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Ground improvement using geocells to enhance trafficability in desert soils

Anand Kumar[a], Akshay P. Singh[b] and Kaustav Chatterjee*

Department of Civil Engineering, Indian Institute of Technology Roorkee, Roorkee 247667, India

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Abstract. Massive investments are going on to promote and build transportation infrastructure all across the globe with the challenges being more than budgetary. Sandy soils which are predominant in coastal and border areas in India have typical characteristics. The shear strength of such soil is very low which makes it difficult for any kind of geotechnical construction and hence soil stabilization needs to be carried out for such soil conditions. The use of geocells is one of the most economical methods of soil improvement which is used to increase strength and stiffness and reduce the liquefaction potential of the soil. The use of geocells in stabilizing desert sand and results from a series of plate load test on unreinforced soil and geocell reinforced homogenous sand beds are presented in the present study. It also compares the field results using various load class vehicles like heavy load military vehicles on geocell reinforced soils with the experimental results and comes out with the fact that the proposed technique increases the strength and stiffness of sandy soil considerably and provides a solution for preventing settlement and subsidence.

Keywords: geosynthetic applications; soil-geosynthetic interaction; unpaved roads; geocell, field results; settlement

1. Introduction

Infrastructure development is one of the most vital needs of the present day, with soil behaviour being the most important parameter which needs to be considered before construction of any type of civil engineering structure. In the world, there are 80% unpaved roads and insufficient structural strength causes 20% failure of pavements. The problem aggravates when the soil is marshy or soft soil as observed in the desert areas of India. Trafficability, particularly related to military vehicles, is an important aspect in these areas being located on the border and having limited infrastructural advancement. Trafficability in such areas is more or less dependent on soil characteristics, vehicle parameters and soil-wheel interaction. Hence, it is vital to analyse each of these factors and develop the interrelation between them. Once these factors are analysed pragmatically, these can be put together to enhance the trafficability in desert soils.

In Indian subcontinent where there is a large variation of terrain, it becomes mandatory to evaluate and define terrain-vehicle relationship particular to its own conditions. Presently, the vehicle specifications are not well matched with Indian terrain specification and the methodology being used to enhance trafficability for military vehicles is not scientifically based. This leads to an increase in both cost as well as time and material resources.

Therefore, the primary objective of this research work is to evaluate the benefits of using geocells to enhance trafficability in desert terrain. To achieve the purpose, small scale plate load tests are conducted on unreinforced and geocell reinforced surfaces. Further numerous direct tests are conducted to determine the shear strength parameters of both unreinforced and geocell reinforced soil. The parameters investigated in this study includes:

1. Carrying out insitu field tests to analyze various soil factors affecting soil trafficability.
2. Experimental tests to study various soil parameters affecting trafficability.
3. Increase in bearing capacity of sandy soil surface when reinforced with geocells at different positions (i.e., depth) in comparison to unreinforced soil.
4. Determination of optimum position, i.e., depth of reinforcement.

2. Previous studies

Geocells being three-dimensional, honeycomb-shaped soil-reinforcing geosynthetics composed of polymeric materials are generally used for confinement of granular material. The first reported field testing was on access roads over soft subgrade in which geocell-reinforced bases were made up of plastic tube assembly and soil (Webster and Watkins 1977). First use of geocell technique was made for stabilization of sand beach by the US Army Corps of Engineers.

Pokharel *et al.* (2009) has reported the behaviour of geocell-reinforced bases under static and repeated loading. The study investigated that both bearing capacity and stiffness are improved by using geocell as reinforcement.

