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STABILIZATION OF SUBGRADE USING GEOSYNTHETICS

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ABSTRACT

Roadways with expansive clay subgrades and exposed to environmental pressures have lately seen the usage of geosynthetics for base course stabilization. The environmental longitudinal fractures that develop as a consequence of differential settlements between the highway sides and its centerline are a direct outcome of the substantial and uneven variations in moisture content that occur within clay subgrades as a result of seasonally wet and dry cycles. Quantifying the field performance of several sites, this article evaluates the efficacy of geosynthetics in stabilizing the base course of highways built on expansive clay subgrades. The assessment includes five complete field projects that were tested under real-life traffic and environmental conditions. By measuring the occurrence and severity of longitudinal cracks as well as the reduction in base course stiffness, the long-term performance of both the geosynthetic-stabilized and control sections could be assessed. The subgrade's property determines the road's performance. Soil stabilization using locally accessible geosynthetics is the subject of this research. Here we see Geotextiles and Geogrid put to work as geosynthetics. Soil was compacted to an ideal moisture content and maximum dry density before CBR tests were carried out. On the same soil that was reinforced with different types of geosynthetics, the changes in CBR value were examined. Therefore, the study aims to recommend the best cost-effective and performance-enhancing geosynthetic for subgrade stabilization.

Keywords: Geosynthetics, Geogrid, Geotextile, Expansive Clay, Subgrade, California Bearing Ratio (CBR).

1. INTRODUCTION

Geosynthetics are game-changers in the ever-evolving world of contemporary engineering and construction, where they solve a wide range of problems and put an end to antiquated methods. According to [10], "geosynthetics are innovative and versatile solutions that change traditional methods and address several problems in the current engineering and building industry." Significant discoveries and turning moments in the history of geosynthetics may be traced back. When conventional construction materials and methods failed, geosynthetics stepped in to fill the void. They started off as supplementary materials but have now evolved into mainstays of several building kinds [7]. Soil stability, erosion control, and environmental protection were the first impetuses for the development of geosynthetics, which began in humble origins. Numerous groundbreaking advancements have marked the historical progression of "geosynthetic materials, including geotextiles, geomembranes, geogrids, and others" [17][15][5][34][36].

As to [27], geotextiles may be defined as continuous sheets made of woven, non-woven, knitted, or yarned materials. These sheets are both flexible and porous; they look like cloth. Each element of a geogrid has an equal number of holes cut into it, both longitudinally and transversely. Rather thick three-dimensional networks made of polymeric sheet strips are known as geocells. Geomattresses are deep geocell layers that are sometimes formed by linking 1/2 meter to 1 meter wide polyolefin geogrid strips with vertical polymeric rods. According to [27], "many environmental protection projects make use of geomembranes, geonets, geocomposites, geosynthetic clay liners, and geopipes." Continuously flexible sheets made of one or more synthetic materials are known as geomembranes. As vapor barriers and liners for fluid or gas contaminants, they are reasonably impervious. "One layer of geotextile or prefabricated bentonite geomembrane are examples of geosynthetic clay liners." Geonets are constructed by means of a continual acute angle intersection between two sets of coarse, parallel, extruded polymeric strands. "Two or more types of geosynthetics, such as geotextile and geonet or geotextile and geogrid, are combined to form geocomposites" [36].

Geopipes are pipes with holes in them that allow liquids or gas to escape. Because geosynthetics are man-made, they contain many of the latest innovations in the polymer and engineering plastics sectors. The findings from the study prompted the creation of more effective geosynthetic building technologies and designs [27][32]. Modern advancements in both materials and design have made it easier for engineers to tackle formerly insurmountable obstacles and build buildings in historically unfavorable environments. For almost twenty years, ingenious constructors stabilized roadways using logs or tree limbs. Subgrade soil can be stabilized using various locally available materials like rice husk ash (RHA), sugar cane bagasse ash (SCBA), and cowdung ash. After stabilization, the natural soil acts as an intermediate plastic clay, lowering the dry density and increasing the ideal moisture content [33].

