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Experimental Study of Strength Development in Black Cotton Soil and Granular Material Reinforced with Geogrid and Non-Woven Geotextile

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Abstract: Reinforcement of flexible pavements using geosynthetics is gaining widespread application. However, there is inadequate understanding of strength development for non-woven geotextile and geogrid as reinforcement in Black Cotton Soil (BCS) and granular material in relation to cement stabilization method. Therefore, this paper presents experimental study to investigate strength development for BCS and granular material reinforced with geogrid and non-woven geotextile using California Bearing Ratio approach. The categories of samples tested were; neat, reinforced and cement stabilized. All samples were tested after 4 days' soak. Placement of reinforcement material in BCS was done at 0.3H and 0.6H for single layer reinforcement while for double layer reinforcement, it was done at both 0.3H and 0.6H. In granular soil, single layer reinforcement condition only was considered at 0.2H, 0.4H and 0.6H. Cement stabilization for both BCS and granular soil was done by the following percentages of cement increment; 1%, 2%, 3% and 4%. From the study, the strength improvement considering single layer reinforcement by geogrid and non-woven geotextile in BCS was 37.5% and 45% respectively. In granular material, CBR strength increased by 21% and 14% due to geogrid and non-woven geotextile respectively. Percentage increase in CBR of reinforced BCS corresponded to that of over >1% cement stabilization. To further enhance decision making between these strength development alternatives, it is recommended to advance it to cost analysis.

Keywords: Geogrid, Non-woven Geotextile, Black Cotton Soil, Granular Material, California Bearing Ratio

1. Introduction

Pavement construction over soft subgrade presents design and construction difficulties due to their low strength and compressibility nature. When such pavements are exposed to static or dynamic loading, they experience an increased rate of base material deterioration and permanent surface deformation. This often results to a reduction of both serviceability and design life of the pavement. Black cotton soil is a typical case of soil characterized by high plasticity, high free swell index and low bearing strength [1–4]. Some of the approaches commonly employed in dealing with BCS include; excavating and replacing it with suitable borrowed material, treatment with chemical stabilizers such as lime or cement, realignment of the road to avoid areas covered with BCS and minimizing moisture variations in the clay. Keeping moisture changes at minimum may involve; constructing at least 1.0 m embankment as surcharge in order to reduce swell, confinement of expansive material under a 300 mm capping using material with at least 10% CBR, processing or placing expansive material at equilibrium levels and provision of sealed shoulders [5]. BCS is widely spread in Kenya and is majorly composed of minerals like montmorillonite, vermiculite, illite and chlorite [3, 6-7]. As rapid construction of roads takes shape in the country, BCS is one of the frequent challenges encountered.

Geosynthetics have been used for various applications in pavement construction over the recent decades. Based on type of the material, intended use and manufacturing method, the categories of geosynthetics are; geotextiles, geogrids, geomembranes, geonets, geosynthetic clay liners and geocomposites [8–10]. In pavement construction, geosynthetics may be used for the following functions; separation, filtration, lateral drainage and reinforcement [11–13]. A geosynthetic may be used to perform one or more functions simultaneously when installed. However, one of the functions will likely result to a lower factor of safety which must be a value greater than 1.0 [14]. For example, the primary function of geogrids is reinforcement but they can also perform separation as a secondary function especially in the case of large soil particle sizes. It is therefore essential to determine primary and secondary functions of the geosynthetic for specific applications.

Field tests, CBR and Numerical Simulation are the major approaches that have been adopted by researchers to study geosynthetics as soil reinforcement materials. For instance, Krishna and Rao [15] investigated bearing strength characteristics of poor graded sand with inclusion of geotextile, geocomposite and geogrid. The Maximum percentage increase in the CBR values were; 103.45%, 81.15%, 143.76%, 103.68% and 81.85% for woven geotextile, non-woven geotextile, geogrid and geocomposite respectively. Charles et al. [16] investigated effect of geogrid reinforcement on CBR of natural gravel and reported an increase in soaked CBR of 12% and 35% for the two types of geogrids used. Pupalwad et al. [17] conducted an experimental study by CBR on expansive subgrade soil reinforced with three kinds of geotextiles; Nonwoven Geotextile (TS-50), Woven geotextile Poly Felt (PEC) and Woven Polypropylene Geotextile (HP-370). It was observed that placement of geotextile near to surface of the CBR mold can result to better performance as compared to other depths below. Negi and Singh [18] through CBR and numerical approach, demonstrated that woven geotextile was more effective than non-woven geotextile.