*Corresponding author, Assistant Professor
E-mail: kchatfce@iitr.ac.in
[a]Former M. Tech. Student
E-mail: anand_engrs@rediffmail.com
[b]Ph.D., Research Scholar
E-mail: asingh4@ce.iitr.ac.in

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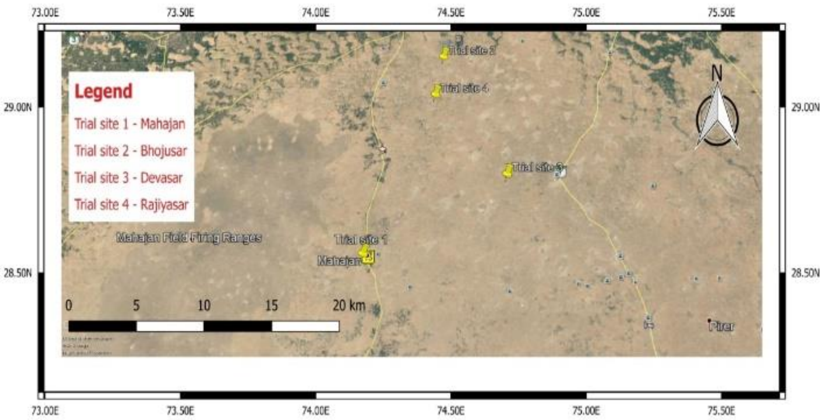

Fig. 1 Details of the test sites in Thar Desert

Table 1 Determination of RCI and CBR for 2.5 ton truck at different test sites

Site	CI for Vehicle Pass 1			Average CI Reading	RCI (CIx0.6)	VCI_1	CI for Vehicle Passes 50			Average CI Reading	RCI (CIx0.6)	VCI_{50}	CBR
Rajiyasar	85	80	75	80	48	30	65	70	60	65	39	69	1.4
Mahajan	110	95	85	97	58		70	75	65	70	42		1.5
Bhojusar	95	85	80	87	52		70	65	60	65	39		1.4
Devasar	105	95	90	97	58		80	75	70	75	45		1.6

Table 2 Variation of sinkage over 50 passes

Type of Vehicle	Vehicle Weight (kgs)	No. of tyres	Diameter of tyres (cm)	Width of each tyre (cm)	Variation in sinkage over 50 passes (cm)
Gypsy	1470	4	67.05	15.24	0.622 -4.45
2.5 ton truck	7650	4	108.7	28.4	1.54-12.22
ALS 9 ton truck	19400	4	108.7	28.4	5.3 -18.1

The authors concluded that single geocell reinforcement increased the stiffness, bearing capacity and percent of elastic deformation for each cycle and reduced the permanent settlement. Zhang *et al.* (2010) proposed a simple calculation method of bearing capacity of soft subgrade soil for the geocell-supported embankment. Khalaj *et al.* (2015) conducted a cyclic plate load testing to analyse the response of multi layers of geocell reinforcement on pavement foundation.

Aboobacker *et al.* (2015) adopted an iterative finite difference scheme to present the solution of governing differential equation for strip footing on geocell reinforced beds and presented different design charts to account the improvement of ground by influence of shear stiffness of the geocell reinforced ground, shear layer width and ultimate bearing capacity of the soft soil. Biabani *et al.* (2016) carried out a series of laboratory experiments using a large scale prismoidal triaxial apparatus and numerical simulation to study the geocell reinforced subballast subjected to cyclic loading and influence of geocell reinforcement on subballast. The study affirmed that increase in geocell stiffness decreases the horizontal displacement and mobilised tensile stresses decrease. Hegde and Sitharam (2016) conducted a laboratory cyclic plate load test and compared the performance of clay bed reinforced with geocells to the unreinforced clay beds. Biswas and Mittal (2017) performed a parametric study for the length of reinforcement, placement of reinforcement and layer spacing and found an improvement of about 86 % in bearing capacity. Mehrjardi and Motarjemi (2018) performed direct shear tests to analyse the effect of residual shear strength, friction angle, apparent cohesion and dilation angle on geocell-reinforced granular soils. Kargar and Hosseini (2018) investigated the geocell-reinforced sand bases by load-settlement response for stiffness and strength of reinforcement and observed that ultimate tensile strength of geocell material is not a variable.

3. Present study

3.1 Test sites

In order to get realistic data from the field, four test sites in different regions of Thar Deserts in Rajasthan, located in western part of India are selected. The border towns of Mahajan, Bhojusar, Devasar and Rajiysar were earmarked for carrying out the field tests. The details of latitude and longitude of these sites are as shown in Fig. 1. Soil samples from these sites were collected using earth augers upto a depth of 1 m for carrying out detailed laboratory tests for determining the basic soil parameters. Measurements of vehicle performance were made and pertinent sand data were obtained for each test.