Important developments, such as the creation of woven geotextiles in the 1950s, have allowed geosynthetics to expand their scope and use [13]. From niche applications to mainstream use, geosynthetics have quickly gained traction in the construction industry as a cost-effective, environmentally friendly alternative to traditional materials. Geosynthetics' continued significance in satisfying evolving engineering demands is shown by its relevance today. Among the many novel applications for these materials, there are landfill liner systems [12][20], “embankments, containment barriers, pavement drainage systems, slope stabilization, shallow foundations, and barriers in earthen dams” [9][4]. According to [8], “geosynthetics are indispensable for modern construction workers due to their versatility, resilience, and usefulness in a wide range of applications.”

There has been a meteoric rise in the variety of geosynthetic uses in road systems throughout the last few decades. As an example, they may be used to stabilize highway subgrades and base courses by acting as a geosynthetic that separates, filters, drains, and stiffens [36][37]. To improve the pavement's performance, base course stabilization is applied by placing a geosynthetic either inside or on top of the base course layer. This is done to reduce permanent deformations and lateral restraint of the unbound aggregates under traffic loading [16]. Incorporating geosynthetics for base course stabilization has previously been pursued in roadway design with the goals of (1) reducing the base course thickness needed to support traffic loads for a given design life and (2) increasing the roadway design life, also for traffic loads, for a given base course thickness [11]. While geosynthetic stabilization of unbound aggregates may have substantial benefits in reducing environmental load issues, these advantages have not yet been well studied or measured.

Indeed, geosynthetics are finding an increasing variety of uses in road construction. The following are included in it [37][36]: stabilizing unbound aggregate layers, stabilizing soft subgrades, reducing layer intermixing, stabilizing structural layers with respect to moisture, and mitigating distress caused by shrinkage and swelling of subgrades. It was previously thought that three common mechanisms—lateral restraint, increased bearing capacity, and membrane tension support—were responsible for two of these road applications, the stabilization of unbound aggregate layers and soft subgrades, respectively [14].

Figure 1(a) shows that lateral restraint works by assuming that the geosynthetic can reduce or eliminate aggregates' lateral movement propensity. The pavement's surface would furrow and become unusable as a consequence of this movement. [37] predicted that geosynthetics with sufficient tensile stiffness and strong interface shear resistance would prevent aggregates from moving laterally. Figure 1(b) depicts an alternate geosynthetic process where the tensile forces of the geosynthetic material intersect at the spot where the bearing capacity failure critical shear surface originally was. Here, the geosynthetic would make the critical shear surface go in an opposite direction, strengthening the system against bearing capacity failure. Finally, a membrane-type support can be shown in Figure 1(c) where the geosynthetic's vertical component of the membrane tension partially resists the vertical wheel load. Tension will develop in the geosynthetic to partially sustain the vertical traffic loads as long as appropriate vertical deformations have occurred and the geosynthetic has not achieved its tensile strength.

The California Bearing Ratio (CBR) test is used to find the subgrade's strength. It evaluates the ratio of test load to standard load at precise penetration using a standard plunger. The mechanical strength of materials used in road building is often determined using this test. Because of its ease of use, the CBR test has become the gold standard for unpaved roadway design [25]. The use of geosynthetics to either raise (or avoid a time-dependent reduction in) the stiffness of the unbound aggregate layer is the ultimate definition of the stabilization of unbound aggregates as it pertains to highway applications. In contrast to geosynthetic stabilization applications for soft subgrades, “where the tensile strength is crucial, in this case the restricted stiffness of the aggregate-geosynthetic composite, under relatively modest displacement,” is the most important characteristic [37]. The geosynthetic tensile strength is usually linked to uses that need relatively big deformations or displacements [26]. [37] state that the lateral restraint mechanism may be best described by focusing on stiffening, a geosynthetic function that involves the development of tensile forces to regulate the deformation of the soil-geosynthetic composite. As a matter of fact, according to [21], the main and only function that results in reduced lateral displacements and enhanced confinement of the soil-geosynthetic composite in the base layer is stiffening. Although the geosynthetic function described here is "stiffening," it is worth mentioning that practitioners in the field have also used the word "stabilization." Here, geosynthetic stiffening is seen as the primary function for the stability of unbound aggregates, which is a highway application [37]. Although the geosynthetic might be laid in the base layer, it is usually put at the interface of the stabilized base and the subgrade to make it easier to build. In order to stabilize unbound aggregate layers, it is common practice to mobilize relatively modest geosynthetic stresses and to have a high level of contact between the geosynthetic and the base material above it. Deformations are at a level that is in line with the projected shallow rutting depths on paved roads [30].