The percentage of fines in soil material can have significant influence on the bearing strength. Naeni and Mirzakhanlari [19] studied effect of geotextile inclusion and grading on bearing strength of granular soils through series of CBR tests. It was observed that the soil with a higher percentage of fines showed more improvement benefit. The influence of geogrid tensile strength and soil plasticity on CBR of soil in both soaked and unsoaked condition was investigated by Rajesh et al. [20]. In the experimental setup, geogrid was placed at mid depth of the soil in the mold for the reinforced test sections. The study demonstrated that soil plasticity, percentage of fines and inclusion of geogrid influences soaked CBR. It was also observed that low percentage of fines content and high grid capacities resulted to high CBR values.

Goudazri et al. [21] carried out an investigation on geosynthetic reinforcement of a two-layered soil test sections with geosynthetic material placed at the subgrade-aggregate base interface. From the study, the percentage increase in CBR was 21% for section reinforced with geocomposite and 24.5% for test section with geogrid. In a laboratory study carried out by MohammadReza and Nade r [22] to evaluate effectiveness of applying drawn and punched geogrids in flexible pavement, the number of load applications increased from 1.5 to 7.5. It was observed that inclusion of geogrid used in the study reduced surface rutting as well as vertical stresses at base-subgrade. In a two layered system of aggregate base overlying weak subgrade and subjected to both static and dynamic loading, a reduction in permanent deformation of up to 31% was observed. Notably, both dynamic and static loading results were comparable and in general agreement [23]. In a relatively similar approach undertaken by Park et al., the bearing capacity for a two-layer reinforcement increased to between 7.85 to 29.4 times than the unreinforced section [24].

While previous researchers have studied different aspects of geosynthetic reinforcement of pavements, there is limited research on the comparative study of reinforcement using geogrid and non-woven geotextile and chemical stabilization methods. Therefore, this study presents an experimental investigation of strength development in BCS and granular material reinforced with locally manufactured non-woven geotextile and geogrid. Besides the comparison made on the two reinforcement methods, Portland cement was also used to stabilize the same materials in order to compare strength evolution in reinforcement and chemical stabilization. The standard CBR approach is adopted in this study to assess strength development. Series of tests were carried out on neat, reinforced and chemically stabilized materials. Thereafter, a comparative analysis is presented.

2. Materials and Methods

2.1. Method

Series of experiments were done for both Black Cotton Soil and Granular soil. Particle Size Distribution, Shrinkage Limit, Plastic Index and Liquid Limit were carried out based on BS 1377: Part 2: 1990 [25]. Compaction test for BCS was done according to AASHTO T99 [26] while that for granular soil was done based on AASHTO T 180 [27]. Standard CBR tests for both neat material and the reinforced soil were done based on AASHTO T 193 [28].

Lastly, cement stabilized BCS and granular soil were also tested for CBR. Carrying out dynamic CBR using standard method for all neat, reinforced and stabilized cases was intended to enable comparative analysis in terms of strength development. The summary of the research process is shown in figure 1.