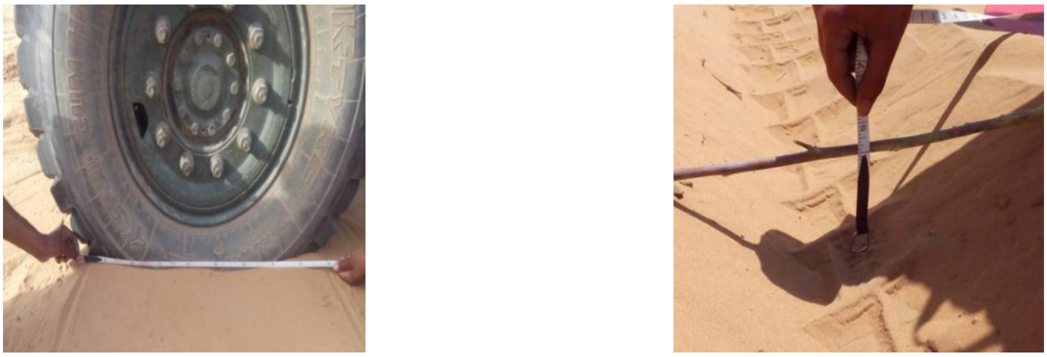

Fig. 2 Measurements of rut depth during field tests

3.2 Soil strength measurement

Bearing and traction capacity of soils are functions of their shearing resistance. Shearing resistance is measured by the cone penetrometer and is expressed in terms of cone index (*CI*). Since the strength of fine-grained soils may increase or decrease when loaded or disturbed, remolding tests are necessary to measure any loss of soil strength expected after trafficability. The CI of fine-grained soil when multiplied by the rating index (*RI*) produces the rating cone index (*RCI*) which is used to denote the strength of soil corrected for remoulding. In the present study, for the various sandy soil sites, the value of *RI* is taken as 0.6 (Rush and Stinson, 1961). Cone penetrometer serves as a useful tool to predict insitu cone index and California Bearing Ratio (*CBR*) and hence the strength of soil. The cone is forced into the soil slowly. The proving ring and calibrated-dial assembly are used to measure the load applied. The penetration resistance is termed as cone index and the dial measures the insitu *CBR*. The *RCI* thus obtained is compared with vehicle cone index (*VCI*) to predict whether the surface is trafficable for a particular vehicle. *VCI* indicates whether the vehicle can negotiate the given soil conditions for a given number of passes of the vehicle. When the magnitude of $VCI_1 \geq RCI$, it implies that the soil cannot take even one pass of a given type of vehicle and if $VCI_{50} \leq RCI$, it implies that given type of soil can take 50 passes of that corresponding vehicle, where VCI_1 and VCI_{50} denotes the *VCI* values for the 1st pass and 50th pass, respectively. The values of VCI_1 and VCI_{50} for a 2.5 ton truck used for the trials are 30 and 69, respectively (Freitag, 1965). Table 1 tabulates the insitu results of test area for trafficability of 2.5 ton army truck. The calculated RCI values are compared with *VCI* of 2.5 ton truck and it was observed that the area is non trafficable for 50 passes and hence there is a requirement of soil reinforcement.

3.3 Rut depth measurement

Sinkage or rut depth plays an important role in the mobility of vehicles in soft soil. A number of field tests were carried out on different class of vehicles. The effects on changing the number of tyres are also analysed. Simulated results are analysed considering the vehicle having six radial tyres with width increased from 30.5 to 38.1 cm. The results showed a significant difference with up to 50% reduction in tyre sinkage. The variation in sinkage for various vehicles over 50 passes are tabulated in Table 2. The sinkage measurement is shown as in Fig. 2.

