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Effect of Geogrid Reinforcement on Strength, Thickness and Cost of Low-volume Rural Roads

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ABSTRACT

Pavements constructed over poor subgrade soil will lead to rapid increase in construction and maintenance costs due to increase in crust thickness and frequent failure. In a developing country, like India, costs play a very significant role. In India, more than 20% of the land area is covered with soils having low California bearing ratio (CBR) and shear strength values. These soils consist of a substantial amount of fines; i.e., a high percent of silt and clay, losing significantly in strength upon coming in contact with water. This paper presents the effect of geogrid reinforcement on the strength behaviour of poor subgrade soil. The geogrids are placed in single and double layers from the top of mold and heavy compaction and soaked CBR tests are performed. It is observed that geogrid reinforcement increases the CBR value significantly, thus causing significant reductions in pavement thickness and cost. Multiple linear regression models were developed for predicting soaked CBR.

KEYWORDS: Geogrid, Pavement, CBR, UCS, Reinforcement.

INTRODUCTION

The performance of pavement depends mainly on the properties of soil subgrade, as it serves as the foundation for pavement. The pavement constructed over poor subgrade soil deteriorates significantly under heavy wheel load. The primary purpose of reinforcing a soil mass is to improve its strength and bearing capacity and to reduce lateral deformation and settlement. Reinforcement can be in the form of synthetic and natural geotextiles, geogrids, discrete random inclusions and metal strips. Several investigations have been conducted by using geosynthetic materials, most of which are on granular soils, while limited studies have been found on fine grained soils.

Murtaza et al. (1989) used undrained triaxial and CBR tests to evaluate the load bearing characteristics of flyash reinforced with geofabrics in different layers. Arrangement of 3 layers shows maximum improvement in CBR value with an increase of 150% as compared to unreinforced sample. Triaxial test shows that there is not any specific pattern in improvement of stress-strain behaviour. Viswanadham and Satkalmi (2008) reported significant reduction in rutting and distress in field trials of geotextile-reinforced portion of pavement. Tuna and Altun (2012) studied the behaviour of sandy soil reinforced with geotextile using direct shear tests. Effects of mold size and number of reinforcing layers are considered for analysis. The cohesion value increased as the size of mold decreased and the loss of shear strength seen after peak strength was considerably reduced. Raisinghani and Viswanadham (2010) studied the effects of normal stress, number of reinforcing layers and sand cushion thickness on the permeability characteristics of sandy soil. With increase in normal stress, the permeability characteristics of a geosynthetic-reinforced soil decreased, whereas it improved significantly with the provision of sand cushion and an increase in its thickness showed a uniform increase in permeability improvement factor. Ghazavi and Roustaei (2013) studied the effect of freeze-thaw cycles on clayey soil samples reinforced with and without geotextile using undrained triaxial tests. Tomography images are

