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Strength Improvement of Poor Subgrade Soil Reinforced with Polyester Biaxial Geogrid

***Ayush Mittal* [1)] *and Shalinee Shukla* [2)]**

[1)] Assistant Professor, Rajkiya Engineering College, Ambedkar Nagar, India.
E-Mail: rce1453@mnnit.ac.in
[2)] Associate Professor, MNNIT Allahabad, India.
E-Mail: sshukla@mnnit.ac.in

ABSTRACT

This paper presents a laboratory study on the effect of polyester biaxial geogrid on the strength behaviour of poor subgrade soil. The soil used in the present study is classified as clay of intermediate compressibility in accordance with IS 1498 (1970) having a substantial amount of fines; i.e., a high percentage of clay and silt and losing its strength significantly upon coming in contact with water. Geogrid sheets are placed in single and double layers at various depths of soil subgrade and heavy compaction. California bearing ratio (CBR) and unconfined compressive strength (UCS) tests are conducted. The test results indicate significant improvements in CBR, UCS and axial strain at failure as well as a reduction in post peak strength loss. Maximum improvements of 36% and 41%, respectively, in CBR and 62% and 70%, respectively, in UCS values are observed when the geogrid is placed in a single layer (i.e., 0.2H) and in double layers (i.e., 0.2H and 0.4H) from the top of the specimen. Scanning electron microscopy (SEM) is used to study the micromechanical interaction between soil and geogrid surface. It is observed that interlocking and surface friction between soil particles and fibers of the geogrid are responsible for strength enhancement of weak subgrade soil. Multiple linear regression models were developed for predicting soaked CBR and UCS.

KEYWORDS: Geogrid, Strength, Subgrade, Compaction, California bearing ratio, UCS.

INTRODUCTION

Roads are the most vital component for economic and social development of any country. Their importance further increases if the economy of a country is based on agriculture. India has a total road network of about 6 million kilometers of which 79% consists of rural roads (Pateriya, 2016). The present demand of road aggregates in India is around 3300 million tons annually which has been increasing at an average rate of 7.7% in the last ten years (Vittal, 2016). In India, more than 90% of passenger traffic and 65% of freight traffic pass through roads. In order to tackle such huge traffic, good-quality roads are required. The performance of pavement depends mainly on the properties of subgrade soil, as it serves as the foundation for pavement. The presence of weak subgrade soil will lead to rapid increase in construction and maintenance costs due to increase in crust thickness and frequent failures because of intermixing of aggregate and soil layer. More than 20% land area of India is covered with soils having low CBR and shear strength values. In order to tackle such situations, soil reinforcement techniques have to be adopted which include chemical, mechanical and physical methods. Earlier, cement, fly ash and lime were

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used for improving strength, but due to certain limitations including brittle behaviour of reinforced soil, improper mixing, longer time required during curing process, weather dependency and requirement of specialty mixing equipment, some alternatives have to be adopted. The use of geosynthetic materials is a new and innovative technique which is gaining acceptance worldwide because of its quick instillation, cost reduction and improved soil properties. The World Bank has made it mandatory to use geosynthetic materials in construction projects funded by it (Indian Infrastructure, 2010).