4. Experimental tests

4.1 Test material

In order to understand and perceive the soil geocell composite system, it is essential to understand and quantify the mechanical properties of constituent materials, i.e., soil and geocell, which has been discussed in this section. The various experimental procedures, test setup and results are thoroughly explained. For experimental tests in the laboratory, a relative density of 70 % is adopted in the present study as the studied desert area was observed to have similar relative density of about 70 %.

4.1.1 Soil

The soil used for the tests is desert soil obtained from Thar deserts in western part of India. The particle size distribution was carried out by dry sieve analysis as per ASTM D6913/D6913M (2017) and is illustrated in Fig. 3. The sand is classified as poorly graded sand as per ASTM D2487 (2017). The specific gravity (*G*) is determined as per ASTM D854 (2014) and is found to be 2.61. The uniformity coefficient (C_u) and coefficient of curvature (C_c) of the sand particles are calculated to be 4.0 and 1.06 respectively. The maximum and minimum dry unit weight of this sandy soil was determined according to ASTM D4253 (2016) and ASTM D 4254 (2000), are 16.21 kN/m^3 and 14.23 kN/m^3, respectively. The minimum and maximum void ratio determined are 0.57 and 0.79 respectively.

4.1.2 Geocell

The geocell used in the present study is High density polyethelene (*HDPE*) material having density of 940 kg/m^3. It has surface treatment of texturing which consists of a multiple of rhomboidal shaped identifications over the entire strip area and perforated with horizontal row of 10 mm diameter. The properties of geocell are tabulated in Table 3. The depth of geocell used for plate load test is 10 cm and with each cell having size of 18 cm x 12 cm. For direct shear tests, the geocell was modified to create a cell of 10 cm x 8 cm and height 10 mm. For uniformity, similar thread was used for stitching in all fabrications and also the

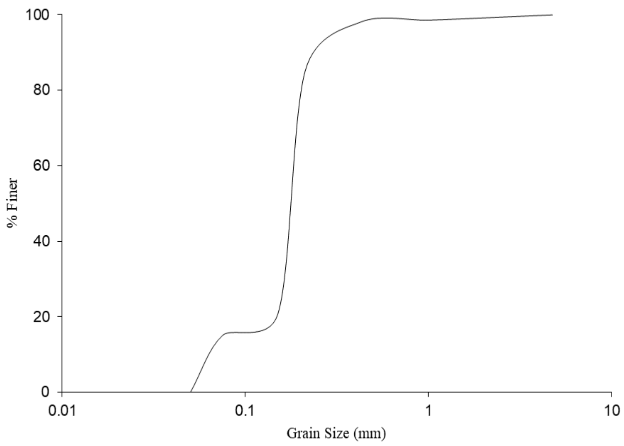

Fig. 3 Grain size distribution curve

Table 3 Properties of geocell used in the present study

Properties	Details
Material	HDPE
Colour	Black
Height	150 mm
Thickness	5 mm
Density	940 kg/m^3
Tensile Strength	5900 kPa
Geosynthetic type	Non-woven geotextiles

number of stitches was kept constant. The tensile strength of geocell was determined by using creep testing machine and found to be 5900 kPa at a constant strain rate of 1.2 mm/min.

4.2 Large scale direct shear test

The conventional small scale direct shear device can only house small size specimens; this puts serious limitations in terms of replicating real field conditions. Due to this, large scale direct shear tests were conducted. The large size direct shear tests were conducted on unreinforced soil and geocell reinforced soil surface to determine the shear strength parameter and analyze the characteristics of geocell reinforced soil when compared with unreinforced soil. For tests using geocells, the soil is enforced to slide along geocell by applying uniform load normal to the plane of relative movement. The maximum shear stress at large displacement is obtained and the test is conducted at different normal confining pressures.

4.2.1 Test setup

A large scale direct shear test machine was employed in this study. The large scale test machine was setup in accordance to ASTM D5321 standard test methods with some modifications as shown in Fig. 4. The apparatus consists of shear box upper and lower each having dimensions of 600 mm × 600 mm and height of the shear box is 150 mm. The lower box is rigidly set to the movable platform, while the upper box is positioned over the lower box and is free to slide or shear when lateral loading is applied. The setup has displacement controlled loading system. Constant vertical loading is applied with the help of a hydraulic jack loaded with a reaction frame. The vertical loading is kept uniform for a particular test. Lateral loading is applied using a hydraulic jack on the upper frame which is free to slide laterally.