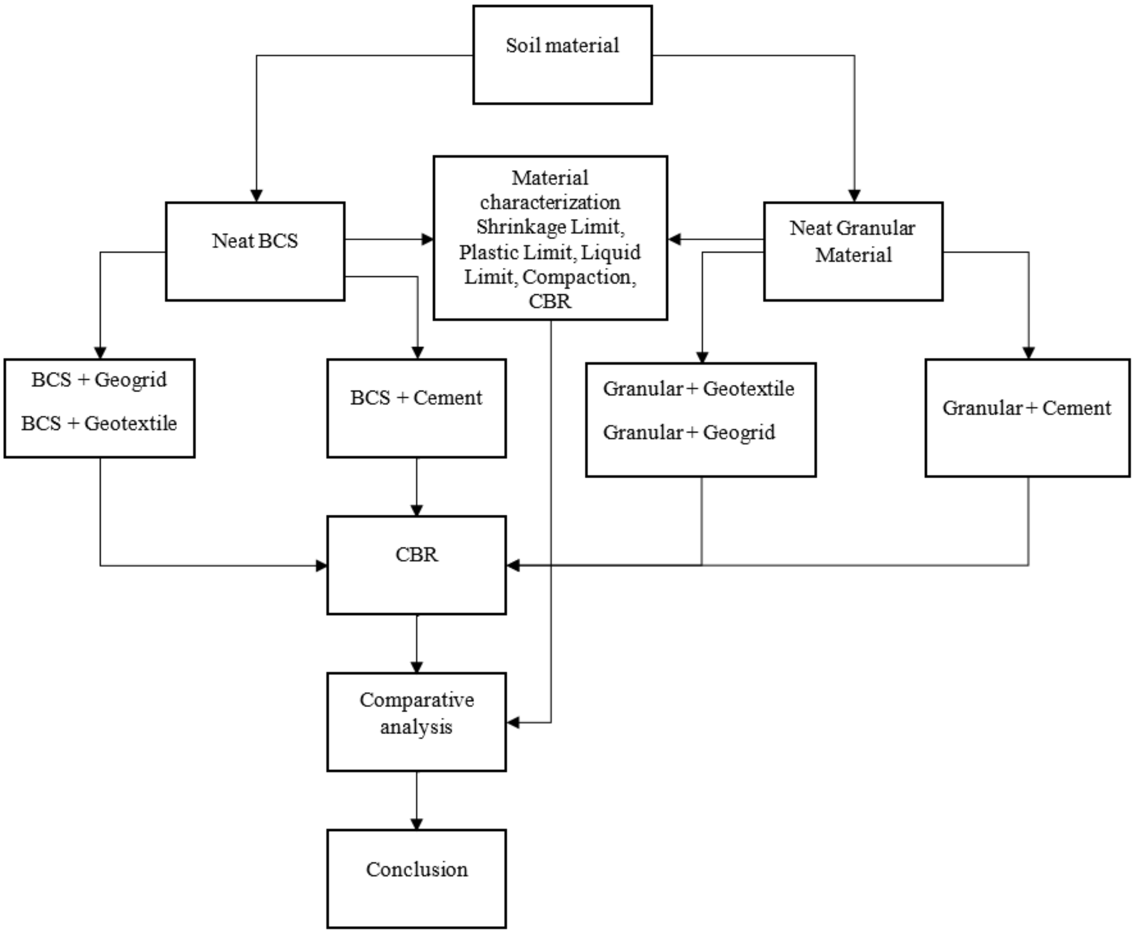

Figure 1. *Research process.*

Figure 2. *Soaked CBR samples.*

2.2. Materials

2.2.1. Black Cotton Soil (BCS) and Granular Soil

Black Cotton Soil was sampled at km 20+080 along RWC264 road in Kenya. Sampling was done below 1.5 m depth in order to exclude unwanted material such as organic matter. The particle size distribution and compaction for neat BCS are presented in figures 5(a) and 5(a) respectively. Granular soil material was sampled from km 22+020 of the same road, a borrowed material intended for use as sub-base course. Likewise, the Particle size distribution and proctor test results for neat granular material are presented in figures 5(b) and 6(b) respectively.

Figure 3. *BCS and Granular material samples.*

2.2.2. Geogrid and Geotextile

Geogrid was sourced from a local manufacturer. It was composed of monolithic polypropylene flat bars that are stretched and have welded junctions. Material properties obtained from the manufacturer are shown in Table 2.

Table 1. *Mechanical properties of geogrid.*

Mechanical property	Test standard	Unit	Value
Mass per unit area	EN ISO 9864	g/m^2	240
Maximum tensile strength, md/cmd	EN ISO 10319	kN/m	≥40/≥40
Elongation at nominal strength, md/cmd	EN ISO 10319	%	≤8/≤8
Tensile strength at 1% elongation, md/cmd	EN ISO 10319	kN/m	8/8
Tensile strength at 2% elongation, md/cmd	EN ISO 10319	kN/m	16/16
Aperture size, md X cmd	-	mm X mm	approx. 32 X 32

Non-woven type of geotextile was chosen for the study. They are made up of virgin polypropylene polymer. Its material properties from the manufacturer are presented in Table 2.