Many studies have been conducted on the use of geotextile (Elshakankery et al., 2013; Kumar and Rajkumar, 2012; Nair and Latha, 2009; Murtaza et al., 1989; Viswanadham and Satkalmi, 2008; Tuna and Altun, 2012; Noorzad and Mirmoradi, 2010; Raisinghani and Viswanadham, 2010; Ghazavi and Roustaei, 2013; Haeri et al., 2000; Ghosh and Dey, 2009; Bera et al., 2009; Lekha and Kavitha, 2006; Chattopadhyay and Chakravarty, 2009; Sarsby, 2007) and random discrete inclusions (Kalantari et al., 2010; Chore et al., 2011; Consoli et al., 2010; Yetimoglu et al., 2005; Botero et al., 2015; Park, 2009; Consoli et al., 2009; Yetimoglu and Salbas, 2003; Pradhan et al., 2012; Shao et al., 2014; Fatahi et al., 2013; Zaimoglu, 2015; Chore and Vaidya, 2015; Correia et al., 2015; Kumar et al., 2006; Li et al., 2014; Tang et al., 2007; Cai et al., 2006; Tang et al., 2010; Anggraini et al., 2015; Prabakar and Sridhar, 2002; Lekha et al., 2015) on the strength behaviour of coarse and fine grained soils, while limited studies are available on the use of geogrid in subgrade strength improvement. Singh (2013) studied the effect of geogrid sheets on stiffness modulus and shear strength parameters (c and φ) of medium-dense granular soil. The effect of triaxial geogrids on the CBR value of sandy silt soil was studied by Adams et al. (2014). Zornberg and Gupta (2009) carried out field trials in order to evaluate the effectiveness of geogrid reinforcement in mitigation of longitudinal cracks formed on pavements constructed over expansive soil. Leshchinsky et al. (2016) studied the effect of microgrid inclusions added in various percentages on the mechanical behaviour of poorly graded sand. Brown et al. (2007) identified the parameters causing reduction in settlement of railway ballast under repeated loading, reinforced with geogrid, through composite element test (CET). In the present work, polyester biaxial geogrid is used as reinforcement to study the strength behaviour of poor subgrade soil. The geogrid sheets are placed in single and double layers at various depths in soil subgrade under heavy compaction, California bearing ratio and unconfined compressive strength tests are conducted. Predictive models were formed for future estimation of CBR and UCS using StatPlus:mac LE software.

MATERIALS AND METHODS

Soil

The soil sample used in this study is collected from Karwi (25.20°N, 80.90°E), Chitrakoot district, Uttar Pradesh. The area is largely covered with fine grained soils. The soil sample is collected from a depth of 1m below ground surface as the top layer is likely to contain organic matter and other foreign materials. The soil sample is classified as clay of intermediate compressibility (CI) as per IS: 1498 (1970). The grain size distribution curve of soil is shown in Figure 1. Table 1 shows various index and engineering properties of the soil.

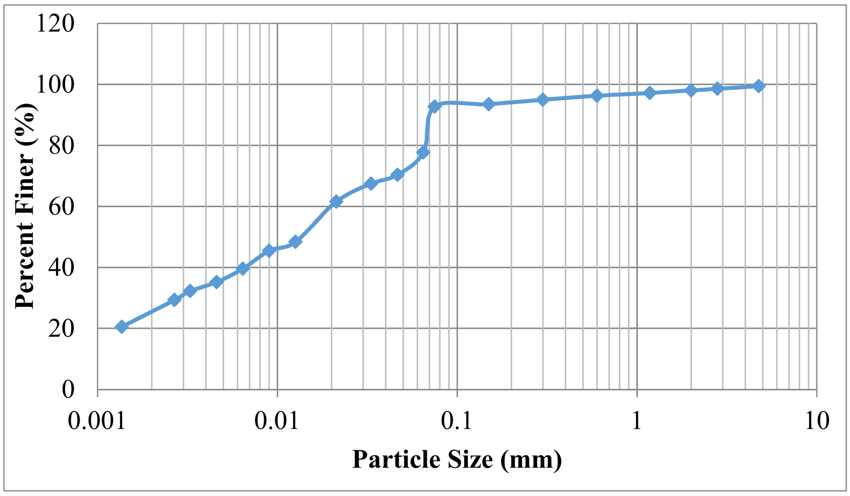

Figure (1): Grain size distribution curve for clayey soil

Table 1. Properties of soil

Properties	Value
Atterberg's Limits	
(a) Liquid Limit (%)	37.30
(b) Plastic Limit (%)	23.18
(c) Shrinkage Limit (%)	18.56
(d) Plasticity Index (%)	14.12
Grain Size Distribution	
(a) Gravel (%)	0.59
(b) Sand (%)	6.72
(c) Silt (%)	67.93
(d) Clay (%)	24.76
Soil Classification (ISCS)	Clay of Intermediate Compressibility (CI)
Water Content (%)	5.13
Specific Gravity	2.72
Free Swell Index (%)	37.50
pH Value	7.21
Optimum Moisture Content (%)	14.50
Maximum Dry Density (kN/m^3)	18.60
Unsoaked CBR (%)	11.86
Soaked CBR (%)	3.83
Swelling Pressure (kN/m^2)	48.12
Unconfined Compressive Strength (kN/m^2)	112.09

Geogrid

Polyester biaxial geogrid (SG3030) is used in the present study, which is selected from the list of materials accredited by the Indian Road Congress. The geogrid sheets are coated with bitumen to provide dimensional stability, durability and resistance to installation damage. Table 2 shows various properties of biaxial geogrid (SG3030). Figure 2 shows the bitumen coated geogrid having aperture of 18 mm in both machine direction and cross-machine direction.