Fig. 4 Setup of direct shear test

4.2.2 Test procedure

The dimensions of shear box were taken and its volume was calculated. The weight of equivalent sand with 70% relative density was calculated. The sand was oven dried for all the tests. For unreinforced soil test, sand was filled in the box in layers and tamped. A rigid loading plate is placed on the top of the soil. The corner screws are then detached and the upper shear box is lifted up to have a 0.5 mm gap between both the shear boxes. Then a uniform vertical load on the rigid loading plate is made to act. The vertical loading equipment consists of a reaction frame which acts as a dead load and a hydraulic jack. The reaction frame was correctly loaded to give the desired reaction load on the plate. Two dial gauges were placed on other side of the shear box to record horizontal displacement. After preparations of the test setup, tests were conducted on both unreinforced and geocell reinforced sections. Tests were conducted at normal stresses of 100 kPa, 200 kPa and 300 kPa. For geocell reinforced soil, first 5 cm of lower box was filled with sand thereafter geocells of cell size 8 cm × 6 cm and height 10 cm was laid and then it was filled with sand in layers after tamping. Then, the test procedure similar to unreinforced case was followed.

4.3 Plate load test

Plate load tests were conducted to determine the effects of geocell confinement and other influencing factors on the behaviour of granular soil before undertaking a full fledge moving vehicle test. A set of laboratory tests were conducted to study the influence of geocell reinforcement on the load carrying capacity and stiffness of soil as compared with unreinforced bases.

Fig. 5 Pluviation technique carried out in present study

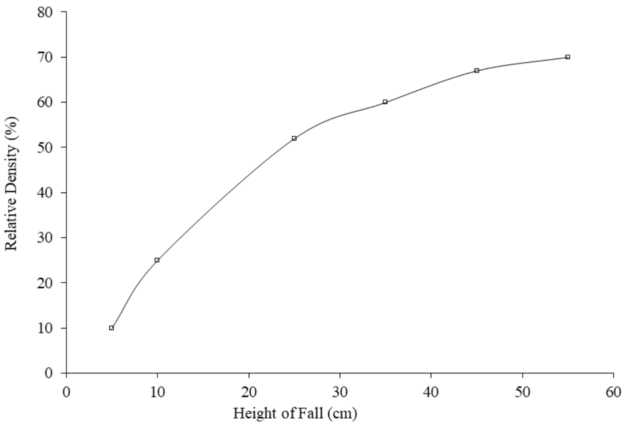

Fig. 6 Calibration curve for relative density of sand using pluviation technique

4.3.1 Test setup

A medium-size loading apparatus was designed and fabricated at the geotechnical laboratory, Indian Institute of Technology Roorkee. A square wooden box having dimensions of 0.53 m × 0.53 m and depth 0.40 m was used for the plate load test. The test bed was instrumented with proving ring and dial gauges. The loading equipment consisted of a reaction frame or dead load and a hydraulic jack. The reaction frame was suitably loaded to give the needed reaction load on the plate. A rectangular loading plate of dimensions 10 cm x 10 cm was used for the tests. Surcharge pressure was applied on the test box using a hydraulic jack. The combined weight of hydraulic jack and plate as 12.5 kg was also considered. The geocell used in the experiment was *HDPE* geocell with each cell 18 cm by 12 cm and height 10 cm.

4.3.2 Test procedure

A total of 16 plate load tests were conducted in the present study at 70% of maximum dry density of the sand. The required uniform density was obtained using rainfall technique or pluviation technique. Pluviation technique is generally used for obtaining uniform samples in the laboratory. It approximates the natural deposition process. In this method, the sand is allowed to fall from different heights to achieve desired relative densities as shown in Fig. 5. However, the use of scoop for pouring the sand may lead to loose slopes at the edge of the rained area and make some non-uniform zones in the surface of the prepared samples. The calibration curve for the sand used in the study is given in Fig. 6. As the sand used in the present study is poorly graded with $C_u = 4$, the sand particles may be on the verge of segregation. However, a precise control over on drop height was maintained and uniformly distributed samples were obtained.