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used for visual analysis. Greater reductions in triaxial strength ratio, cohesion and angle of internal friction for unreinforced sample as compared to reinforced one as the number of cycles increases were reported. Scholz and Grabowiecki (2007) reviewed the permeable pavement system (PPS) used in commercial, industrial and residential applications. PPS helped in reducing runoff, providing recharging of groundwater, preventing pollution and saving water by recycling. Haeri et al. (2000) studied the effect of geotextile reinforcement on sandy soil using triaxial testing apparatus. The analysis was conducted on the basis of sample size, confining pressure and geotextile arrangement. Geotextile inclusion reduced the dilatancy of sand samples due to lateral restraint mechanism and the failure of reinforced sand was observed by bulging between geotextile layers as against planner failure in unreinforced samples. Ghosh and Dey (2009) studied the effect of geotextile reinforcement on the bearing ratio of flyash. Water content, thickness of flyash layer and position of geotextile are the governing factors. Shah et al. (2013) conducted UU triaxial test in order to study the effect of number of geogrid layers on sand sample. Zornberg and Gupta (2009) carried out field trials in order to evaluate the effectiveness of geogrid reinforcement in mitigation of longitudinal cracks formed on pavement constructed over expansive soil. Kuity and Roy (2013) conducted soaked and unsoaked CBR tests on clayey soil reinforced with pond ash (PA), rice husk ash (RHA), lime and geogrid in various combinations. Soaked and unsoaked CBR values of mix increased by 1.22 to 3.72 times and 1.16 to 2.06 times, respectively, by adding PA, RHA and lime. Leshchinsky et al. (2016) conducted CD triaxial tests on poorly graded sand reinforced with microgrid inclusions having three different aspect ratios. Microgrid reinforcement was found to be sufficient for projects where shallow ground improvement was required, such as subgrade stabilization. Brown et al. (2007) identified the parameters influencing the reduction in settlement behaviour of railway ballast reinforced with geogrid using composite element test. Bera et al. (2009) performed a series of unconfined compressive strength tests on flyash samples reinforced with jute geotextile. Influences of variables, such as sample size, age hardening property and number of reinforcing layers, were studied. It was found that in case of reinforced flyash, as the specimen size increased, UCS value also improved, but no improvement in case of unreinforced flyash specimen was reported for different dry unit weights. Lekha and Kavitha (2006) presented results on waterfront clay dikes reinforced with coir geotextile. Analysis was carried out on the basis of penetration resistance, horizontal and vertical displacement and time-settlement response. Chattopadhyay and Chakravarty (2009) presented the effectiveness of using jute geotextile as drainage facilitator. Greater settlement was observed at lower magnitude of surcharge load and during initial stage of construction. Sarsby (2007) presented the results on embankments constructed on soft soil reinforced with limited-life geotextiles. The analysis was done on the basis of reduction in reinforcement force required. Basu et al. (2009) used jute-HDPE blended geotextile for soil reinforcement. Results were presented on the basis of improvement in CBR and reduction in rut depth. No marks of subsidence and rutting were observed in the portion of road where blended geotextile was used even after 18 months. However, unreinforced portion showed 5 to 35mm deep rut formation, leading to disintegration of pavement. Rawal and Saraswat (2011) performed tensile and puncture strength tests on hybrid geotextiles. It was concluded that geotextiles formed from blend of polypropylene or polyester and viscose rayon can be used for soil stabilization purpose. Ramasubbarao and Shankar (2013) developed a regression model to predict CBR using index and compaction characteristics.

In the present study, strength behaviour of poor subgrade soil in terms of CBR has been analyzed by using biaxial polyester geogrid as reinforcement. The thickness of pavement is determined as per design catalogues of IRC:SP:72-2015. SEM analysis is conducted to study the micromechanical behaviour of soil and geogrid. Predictive models were formed for future estimation of CBR using StatPlus:mac LE software.

MATERIALS USED

Soil

The soil samples used in this study are collected from Gaura (25.04°N, 81.73°E), Prayagraj district, Uttar Pradesh and classified as clay of high compressibility (CH) as per Indian standard classification system (IS: 1498-1970). Soil samples are collected by digging trial pits at a depth of 1m below the ground level. The grain size distribution curve of soil is shown in Figure 1. The various physical and index properties of soil are shown in Table 1.