Table 2. Index properties of geogrid (SG3030)

Particulars	Value
Geogrid type	Bitumen-coated biaxial polyester yarn
Tensile strength (ASTM D6637B) (kN/m)	30/30 (MD/CMD)
Creep limited strength (kN/m)	20.4/20.4 (MD/CD)
Grid aperture size (mm)	18/18 (MD/CMD)
Aperture shape	Square

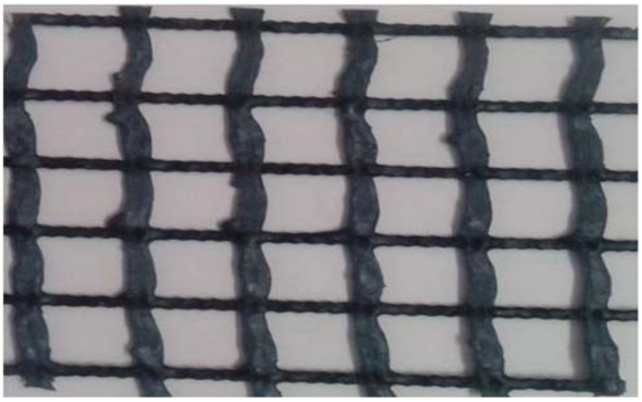

Figure (2): Biaxial polyester geogrid

Experimental Procedure

A series of heavy compaction, California bearing ratio and unconfined compressive strength tests are conducted on soil samples reinforced with and without geogrid sheets to determine the effect of reinforcement. Heavy compaction test is conducted as per IS 2720 (Part 8)-1983, CBR test as per IS 2720 (Part 16)-1987 and UCS test as per IS 2720 (Part 10)-1991. The geogrid is placed in single (i.e., 0.2H, 0.4H, 0.6H and 0.8H) and double layers (i.e., 0.2H & 0.4H, 0.2H & 0.6H and 0.4H & 0.6H) from the top of the specimen. The term H used is the height of soil specimen in heavy compaction, CBR and UCS tests. This height is 127.3mm in heavy compaction and CBR tests and 87mm in UCS test. All the samples for CBR and UCS tests are prepared based on the optimum moisture content and maximum dry density of the corresponding reinforcement layers. UCS samples are prepared in a split mold of 38mm internal diameter and 87mm height by compacting soil in six layers with a tamper having a diameter of a half of that of the mold. Strain rate of 1.25mm/min is used for both CBR and UCS tests. Figure 3 shows the position of different geogrid layers from the top of the specimen.