The test tank was filled for conducting unreinforced plate load test using pluviation technique. However, for reinforced cases, the geocell was laid after levelling the sand bed and putting a layer of geosynthetics for vertical confinement as shown in Fig. 7. After preparations of the test setup static tests were conducted on both unreinforced and geocell reinforced sections. During each test, the pressure versus deformation readings was taken, till the ultimate capacity was reached. After each test, the entire sand was scooped out and the geocell mattress was removed carefully. The soil was freshly prepared for next test to maintain uniformity of moisture content and density. The position of geocell was also varied for the tests. The tests were conducted keeping the loading plate at the interlocking of geocell joints and at the center of the geocell chambers to compare the results.

4.4 Field tests

A number of field trials using geocell as reinforcing material on desert tracks were conducted at the test site location to verify the experimental results and assess the efficacy of geocells on unpaved tracks.

4.4.1 Methodology adopted for field tests

The geocell used for the field trials was of height 15 cm and laid over 20 m × 4 m of area to get mechanical means. Skid steer was used to fill sand from one end and two to three persons were employed to spread the sand over the geocell. After filling the geocell with the desert sand, a sand cover of 20 mm was put on the top of the geocell layer so as to prevent the damage of the geocell wall due to direct load application from the vehicles. The geocell track is ready to conduct the field trials when it was filled with sand. Three different kinds of vehicles i.e., Gypsy, 2.5 ton truck and ALS 9 ton truck were used for the trials. The vehicles were moved at a constant speed and each vehicle made 60 passes over the track. The settlement after every 10 passes for each vehicle was noted.

5. Results and discussions

The results observed during experimental and field tests are sensitive to different arrangement and may have variation from preceding test result for same test conditions. So, it is always advised to take the average of the observed result which can help to minimize the errors occurred during observation. Therefore, the reliability of the measured data is shown in Fig. 8 which represents the test results of direct shear test at different magnitudes of vertical load conducted three times.

Fig. 7 Setup for plate load test in the present study

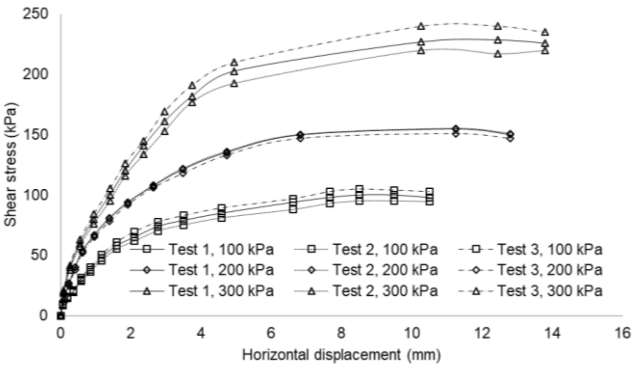

Fig. 8 Three repeated results for each vertical load showing shear stress vs horizontal displacement for unreinforced soil in direct shear test