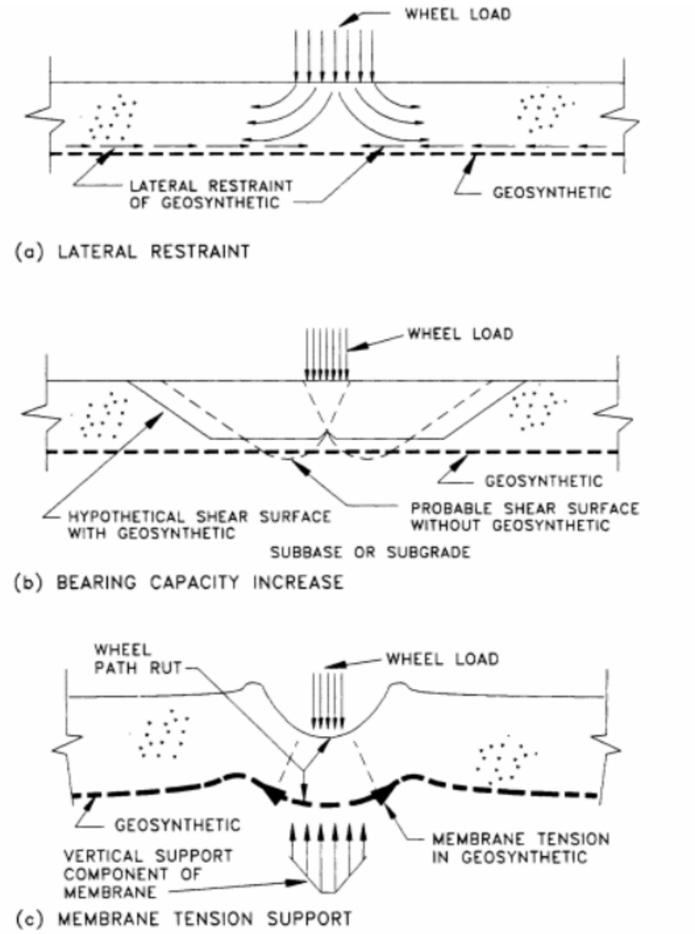

Figure 1. "Possible mechanisms provided by geosynthetics in roadways" [14].

A number of studies have pointed to geogrid's potential as an upgrade material for pavement sections and poor subgrades. Three soft clay samples with different plasticity levels were discovered by [23] to have significantly higher wet and unsoaked CBR values when reinforcing with geogrids was applied. Geogrid reinforced on weak subgrade material was shown to improve by [6] using numerical analytical techniques. For road rehabilitation and building projects over deficient pavement subgrades, geogrid stabilization of subgrade soil is currently the most effective and cost-effective method [1]. The purpose of this project is to study how nonwoven geotextiles work and how they impact the soil's shear strength characteristics. Due to their low density and portability, they find primary application in the following areas: filtering (to stop pipes from leaking), drainage (to stop water from flowing into the subgrade and lower hydrostatic pressure), and separation (to stop different materials from migrating into pavements). One way to find out how it affects soil shear characteristics is to do a direct shear test, which involves placing geotextiles with different shear box sizes on the soil's surface and subsurface and then comparing the findings to those of regular soil.

2. BACKGROUND & RELATED WORKS

Premature aging and road building failure may occur on bound or unbound pavements due to their exposure to repetitive, high, concentrated stresses. According to [22], highways should be built on top of robust native soil deposits. The surface of the road is affected by the fill material's strength and the subgrade underneath it. The subgrade is the basis of the pavement, thus it is important that the soil used to build it has a suitable CBR value to withstand the traffic loads that will be applied. Nevertheless, due to inappropriately low CBR values, not all subgrades can fulfill this requirement. The subgrade must be sufficiently strong to withstand the pavement's weight, even in the face of extreme weather like floods or heavy rains [24].