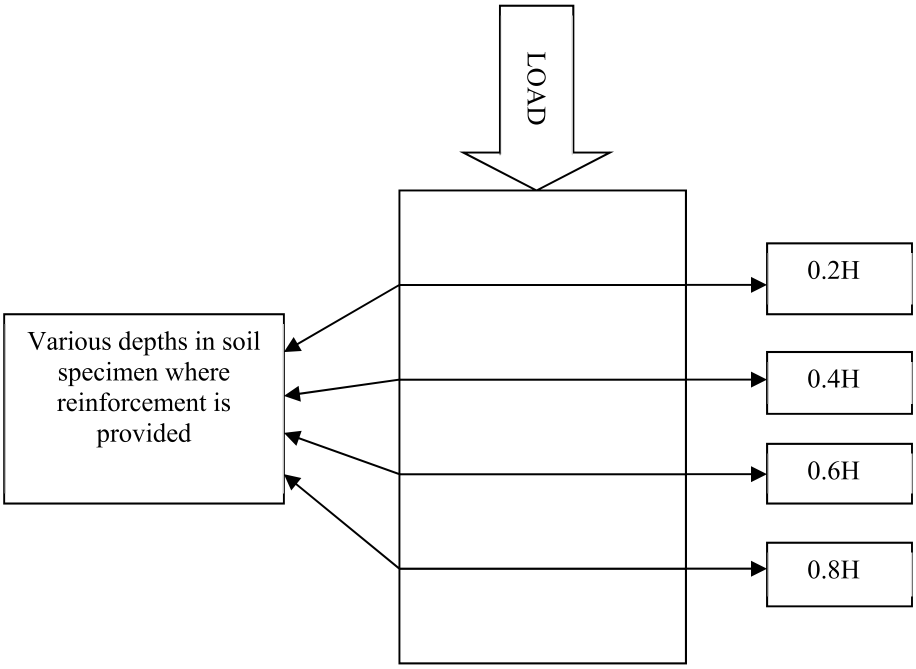

Figure (3): Position of geogrid layers in the soil specimen

RESULTS AND DISCUSSION

Heavy Compaction

The results of optimum moisture content and maximum dry density of the soil sample reinforced with and without geogrid are shown in Table 3. It is observed that the MDD values for all single-layer geogrid reinforced specimens are more as compared to virgin soil with a maximum of 1.892 g/cc corresponding to 0.6H depth from the top of the mold. This increase in MDD is due to greater compactness achieved with geogrid layer, resulting in reduction of voids with void spaces occupied by solid particles having greater specific gravity. However, double-layer reinforced specimens show similar MDD results as virgin soil. The OMC for the unreinforced specimen is 14.50% which changes to 15.60%, 14.70%, 14.30% and 14.70%, respectively, when the geogrid is placed in a single layer at depths of 0.2H, 0.4H, 0.6H and 0.8H. This value further increases to 16.00%, 16.30% and 15.60%, respectively, for double-layer geogrids at 0.2H & 0.4H, 0.2H & 0.6H and 0.4H & 0.6H depths from the top of the mold. This increase in OMC is attributed to water absorption tendency of polyester fibers which are woven to form the geogrid.

Table 3. OMC-MDD values of soil reinforced with and without geogrid

Position of Geogrid from the Top of the Specimen	Experimental Value	
	MDD (kN/m^3)	OMC (%)
Virgin Soil	18.60	14.50
0.2H	18.66	15.60
0.4H	18.82	14.70
0.6H	18.92	14.30
0.8H	18.86	14.70
0.2H & 0.4H	18.60	16.00
0.2H & 0.6H	18.46	16.30
0.4H & 0.6H	18.66	15.60

California Bearing Ratio

The results of CBR for the soil specimen reinforced with and without geogrid are shown in Table 4. The CBR value for unreinforced soil is 3.83% which changes to 5.23%, 4.18%, 4.01% and 3.31%, respectively, when the geogrid is placed in a single layer at depths of 0.2H, 0.4H, 0.6H and 0.8H. This value increases to 5.40%, 4.88% and 4.36%, respectively, for double-layer geogrids at 0.2H & 0.4H, 0.2H & 0.6H and 0.4H & 0.6H depths from the top of the mold. Greater improvement in CBR is observed when geogrid sheets are placed in the upper layers of soil subgrade as compared to the lower ones. This is due to greater resistance offered by the geogrid to penetration of plunger and for tensile strength of fabric to come into action, a certain amount of deformation is required in soil with much greater deformation occurring in the upper portion of the soil subgrade as compared to the lower one due to higher traffic load intensity.

Table 4. CBR values of soil specimen reinforced with and without geogrid

Position of Geogrid from the Top of the Specimen	CBR (2.5mm) (%)	CBR (5mm) (%)
Virgin Soil	3.83	3.72
0.2H	5.23	4.76
0.4H	4.18	3.95
0.6H	4.01	3.69
0.8H	3.31	3.02
0.2H & 0.4H	5.40	5.34
0.2H & 0.6H	4.88	4.65
0.4H & 0.6H	4.36	4.18

Unconfined Compressive Strength

The unconfined compressive strength and failure strain of soil specimens reinforced with and without geogrid are shown in Table 5. Stress-strain curves of unreinforced and geogrid-reinforced specimens are shown in Figure 4. Significant strength improvement is observed when the geogrid is placed in the upper layers of the soil subgrade as compared to the lower ones for both single-and double-layer reinforcement cases. The UCS value for unreinforced soil is 112.09 kN/m^2 which changes to 181.52 kN/m^2, 157.29 kN/m^2, 136.59 kN/m^2 and 108.47 kN/m^2, respectively, when the geogrid is placed in a single layer at depths of 0.2H, 0.4H, 0.6H and 0.8H. These values increase to 190.01 kN/m^2, 160.62 kN/m^2 and 152.72 kN/m^2, respectively, for double-layer geogrids at 0.2H & 0.4H, 0.2H & 0.6H and 0.4H & 0.6H depths from the top of the mold. This increase in UCS is attributed to surface friction, interlocking effect and interception of failure plane within the specimen by the geogrid layer causing uniform stress distribution within the soil sample. Smaller post peak strength loss and greater strain at failure are observed for all geogrid-reinforced specimens indicating more ductile behaviour and improved rupture strength. The failure strain has increased from 2.87% for unreinforced soil to a maximum value of 3.44% and 5.17%, respectively, for single-and double-layer geogrid-reinforced specimens. This is due to greater flexibility of the geogrid as compared to the soil.