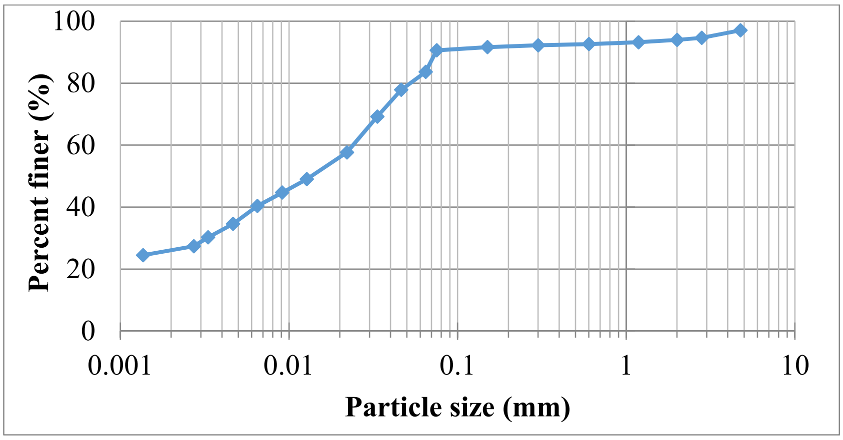

Figure (1): Grain size distribution curve for Gaura soil

Table 1. Properties of Gaura soil

Properties	Value
Atterberg's Limits	
(a) Liquid Limit (%)	57.35
(b) Plastic Limit (%)	29.14
(c) Shrinkage Limit (%)	17.58
(d) Plasticity Index (%)	28.21
Grain Size Distribution	
(a) Gravel (%)	0.48
(b) Sand (%)	4.26
(c) Silt (%)	59.81
(d) Clay (%)	35.45
Soil Classification (ISCS)	Clay of High Compressibility (CH)
Specific Gravity	2.65
Free Swell Index (%)	54.59
Optimum Moisture Content (%)	15.60
Maximum Dry Density (kN/m^3)	17.65
Soaked CBR (%)	2.26
Swelling Pressure (kN/m^2)	81.74
Unconfined Compressive Strength (kN/m^2)	98.37

Geogrid

The geogrid used is a biaxial type (SG3030) selected from the list of materials accredited by the Indian Roads Congress. The biaxial geogrid (SG3030) is shown in Figure 2 and Table 2 shows the various index properties of geogrid as provided by manufacturer and tested at Bombay Textile Research Association (BTRA), Mumbai.

Figure (2): Biaxial polyester geogrid

Table 2. Index properties of geogrid (SG3030)

Particulars	Value (Manufacturer)	Value (BTRA)
Geogrid type	Bitumen coated biaxial polyester yarn	---
Tensile strength (ASTM D6637A) (kN/m)	30/30 (MD/CD)	34.32/32.30 (MD/CD)
Tensile elongation (%)	---	11.6/13.4 (MD/CD)
Junction strength (ASTM D7737) (kN)	---	0.234
Creep limited strength (kN/m)	20.4/20.4 (MD/CD)	---
No. of ribs per meter	---	39/38 (MD/CD)
Grid aperture size (mm)	18/18 (MD/CD)	18.4/18.2 (MD/CD)
Aperture shape	Square	Square

EXPERIMENTAL DETAILS

Heavy compaction and soaked California Bearing Ratio (CBR) tests are performed on soil samples to determine the performance of geogrid in different layers (i.e., single and double) of soil subgrade. Three and four layers of geogrid are avoided due to loss of integrity in soil system, as it results in separation of soil layers completely from each other, resulting in formation of more void spaces causing strength reduction (Shukla et al., 2019). Heavy compaction test is conducted as per IS: 2720 (Part 8)-1983 and CBR test as per IS: 2720 (Part 16)-1987. Figure 3 shows the positions of different geogrid layers from the specimen top.