Pavement thickness rises with a weaker subgrade, which in turn drives up the cost, and natural soil isn't very strong in a lot of places throughout the world. When the moisture level in the subgrade soil rises, either below saturation or beyond, it weakens the soil's shear strength due to less aggregate contact and interlock, which in turn causes rutting in road pavements [2]. To prevent overall rutting and ensure correct construction of the base course gravel layer, soil stabilization may be required when excavating and replacing the soils is not a cost-effective option. Here, geosynthetics—planar polymeric materials—have shown to be invaluable in reinforcing and separating the underlying soils, a process known as subgrade stabilization [22].

One process that causes the mechanical characteristics of aggregate base materials to deteriorate is the lateral displacement of aggregate particles, which happens under frequent traffic stress [19]. Aggregates inside the base layer may cause lateral displacements, as seen in Fig. 2(a). Since the aggregate's lateral stresses (i.e., confinement) are reduced as a consequence of the displacements, the modulus of the base material may be dramatically affected [36]. The base layer's relatively high modulus is the most distinguishing feature of a multi-layer pavement system; this property allows for a more uniform distribution of vertical loads and, in the end, reduces the maximum vertical stresses operating at the base-subgrade contact interface. The initial modulus in the aggregate is degraded by traffic, leading to higher contact pressures at the base-subgrade interface and, ultimately, deep rutting in the highway construction.

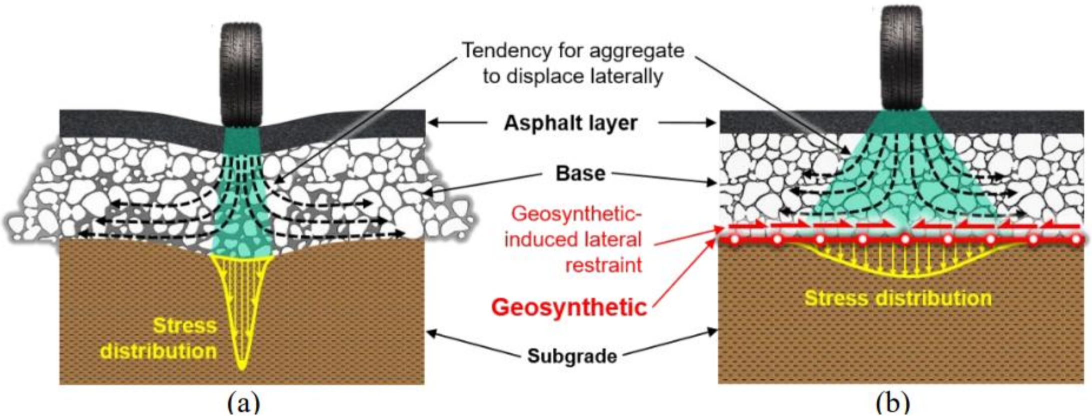

Figure 2: "Use of geosynthetics to stabilize unbound aggregate layers in roadways" [36].

As seen in Figure 2(b), the geosynthetic addition serves to limit lateral movement. Shear stresses in the aggregate base are converted into tensile stresses in the geosynthetic as a consequence of interactions between the two materials [3]. The geosynthetic's tensile stresses boost the aggregate's shear strength by enclosing the base course material more tightly. Lateral constraint is caused by the soil-geosynthetic interface's frictional and interlocking properties. The correct selection of geogrid aperture and base material particle sizes is crucial when using geogrids to stabilize a road base. However, it is important to ensure that geotextiles used for base stabilization have the appropriate interface frictional characteristics [28]. The large dispersion of traffic loads and the relatively modest vertical stresses operating at the base-subgrade contact are both caused by the relatively greater stiffness of the geosynthetic-stabilized base, as seen in 2(b) as well.