Table 2. *Mechanical properties of non-woven geotextile.*

Mechanical property	Test standard
Tensile strength -MD	EN ISO 10319
Tensile strength -XD	EN ISO 10319
Elongation at break -MD	EN ISO 10319
Elongation at break -XD	EN ISO 10319
Dynamic cone drop	EN ISO 13433
CBR Puncture Resistance	EN ISO 12236

Table 3. *Properties and Characteristics of cement used in soil stabilization.*

Characteristic/property	Description
Minimum comprehensive strength	42.5 MPa
Manufacturing specification	Manufactured to specifications of harmonized EA standard KS EAS 18-1 as adopted from EN 197-1 standards
Constituents	Gypsum, Limestone and Clinker
Technical name	Portland Cement CEM II

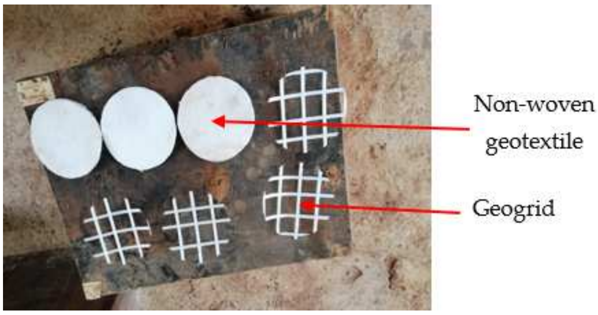

Figure 4. *Geogrid and Non-woven geotextile materials.*

2.2.3. Cement

Portland cement of 42.5 MPa minimum strength was used for stabilization. Table 3 summarizes its characteristics as provided by the manufacturer.

3. Results and Discussion

3.1. Particle Size Distribution

The particle size distribution of BCS and granular soils are presented in figure 5. Based on the grading curve, BCS is dominantly fined grained.