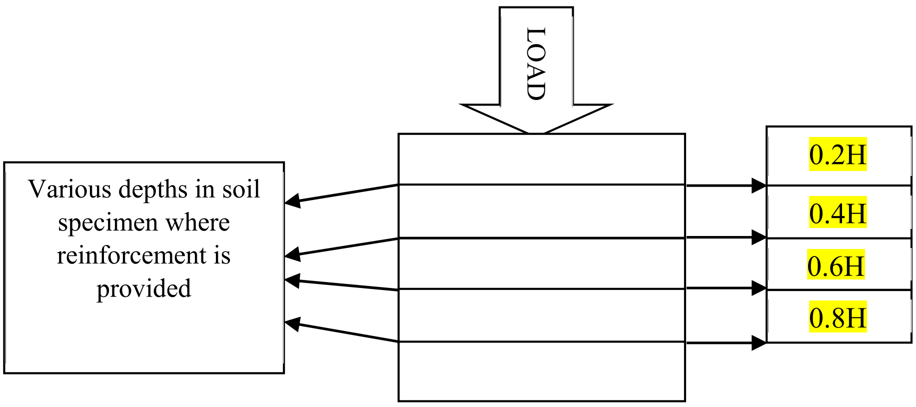

Figure (3): Positions of geogrid layers in soil specimen

The term H used in Figure (3) is the height of mold used for tests. This height is 127.3 mm for compaction and CBR tests.

Compaction Test

Heavy compaction tests are performed on soil samples reinforced with and without geogrid. 3-kg mass of soil passing 4.75mm sieve is taken and water is added, followed by 20 min continuous hand mixing. The soil is initially mixed with 12% water and packed in plastic bags for 24 hours to achieve uniform water content; five such samples were prepared and after that, water was added in increment of 2% to perform the test.

California Bearing Ratio (CBR) Test

The soil samples for CBR tests are prepared based on the corresponding OMC and MDD values. The samples are tested in most critical conditions; i.e., after a soaking period of 96 hours. The penetration rate of plunger is kept constant at 1.25 mm/min and the load values corresponding to penetration levels of 2.5 mm and 5 mm are reported.

RESULTS AND DISCUSSION

Effect of Geogrid on OMC and MDD

The effect of geogrid reinforcement on maximum dry density (MDD) and optimum moisture content (OMC) of soil is shown in Table 3. For all reinforced specimens, the dry density value comes out to be higher than that of virgin soil. The moisture content decreases with increase in dry density with more pronounced effect in double-layer reinforcement. This increase in dry density is due to greater compactness achieved with geogrid layers, resulting in reduction of voids with void spaces occupied by solid particles having greater specific gravity.

Effect of Geogrid on CBR

Table 4 shows the test results of soil samples reinforced with geogrid. Greater improvement in CBR is seen in upper layers of subgrade as compared to lower ones for both single- and double-layer reinforcement conditions. This increase is due to greater resistance offered by geogrid to penetration of plunger. Another reason is that for tensile strength of fabric to come into action, a certain amount of deformation is required in soil and much greater deformation will take place in the upper portion of subgrade due to greater traffic load intensity.

Table 3. OMC-MDD values of soil reinforced with geogrid

Position of Reinforcement from Top of Mold	Geogrid-reinforced Specimen	
	MDD (kN/m^3)	OMC (%)
Virgin Soil	17.65	15.60
0.2H	19.18	14.70
0.4H	18.92	14.90
0.6H	18.74	15.10
0.8H	18.65	15.30
0.2H and 0.4H	19.32	14.20
0.2H and 0.6H	19.10	14.30
0.4H and 0.6H	18.80	14.50

Table 4. CBR values of soil reinforced with geogrid

Position of Reinforcement from Top of Mold	Geogrid-reinforced Specimen CBR (%)
Virgin Soil	2.26
0.2H	4.18
0.4H	3.48
0.6H	2.79
0.8H	2.44
0.2H and 0.4H	5.23
0.2H and 0.6H	4.01
0.4H and 0.6H	3.83

Cost Analysis

Cost analysis of single-lane pavement of 3.75m width and 1km length, constructed on soil reinforced with and without geogrid, was conducted as per IRC:SP:72-2015 design catalogues of flexible pavements for low-volume rural roads. Traffic categories T-6 (0.3msa - 0.6msa) and T-9 (1.5msa – 2msa) are considered for analysis. Materials required for 1km length, 3.75m width and variable thickness depending on different pavement layers are considered. The rates of various pavement layer materials are obtained from the detailed project report for construction of roads under Pradhan Mantri Gram Sadak Yojana (PMGSY-II) for Chitrakoot region of Uttar Pradesh, India. Table 5 shows the various works and rates of materials in Indian Rupee (INR). Table 6 and Table 7 show the cost and thickness of pavement constructed on soil reinforced with and without geogrid sheets in single and double layers. With the use of geogrid in various depths of subgrade, reduction in pavement thickness is reported, which leads to less pavement cost. Maximum cost reduction of 12% to 13% for both traffic categories T-9 and T-6 corresponding to double layer of geogrid (0.2H and 0.4H) reinforcement is observed.

