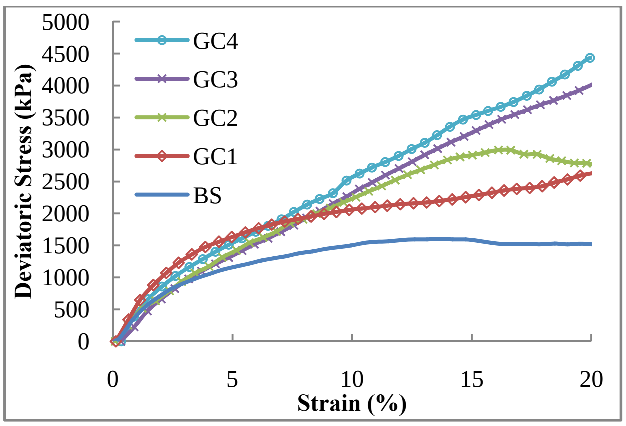

Fig. 12. Stress-strain response of geocell-fibre reinforced sand (82% relative density, 400 kPa confining pressure)

At the high confining pressure of 400 kPa (Figs. 10 & 12), the strength of the geocell-fibre reinforced sand for the higher relative density (82%) is substantially greater than that of the lower relative density (50%).

3.4. Shear Strength Parameters of Geocell-Fibre Reinforced Sand

P-q plots have been made to analyze the shear strength parameters for different geocell reinforced specimens. Figs. 13 & 14 show the modified failure envelopes of geocell-fibre reinforced sand at 50% & 82% relative densities respectively, and the shear strength parameters are listed in Table 4. It can be seen that shear strength parameters vary with the geocell type and relative density of sand. In comparison to Table 3, it can be observed that the apparent cohesion has increased much more than the friction angle.

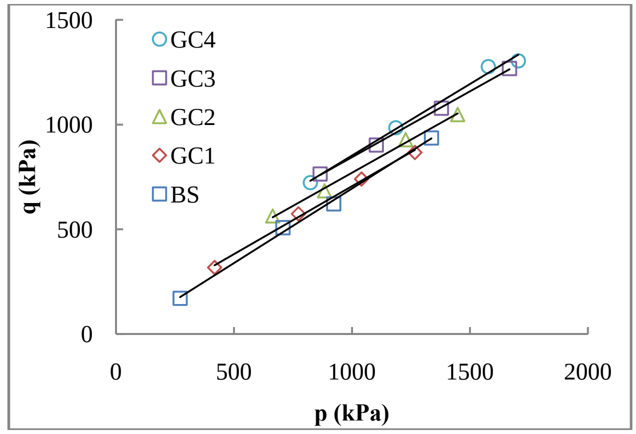

Fig. 13. Modified failure envelopes of geocell-fibre reinforced sand (50% relative density)

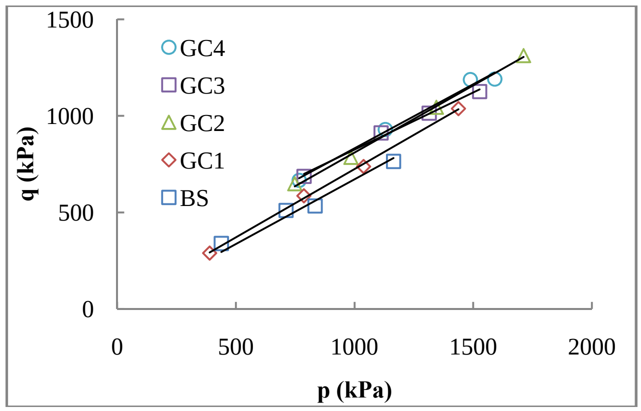

Fig. 14. Modified failure envelopes of geocell-fibre reinforced sand (82% relative density)

Table 4: Shear strength parameters of geocell-fibre reinforced sand

Relative Density	Geocell Type	c (kPa)	φ (degree)
50%	BS	0.17	34.2
	GC1	75.53	36.1
	GC2	178.62	38.9
	GC3	230.49	39.2
	GC4	277.64	40.3
82%	BS	0.19	39.1
	GC1	47.97	41.2
	GC2	150.39	43.1
	GC3	177.66	43.5
	GC4	428.11	44.8

4. CONCLUSIONS

Both geocell and geocell-fibre reinforced sand showed improved stress–strain response compared to unreinforced sand at all relative densities and confining pressures, in terms of increased stiffness, increased failure strains and improved peak deviatoric stress.

In the case of geocell reinforcement, the stress increases gradually with increase in deformation with no post-peak strength loss. However, in the case of geocell-fibre reinforcement, post-peak strength loss is observed.

The increase in strength of geocell reinforced sand soil is due to substantial increase in apparent cohesion of the soil composite. The further addition of fibres has caused further increase in apparent cohesion due to interlocking between the sand and fibres and the development of tensile stress in the fibres.

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