"Reinforcing paved and unpaved roads using geosynthetics may increase subgrade bearing capacity or decrease base/sub-base thickness," according to research by [35]. With paved roads, geosynthetic reinforcement is laid at the interface of the subgrade and sub-base layers; with unpaved roads, it is put at the base/subgrade contact. This increases the subgrade bearing capacity. Pavements that are not reinforced, "as opposed to those that are reinforced with geosynthetics, place greater strains on the subgrade." Particularly in the direction of traffic and on thin pavements, [18] demonstrated that geogrid effectively reduced granular material shear deformation. They also found that "thick-base layers would have better pavement performance with only one geogrid layer inserted in the top one-third of the layer."

Research by [29] on the use of coir geotextile as a reinforcing agent revealed significant behavioral changes, suggesting that this material might be a great and affordable option for strengthening rural roads' subgrade. Soils strengthened with coir geotextile outperformed those without. In comparison to an unreinforced subgrade, it also aids in reducing the subgrade's permanent deformation. Soil samples that have a geotextile with a greater tensile strength are less likely to distort and have a higher load bearing capability. The results show that CSB-400450 (Coir Stitched Blanket) is the superior option among the six types of reinforcing.

Adding jute fiber to soil raises its CBR value, as shown by [31]. Soil CBR value rose as jute fiber concentration increased. Additionally, they discovered that it is not feasible to prepare similar soil samples for CBR tests with a fibre level higher than 1% by dry weight of soil, and that 1% was determined to be the optimal fibre content. Soil CBR values are proportional to fiber diameter and length. At a fiber concentration of 1%, for fibers with a diameter of 2 mm and a length of 90 mm, the CBR value improved by 24% compared to plain soil.

3. MATERIALS AND METHODS

Soils that are clayey, organic, and lateritic were the materials used in this experiment. We took three soil samples for the lab testing. The Delhi-Sirsa Highway provided the organic and clayey soils. To keep the materials from drying out in the air, they were wrapped in polythene. The samples' physical and engineering qualities were determined by the analysis.

Table 1: Properties of Laterite Soil

Sl. No	Property	Test	Value	Remarks
1	Specific gravity	Pyconometer	2.65	Range:2.6-2.8
2	Compaction	Modified proctor test	OMC-25% Max. dry density:1.56x10^3 kg/m^3	-
3	Permeability	Constant head permeability test	K=0.105mm/s	Coarse & medium sand
4	CBR	CBR Test	$CBR_{2.5}$=7.13 CBR_5=7.09	Medium
5	Particle size distribution	Sieve Analysis	D_{10}:520microns; C_u=8.26 C_c=1.003; gravel=38.4% Coarse=22%; Medium sand=31% Fine sand=7%; Silt and clay=0.7%	Well graded

A company in Punjab, India, called Singh Coir Manufacturers, supplied the geotextiles used in the project.

- Standard for geotextiles—H2M5
- Weighing in at 0.740 kg/m
- The tensile strength is 10.4 C, and the mesh opening size is 9 x 9.

Grogrid Manufacturers, Punjab, India Ltd. supplied the geogrids used in the project.

- Geogrid design information-Biaxial geogrid.
- Polyester is the basic material.
- Impact force: 35 kN
- Color: jet black
- Mesh opening dimensions: 2.5 mm x 3 mm.

Figure 3: Geosynthetics used (a) Woven Geotextile (b) Geogrid

To do the wet sieve analysis, use a 75µ sieve and put around 200 g of soil in it. Rinse it well with clean water until clear water comes out, and save the leftover soil for oven drying. A motorized sieve shaker or human hands are used to separate the residual particles. What IS sieves were utilized? 500µ, 425µ, 300µ, 212µ, 150µ, 75µ; 4.75mm, 2.0mm, 1.0mm. Put the soil into a mechanical sieve shaker and let it shake for ten minutes. For every sieve, you should be able to keep 1g of material. The portion of soil that goes beyond 75µ is mostly clay and silt, whereas the portion that stays above 75µ is made up of sand, whether it's coarse, medium, or fine. Particles in the soil that are larger than a 2.0 mm sieve are called the gravel fraction.