Table 5. Works and rates of pavement layer materials

Works	Rates (Chitrakoot Region)
Drainage layer of 100 mm thickness 9.5-4.75 mm = 35% 4.75-2.36 mm = 12.5% ≤ 2.36 mm = 52.5%	` 1,850.02 /cu.m
Granular sub-base grading 1 53-9.5 mm = 50% 9.5-2.36 mm = 20% ≤ 2.36 mm = 30%	` 2,016.14 /cu.m
Water bound macadam grading 2 a) Aggregate (63-45 mm) b) Stone Screening (11.2 mm) c) Binding material	` 1,830.21 / cu.m
Water bound macadam grading 3 a) Aggregate (53-22.4 mm) b) Stone Screening (11.2 mm)	` 2,896.03 /cu.m
Bituminous macadam of 50 mm thickness 25-10 mm = 40% 10-5 mm = 40% ≤ 5 mm = 20%	` 7,378.52 /cu.m
Open graded premix carpet of 20mm thickness composed of 13.2 mm to 5.6 mm, crushed chipping stones using either penetration grade bitumen or emulsion	` 140.86 /sq.m
Polyester biaxial geogrid (SG3030)	` 50/sq.m

Source: DPR reports of Chitrakoot region.

Table 6. Cost of pavement using rates of Chitrakoot region for traffic category T-6

Depth of Geogrid from Top of Mold	Thickness of Pavement (mm)	Reduction in Thickness (%)	Cost of Pavement (`)	Change in Cost (%)
Virgin Soil	670	---	4,441,537	---
0.2H	595	11.20	4,009,725	9.72
0.4H	595	11.20	4,009,725	9.72
0.6H	595	11.20	4,009,725	9.72
0.8H	670	0	4,629,037	-4.22
0.2H and 0.4H	495	26.11	3,871,537	12.83
0.2H and 0.6H	595	11.20	4,197,225	5.50
0.4H and 0.6H	595	11.20	4,197,225	5.50

Table 7. Cost of pavement using rates of Chitrakoot region for traffic category T-9

Depth of Geogrid from Top of Mold	Thickness of Pavement (mm)	Reduction in Thickness (%)	Cost of Pavement (`)	Change in Cost (%)
Virgin Soil	845	---	6,039,884	---
0.2H	695	17.75	5,849,384	3.15
0.4H	695	17.75	5,849,384	3.15
0.6H	695	17.75	5,849,384	3.15
0.8H	845	0	6,227,385	-3.10
0.2H and 0.4H	570	32.54	5,315,760	11.98
0.2H and 0.6H	695	17.75	6,036,884	0.05
0.4H and 0.6H	695	17.75	6,036,884	0.05

SEM Analysis

The micromechanical analyses of soil and geogrid materials are conducted by using scanning electron microscope images of different magnifications. It is observed that surface friction and interlocking between soil particles and geogrid fibers are responsible for improvement in properties of poor subgrade soil. Figure 4(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., more than 90% material passing through 200-mesh sieve. Figure 4(b) shows crack formation and roughness on geogrid surface upon interaction with soil. Figure 4(c) shows fibers of geogrid which interact with soil particles mechanically through surface friction and interlocking. Figure 4(d) shows bonding of soil particles and fibers of geogrid, leading to a more compact system, causing improvement in strength and mechanical behaviour of poor subgrade soil.