Table 5. UCS and failure strain value of soil reinforced with and without geogrid

Position of Geogrid from the Top of the Specimen	UCS (kN/m^2)	Failure Strain (%)
Virgin Soil	112.09	2.87
0.2H	181.52	3.44
0.4H	157.29	2.87
0.6H	136.59	3.44
0.8H	108.47	2.87
0.2H & 0.4H	190.01	4.59
0.2H & 0.6H	160.62	5.17
0.4H & 0.6H	152.72	4.59

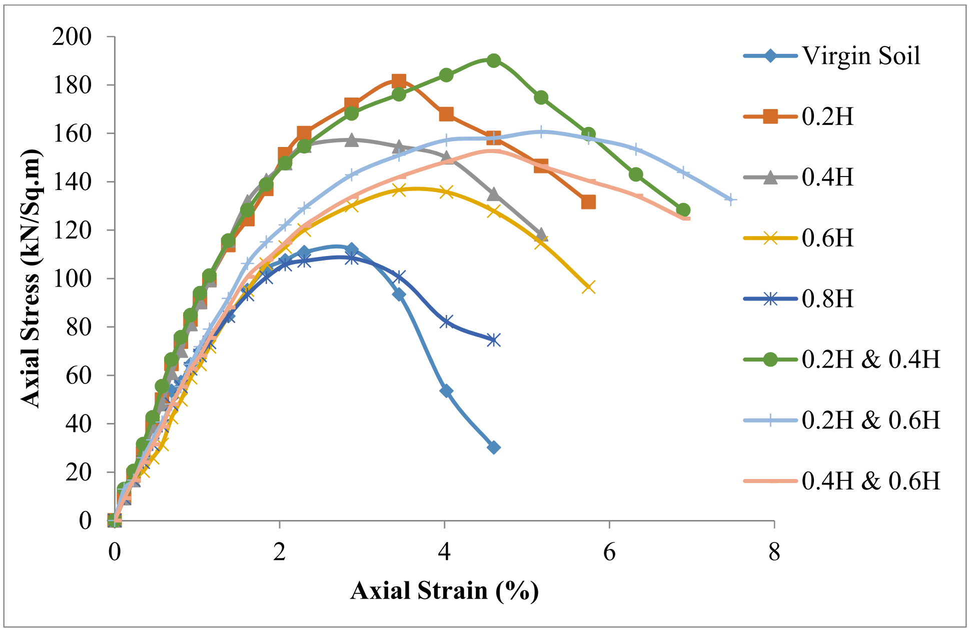

Figure (4): Stress-strain curves for unreinforced and geogrid-reinforced specimens at various depths of the soil subgrade

SEM Analysis

Scanning electron microscope images of unreinforced soil, plane geogrid and geogrid-soil interaction are presented in Figure 5. Figure 5(a) shows the surface morphology of natural soil specimen used in the study. It can be seen clearly that soil contains a substantial amount of fines; i.e., silt and clay fraction. Figure 5(b) shows the geogrid sheet used for soil reinforcement having smooth surface topography. Figure 5(c) shows the cracks and irregularities formed on the surface of the geogrid when compacted with soil, which leads to better bonding between soil particles and the geogrid. Figure 5(d) shows soil particles attached with fibers of the geogrid, providing lateral restraint or confinement effect, which leads to an overall strength improvement of poor subgrade soil specimens.