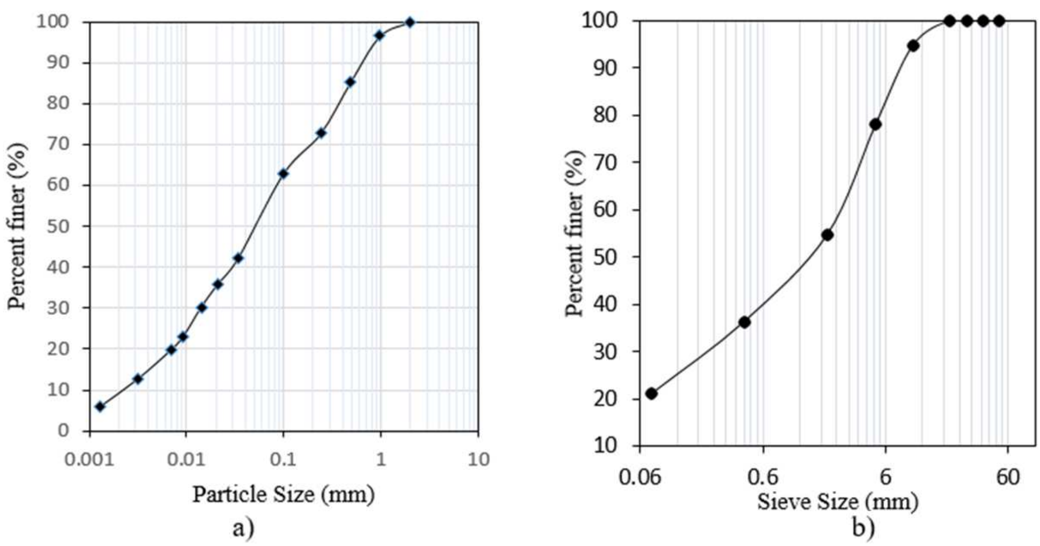

Figure 5. *a) Grading curve for BCS; b) Grading curve for granular soil.*

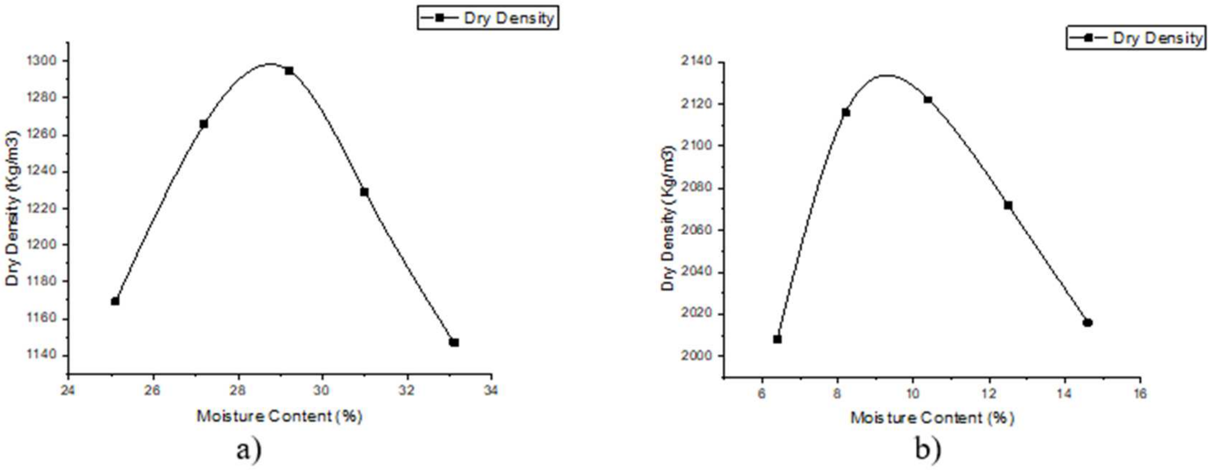

Figure 6. *a) Compaction curve for neat BCS; b) Compaction curve for neat granular soil.*

3.2. Compaction Test

Table 4. *Atterberg Limits of BCS.*

Property	Neat Black Cotton Soil
Liquid Limit	70.7
Plastic Limit	35.7
Linear Shrinkage	16.4
Plasticity Index	35
Plasticity Modulus	1680

For neat BCS, a Maximum Dry Density (MDD) of 1282 Kg/m^3 at Optimum Moisture Content (OMC) of 29.0% was obtained as shown in the compaction curve in figure 3a. In the case of granular material, MDD achieved was 2122 Kg/m^3 at OMC of 10.4%.

3.3. CBR and Atterberg Limits of the Neat Soil Materials

Neat BCS achieved a CBR of 4 tested after 4 days' soak. Based on Design Guideline for Low Volume Sealed Roads in Kenya, this material is classified under subgrade class S1 with a range of CBR from 2 to 5 [5, 26, 29]. On the other hand, neat granular material attained a CBR of 55.