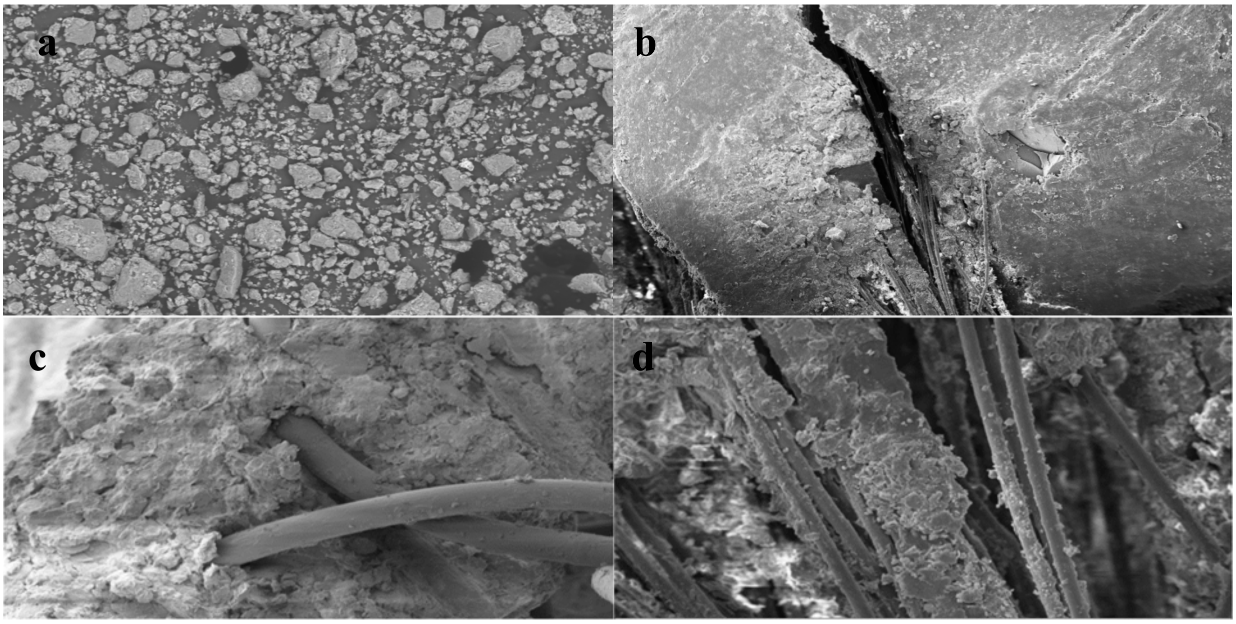

Figure (4): SEM images (a) Natural soil (500X); (b) Cracks and surface irregularities formed on geogrid surface (100X); (c) Polyester fibers of geogrid interacting with soil particles (200X); (d) Bonding between soil and fibers of geogrid (1000X)

Multiple Linear Regression Analysis

Regression analysis is a statistical technique for investigating and modeling relationships between variables (Montgomery et al., 2003). A statistical analysis has been performed to obtain the correlations of CBR with the compaction characteristics and various depths of geosynthetic reinforcement from top of mold through StatPlus:mac LE and excel software. Table 8 shows the model summary of CBR. Influence of each parameter is shown in parameter estimate Table 9. Figure 5 shows the plots of observed and predicted values of soaked CBR. Eq. (1) formulated is presented as:

Soaked CBR (%) = - 0.9613 * OMC (%) + 0.9739 * MDD (kN/m^3) - 0.0109 * Single Layer Depth (mm) - 0.0018 * Double Layer Depth (mm) ……………..… For geogrid reinforcement (1)

Table 8. Model summary for soaked CBR

Reinforcement	R	R Square	Adjusted R Square	Prediction R Square	Standard Error (S)
Geogrid	0.998	0.995	0.992	0.879	0.329

Table 9. Parameter estimate of response and regressor variables

Variables	Coefficients	Standard Error	LCL	UCL	P-Value	H0 (5%)
OMC (%)	-0.9613	0.1835	-1.4707	-0.4519	0.0063	Rejected
MDD (kN/m^3)	0.9739	0.1499	0.5578	1.3899	0.0029	Rejected
Single Layer Depth (mm)	-0.0109	0.0041	-0.0222	0.0003	0.0544	Accepted
Double Layer Depth (mm)	-0.0018	0.0047	-0.0148	0.0111	0.7143	Accepted

LCL – Lower limit of the 95% confidence interval.