Statistical Analysis

Multiple linear regression analysis has been performed to obtain correlations of CBR and UCS with the compaction characteristics and various depths of the geogrid from the top of the specimen using StatPlus: mac LE and excel software. Table 6 shows the model summary of CBR and UCS. Figure (6) and Figure (7) show the plots of predicted and measured values of CBR and UCS, respectively. Eq. (1) and Eq. (2) formulated are presented as shown below:

Soaked CBR (%) = - 142.589 + 1.485 * OMC (%) + 6.714 * MDD (kN/m^3) - 0.025 * Single Layer Depth (mm) - 0.002 * Double Layer Depth (mm)………………………………… ………(1)

UCS (kN/sq.m) = - 8,207.360 + 70.114 * OMC (%) + 392.684 * MDD (kN/m^3) - 1.7187 * Single Layer Depth (mm) + 0.0446 * Double Layer Depth (mm)……………………… ………..(2)

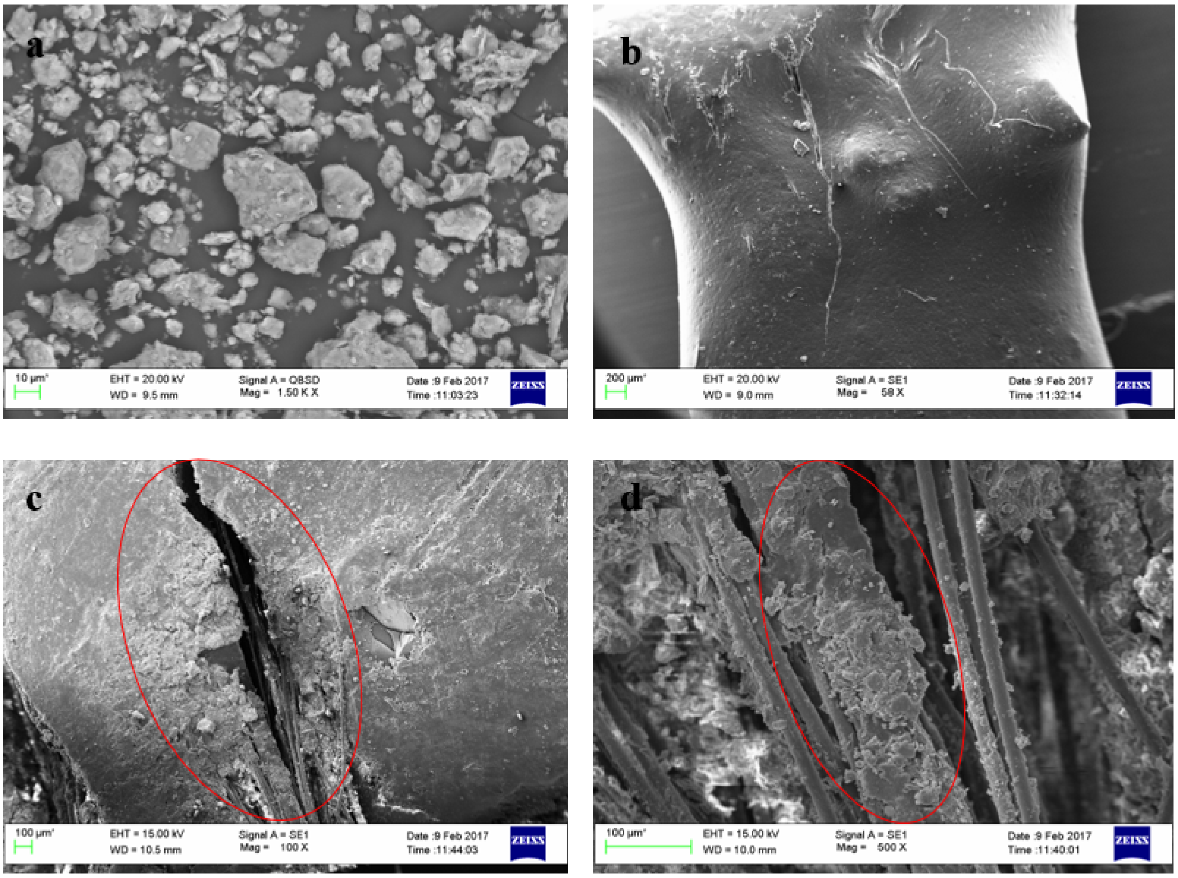

Figure (5): SEM images (a) Unreinforced soil with a magnification of 1500 times; (b) Plane geogrid with a magnification of 58 times; (c) Cracks and surface irregularities formed on the surface of the geogrid with a magnification of 100 times; (d) Interlocking of soil and fibers of the geogrid with a magnification of 500 times