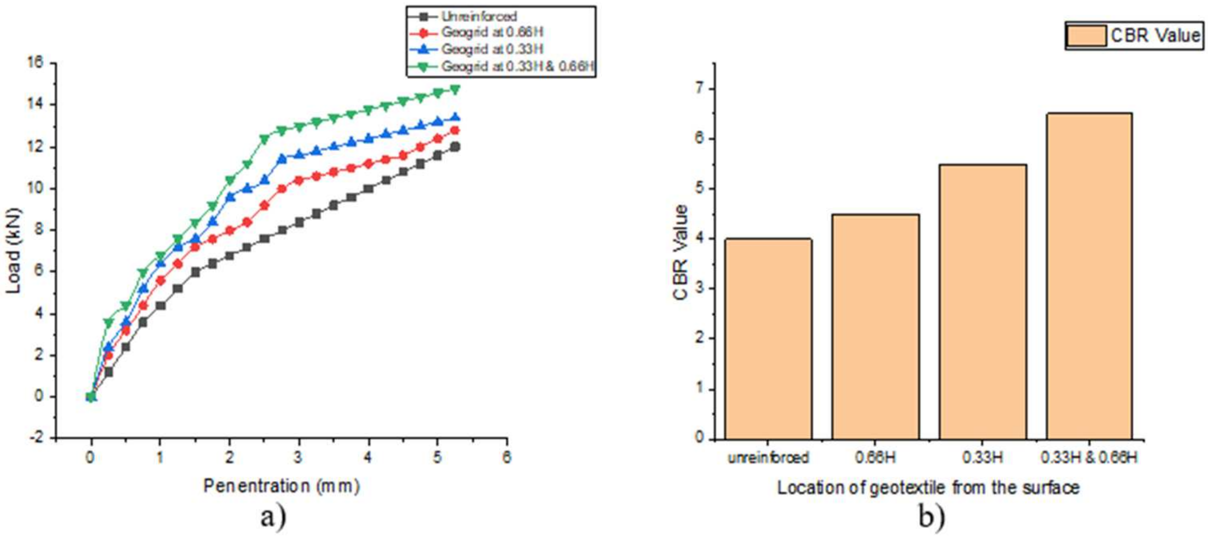

Figure 7. *a) Load-Penetration curves for BCS reinforced with geogrid; b) CBR values for BCS reinforced with geogrid.*

3.4. Geosynthetic Reinforcement

3.4.1. Reinforced BCS

The highest percentage increase in CBR was 62.5% for the BCS reinforced with geogrid, this was achieved by double reinforcement. In the case of single reinforcement, maximum percentage increase of 37.5% in CBR was attained at 0.3H placement location.

The CBR results in Figure 8 shows significant improvement of strength in BCS due to reinforcement with non-woven geotextile. While a 45% increase in CBR for single reinforcement was achieved at 0.3H, 25% increase was observed at 0.6H. Double reinforcement resulted to 63% increase. It can be seen that non-woven geotextile performed relatively better than geogrid in the case of single layer reinforcement. However, the difference in performance for the two types of geosynthetics was negligible when two layer of reinforcement were used. It can be noted that in both cases, higher CBR values were recorded at 0.3H in comparison to 0.6H.

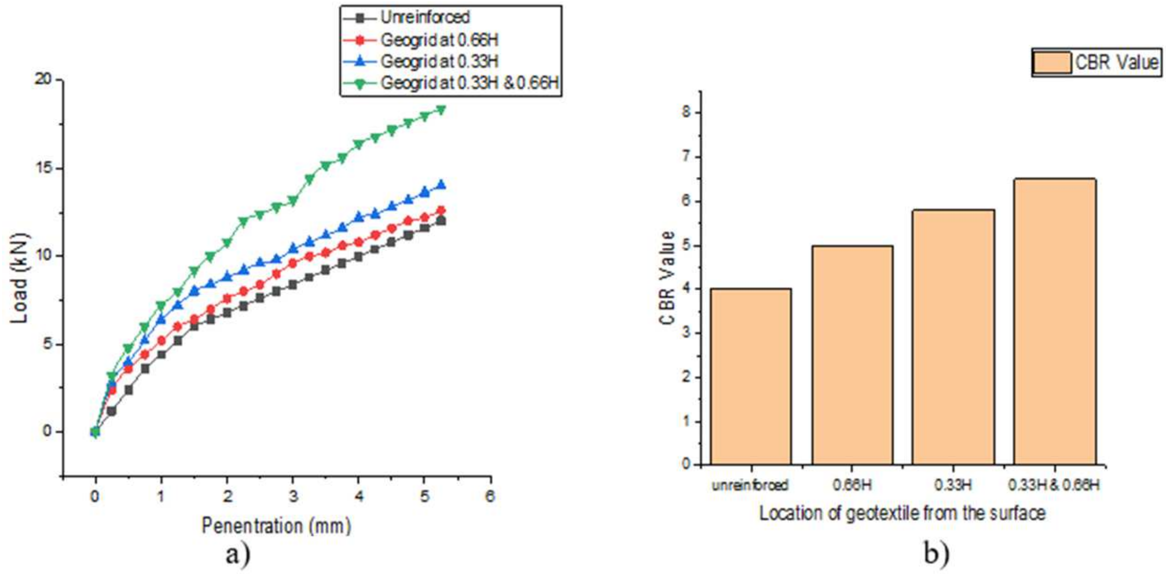

Figure 8. *a) Load-Penetration curves for BCS reinforced with non-woven geotextile; b) CBR value for BCS reinforced with non-woven geotextile.*