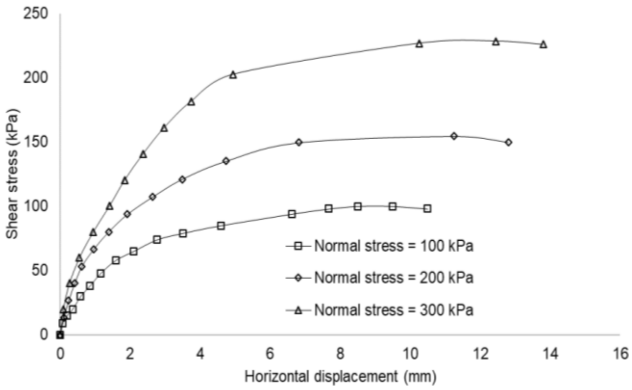

Fig. 9 Shear stress vs horizontal displacement for unreinforced soil

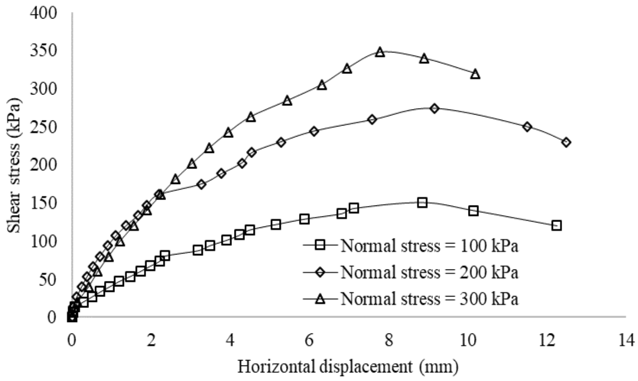

Fig. 10 Shear stress vs horizontal displacement for geocell reinforced soil

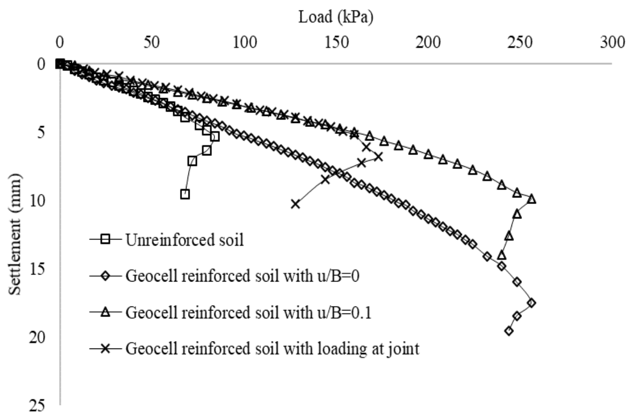

Fig. 11 Load vs settlement curve obtained from plate load test

Table 4 Maximum shear stress for different normal stress

Unreinforced Soil		Geocell reinforced soil	
Normal stress (kPa)	Max shear stress (kPa)	Normal stress (kPa)	Max shear stress (kPa)
100	98.5	100	150.5
200	149.5	200	254
300	228.5	300	318

Table 5 Shear strength parameters obtained from direct shear test

Material	Friction angle (Ø) [°]	Cohesion (c) [kPa]
Unreinforced soil	37.4	0.0
Geocell reinforced soil	38.3	76.8

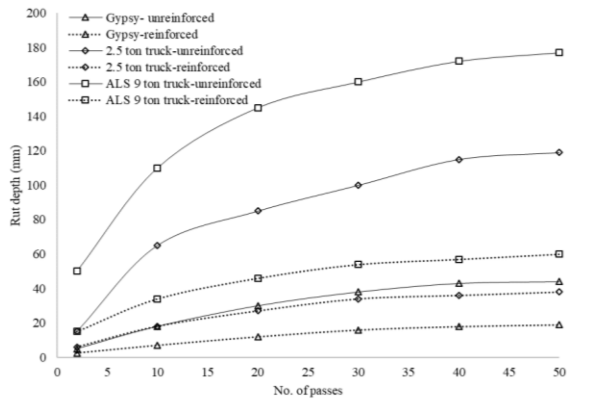

Fig. 12 Rut depth vs no. of passes in unreinforced and geocell reinforced soil

5.1 Direct shear test results

A series of large scale direct shear tests were conducted with three different vertical loads. The horizontal shear stress was plotted against the horizontal displacement to get the value of maximum shear stress for each test. Fig. 9 and Fig. 10 depicts the plot of shear stress vs horizontal displacement for unreinforced and reinforced sand respectively. The maximum shear strength for different normal stress as observed from the curve is depicted in Table 4. The above result shows that there is an increase in the maximum shear stress of geocell reinforced soil when compared with the unreinforced soil. In case of unreinforced soil, the shear stress increases with increase in horizontal displacement. However, in case of geocell reinforced soil, due to the better stiffness of the material, significant decline in post peak shear stresses are observed as shown in Fig. 10. This is due to considerable degree of interlocking and additional friction on interface between sand and geocell.