Table 6. Model summary of CBR and UCS

Test	R	R Square	Adjusted R Square	Predicted R Square	Standard Error (S)
CBR	0.986	0.972	0.936	0.836	0.182
UCS	0.995	0.991	0.980	0.820	4.118

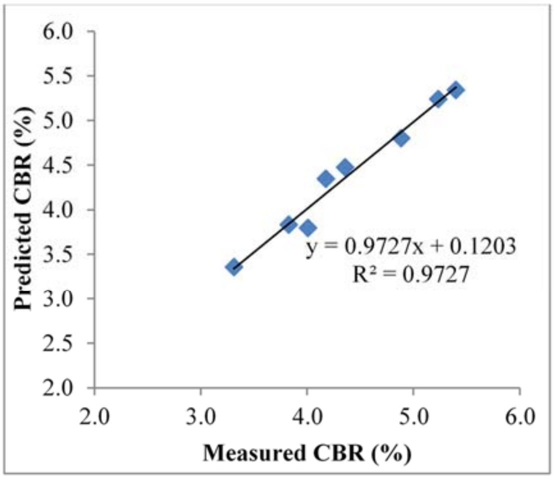

Figure (6): Correlations between predicted and measured values of CBR

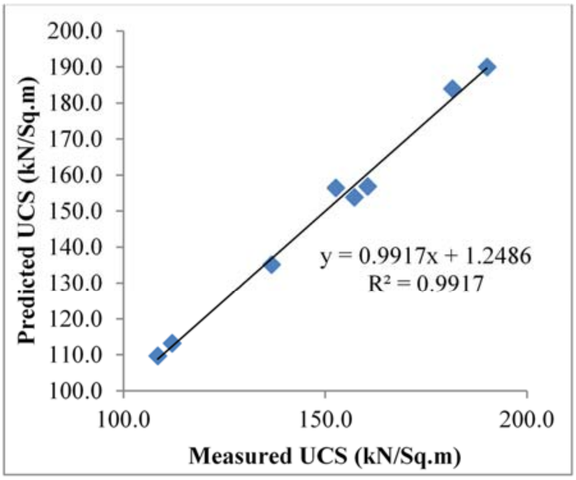

Figure (7): Correlations between predicted and measured values of UCS

CONCLUSIONS

In the present study, the effect of geogrid reinforcement on the strength behaviour of poor subgrade soil is studied. The geogrid sheets are placed in single and double layers at various depths in the soil subgrade. Heavy compaction, California bearing ratio and unconfined compressive strength tests are conducted. Scanning electron microscopy images of different magnifications are used for topographical and morphological analyses. The following conclusions are drawn from these tests.

1) The maximum dry density of all single-layer geogrid-reinforced soil specimens is more as compared to virgin soil. However, for double-layer geogrid reinforcement, it remains more or less similar to unreinforced soil.
2) The optimum moisture content of all geogrid-reinforced specimens is more as compared to natural soil sample with more pronounced effect in double-layer geogrid reinforcement, indicating hydrophilic nature of polyester fibers which are woven to form the geogrid.
3) Maximum increase of 36% and 41%, respectively, in CBR values is observed when the soil specimen is reinforced with a single layer of geogrid at 0.2H depth and a double layer of geogrid at 0.2H and 0.4H depths from the top of the specimen.
4) Maximum increase of 62% and 70%, respectively, in UCS values is observed for a single layer of geogrid at 0.2H depth and a double layer of geogrid at 0.2H and 0.4H depth from the top of the specimen.
5) More ductile behaviour and improved rupture strength are observed for all geogrid-reinforced specimens, thus making the structures fit to sustain severe earthquake loading.
6) SEM analysis clearly indicates significant bonding between geogrid fibers and soil particles, thus causing transfer of tensile stresses from soil to reinforcing material.
7) Models developed correspond well with experimental results. They can explain 83.60% of the variability in new data for CBR and 82.01% of the variability in new data for UCS.

The results of laboratory investigation can be effectively used in the construction of many civil engineering structures, such as pavements and embankments on soft soils. It also gives an idea about the development of new and improved reinforcement techniques with cost and time savings. Thus, it can be summarized that the application of geogrid in the upper layers of the soil subgrade will be more beneficial in terms of improvement in soil properties as compared to lower layers.

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