3.4.2. Reinforced Granular Material

Single reinforcements only were carried out for granular soil. Figure 9 shows the CBR values for the case of geogrid reinforcement. Improvement observed was 5.5%, 14.5% and 21.8% for 0.6H, 0.4H and 0.2H placement locations respectively. Likewise, the CBR for granular soil reinforced with non-woven geotextile are presented in figure 10. The percentage increase in CBR achieved for 0.6H, 0.4H and 0.2H were 4.5%, 5.5% and 14.6% respectively. The results show a relatively better performance of geogrid than non-woven geotextile with a margin of about 5%. This may be attributed to the interlocking of soil material in the apertures of geogrid material and further confinement. Under loading condition, the soil material will tend to move in the lateral direction in the case where there is no restraint. Since geogrid is stiff in tension, it is able to limit extensional lateral strains developed in the soil material resulting to improved shear strength and stiffness [11–13].

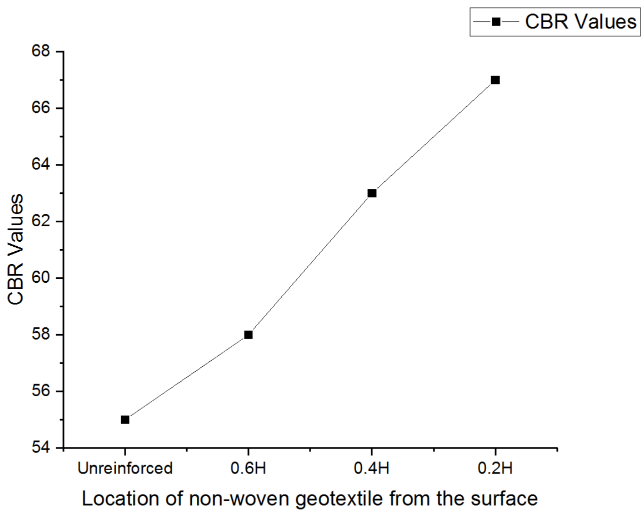

Figure 9. *CBR values for granular reinforced with geogrid.*

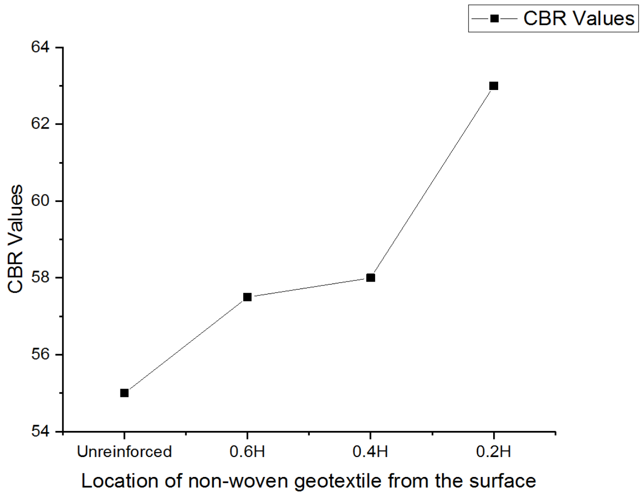

Figure 10. *CBR values for granular material reinforced with geogrid.*

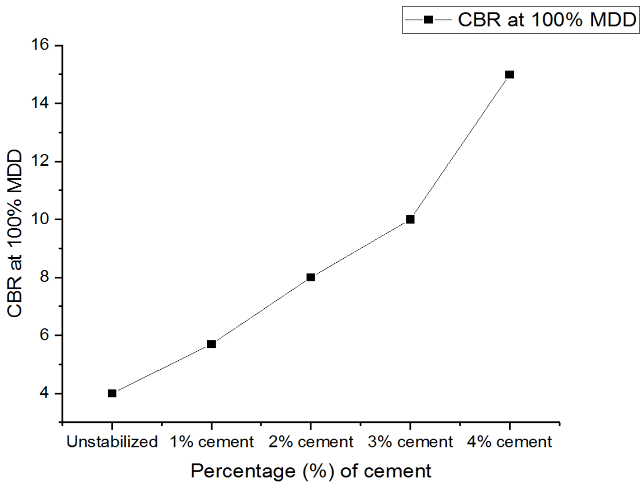

Figure 11. *CBR values at 100% MDD for cement stabilized BCS.*

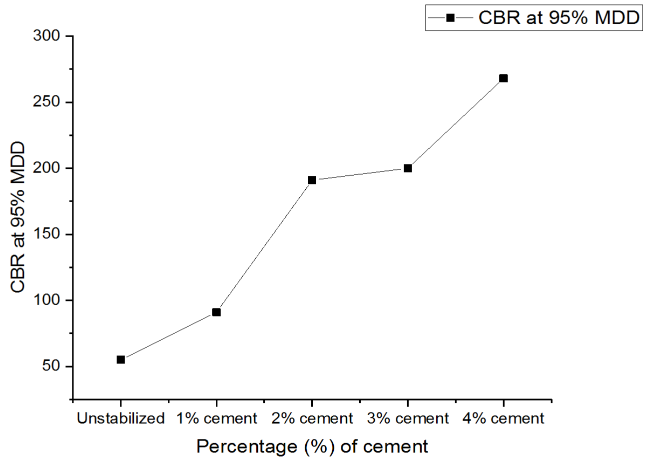

Figure 12. *CBR values at 95% MDD for cement stabilized granular soil.*

For geotextiles, the improvement in CBR can be attributed to tension membrane effect. When the test sample is exposed to loading, the soil material undergoes deformation transferring significant stress to the geosynthetic material. As the geotextile deforms into a concave shape, tension develops due to the vertical strain. This helps in load distribution and reduction in vertical stress.

3.5. Chemical Stabilization of BCS and Granular Material

Tests on cement stabilized BCS and granular soils were carried out in order to provide a basis for comparative analysis with the traditional chemical stabilization method in terms of strength development. Standard CBR tests were done with variation of cement content as from 1%, 2%, 3% and 4%.