The shear strength parameters i.e., cohesion and angle of internal friction for both unreinforced and geocell reinforced soil are shown in Table 5. The result observed from above indicates existence of apparent cohesion in the sample with geocell reinforced soil. This apparent cohesion can be interpreted as the cohesive strength imparted due to confinement provided by the geocell reinforcement. Hence the insertion of geocells in the soil sample imparts cohesive strength to the soil with minor difference in the friction angle.

5.2 Plate load test results

Plate load test was carried out on both unreinforced and geocell reinforced sand bed. The depth of reinforcement u and location of loading plate was varied in the present study. The load-displacement curves obtained from the plate load tests are plotted in Fig. 11. It is observed that geocell reinforcement increased the bearing capacity of the sand. The improvement factors for the geocell-reinforced bases over the unreinforced bases ranged from 1.3 to 2.0 in terms of stiffness and 1.5 to 2.5 in terms of bearing capacity. The unconfined geocells failed at the welds while the confined geocells failed due to uplifting of the geocell.

The test results also showed that the slopes of the load-displacement curves for both unreinforced and geocell reinforced soil conditions are initially close to each other. The curves started to separate once the displacement reached 2 mm. This is because the geocell reinforcement needed some displacement for it to take effect. The reason for this phenomenon may be attributed to the hoop stress from the geocell which is proportional to the tensile stress of geocell. So, the geocell provides significant confining stress to sand as the tensile stress (or strain) in the geocell increases.

It is also observed from Fig. 11 that the optimum depth of geocell reinforcement is about $(u/B) = 0.1$ where B is the width of footing. These results suggest that to get maximum influence, the top of the geocell mattress should be at a depth of $0.1B$ from the bottom of the footing. The increase in ground improvement till $u/B = 0.1$ could be due to the surface soil layer, above the geocell reinforcement, acting as a cushion and thereby preventing the direct contact of the footing base with the cell walls and distributing the footing pressure more uniformly over the cellular geocell. The other probable reason that these u/B values are optimal is that at smaller cover thicknesses, the soil mass above the geocell reinforcing layer provides insufficient overburden to generate the required friction resistance at the interface between the geocell layer and the soil.

5.3 Field test results

Based on the field observation, the graphical representation of sinkage for different class of vehicles considered in the present study is shown in Fig. 12. It can be seen from Fig. 12 that the rut depth becomes almost constant after a specific number of passes. This is because the soil has attained maximum compressibility and hence cannot be further compressed. It is also evident from the results that the rut depth decreased by 2 to 3 times when compared with unreinforced surface. Hence it can be inferred that when geocell is filled with sand and compacted, it forms a composite mattress which redistributes the surcharge over a wider area which increases the bearing capacity of soil substantially.

6. Conclusions

The problems associated with movement of vehicles in desert terrain have been addressed in this present research work. Various experimental studies were undertaken to check the efficacy of geocells in desert soil as a suitable ground improvement technique. The major conclusions drawn from this work are as follows:

1. Unreinforced specimens are observed to have negligible apparent cohesion while in case of geocell reinforced soil, there is significant apparent cohesion. The friction angles in both the cases are almost same.

2. The strength of geocell encased soil is improved by almost twice and the stiffness is improved by 150% when compared to unreinforced soil.

3. The improvement factors for the geocell-reinforced bases over the unreinforced bases ranged from 1.3 to 2.0 in terms of stiffness and 1.5 to 2.5 in terms of bearing capacity.

4. The optimum depth of geocell reinforcement is about u / B = 0.1, for best performance of the geocells.

5. For geocell reinforced sand surface, the settlement or the rut depth reduces almost by 3 times as compared to unreinforced sand surface.

The present study shows that geocells can prove extensively useful and beneficial in construction of unpaved roads or tracks in rural areas. However, the present study is valid in certain conditions in which it is carried out. But this can serve as a useful alternative for movement of military vehicles along or across the border areas where no paved roads exist as time and resources under such circumstances are scare. The use of geocells is not only economical but also saves upon time and can also be considered for construction of helipads in rural and inhospitable terrain.

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