UCL – Upper limit of the 95% confidence interval.

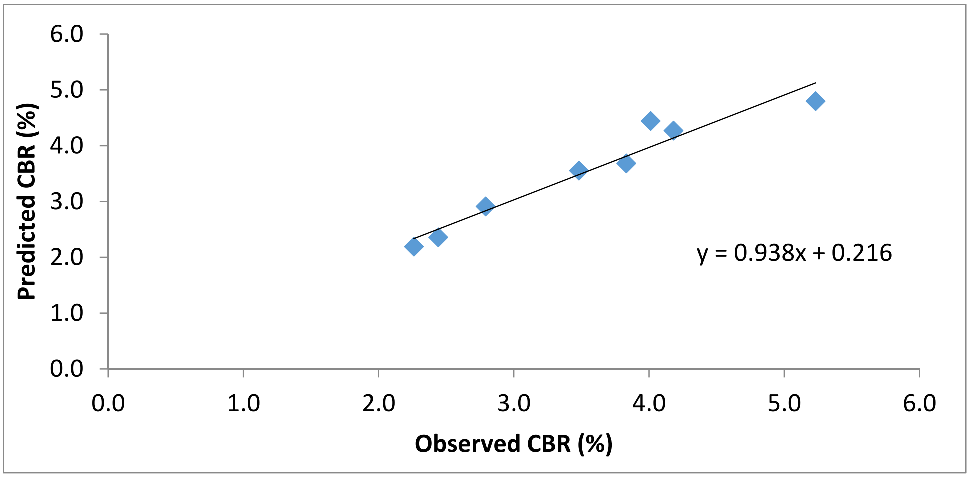

Figure (5): Correlations between predicted and observed CBR values for geogrid-reinforced condition

CONCLUSIONS

The following conclusions are drawn from the present investigation.

1. The inclusion of geogrid causes increase in MDD value for all reinforced cases, indicating improved strength and stability. The pavement constructed over such stabilized soil will perform better under heavy wheel loads and there will be less possibility of future settlement and compressibility.
2. OMC values for all reinforced specimens are less as compared to virgin soil with more pronounced effect in double-layer reinforcement, indicating hydrophobic nature of polyester fibers which are woven to form geogrid.
3. Maximum increase of 83% and 130%, 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 reduction in pavement thickness is 32.54% and 26.11% for traffic category T-9 and traffic category T-6, respectively, corresponding to double-layer geogrid reinforcement at 0.2H and 0.4H depths.
5. This thickness reduction will significantly reduce the cost of construction and lead to environmental benefits, such as less transportation of aggregate, less diesel consumption and hence less libration of toxic gases.
6. SEM images clearly indicate significant bonding between geogrid fibers and subgrade soil, causing transfer of tensile stresses from soil to reinforcing materials, thus enabling it to bear greater traffic load intensity.
7. The model developed will help in future prediction of soaked CBR of soil samples having similar composition, thus eliminating the requirement of experimental analysis which is cumbersome, time-consuming and costly.
8. Double-layer geogrid placed at 0.2H and 0.4H depths is found to be the most optimum position for reinforcement in clayey soil subgrade when analyzed on the basis of three parameters; i.e., strength improvement, thickness and cost reduction.

These conclusions are of significance for application in engineering projects, such as construction of pavement and embankment on weak soil and developing improved reinforcement techniques. Thus, it can be concluded that geogrid can be used as an effective reinforcement material for ground improvement.

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