Figure 11 shows strength development of cement stabilized BCS. From cement percentage of 1% to 4%, the CBR achieved were 6, 8, 10 and 15 respectively. This represents percentage increase of 42.5%, 100%, 150% and 275% respectively. Similarly, strength improvement in cement stabilized granular soil is presented in Figure 12. The percentage increase in CBR were 65.4%, 247.2%, 263.6% and 387.2% for cement content of 1%, 2%, 3% and 4% respectively. Comparison is made in consideration of single reinforcement condition. Whereas percentage increase in CBR for reinforced BCS corresponded to that achieved by >1% cement stabilization, the granular material attained percentage increase in CBR that was <1% cement stabilization.

4. Conclusion and Recommendation

In this study, series of CBR tests were carried out on BCS and granular soil under soaked condition. The tests comprised neat and reinforced samples. Reinforcement materials used were non-woven geotextile and geogrid materials. The study aimed at investigating strength development as a result of reinforcement by geosynthetic materials. Moreover, CBR tests were done for cement stabilized samples and a comparative analysis was conducted. Based on the series of tests performed on neat, reinforced and cement stabilized samples, the following conclusions were drawn;

For single layer reinforcement, BCS attained highest percentage increase in CBR of 45%. This was due to reinforcement by non-woven geotextile as shown in figure 8. Similarly, geogrid resulted to percentage increase of 37% as observed in figure 7. On the other hand, double layer reinforcement in BCS contributed to a percentage increase of 62% and 63% for geogrid and non-woven geotextile. The difference in strength improvement for the two reinforcement materials was negligible for multilayer case.

In granular material, CBR strength increased by 21% and 14% due to geogrid and non-woven geotextile respectively. The effectiveness of geogrid in granular material may be attributed to interlocking.

Percentage increase in CBR of reinforced BCS corresponded to a percentage increase achieved by stabilization of over 1% cement. On the other hand, the percentage increase in CBR of reinforced granular soil was lower than that attained by samples stabilized by 1% cement.

In regard to placement location of the reinforcement material, there was a general improvement in CBR strength for placement closer to the surface. However, this is based on the selected placement locations used in the study.

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