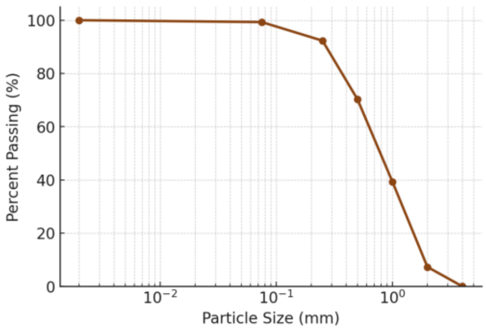

Figure 4: Particle size distribution curve of Laterite soil

A mechanical device that typically serves as a liquid limit apparatus is a cup with a mechanism that can be adjusted to raise or reduce the liquid level to a certain height, in this case 10mm. Two common instruments are groovers. You will also need a thermostatically controlled drying oven with a temperature range of 105˚C to 110˚C degrees Celsius, a 200 gram capacity balance with a 0.01 g sensitivity level, moisture containers, an evaporating dish, and a spatula. A homogeneous thick paste is made by combining 150 g of dry soil sample, which has passed through a 425 micron IS filter, with distilled water and mixing it well in the evaporation dish. To promote constant moisture distribution in clayey soil, keep the paste in an airtight container for as long as required, up to 24 hours. A precise free fall of 10 mm into the cup is configured for the liquid limit device. Everything has been cleaned, including the cup and the grooving tools. In the test run, the paste should be firm enough that it takes thirty to thirty-five blows or drops of the cup to seal the standard groove for a specified length of twelve millimeters at the bottom. Pressing down with the spatula, a portion of the soil paste is added to the device's cup above the lowest part to form a flat surface. To trim the soil paste to a maximum depth of 10 mm in the cup, use strong strokes of the spatula. After dividing the soil sample in the cup along the diameter and center line of the cam, a clean, crisp groove may be achieved by using strong strokes of the grooving tool. Any soil will work with the curved grooving tool, but clayey soils devoid of sand and fiber materials are the only ones that the V-shaped grooving tool is meant for. By turning the crank at a speed of two revolutions per second, the test cup is raised and lowered in accordance with the prescribed procedure. This may be done manually or electrically, depending on the kind of control system used. This process is carried out until the two halves of the dirt cake are gently pushed under the blows and touch at the base of the groove for a distance of 12 mm. At this stage, the number of blows administered is recorded. To conduct the next experiment, we will mix the soil paste in the dish with a little amount of water, stir it well using a spatula, and then transfer the required amount of paste to the test cup. If you add more water to the paste, you won't need as many blows to seal the groove. In order to get a range of readings between 15 and 35 for the number of blows, the procedure is performed three or more times with slightly higher water contents each time. The number of blows is then recorded.

4. ANALYSIS AND RESULTS

A 150 gm test sample was collected from the site and passed through a dynamic cone penetrometer (DCP) at 425 µ for the liquid limit test (wL). Based on the data in figure 5, the liquid limit (wL) is 60%, which is equivalent to a penetration of 20 mm.

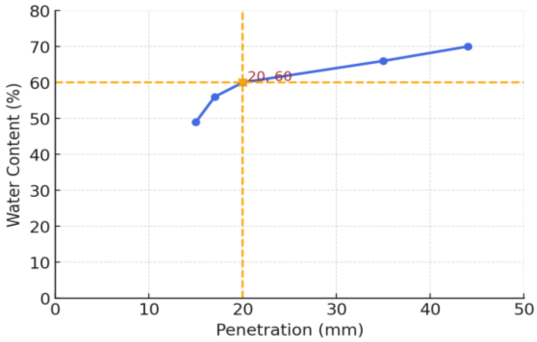

Figure 5: Liquid Limit curve (Cone Penetration)

The testing procedure remains same across all cases, with the exception of the incorporation of geosynthetic layers into the soil and the varying depths of compacting inside the mould. The geotextile and, therefore, the geogrid were cut into exactly round pieces to suit the mold. Prior to inverting the mold for cosmic microwave background and CBR testing, layers were positioned above the main, hence the third, layer in order to compress the soil, which might eventually become the top of the second and fourth layers. It is anticipated that geosynthetics will gain popularity and eventually replace more traditional materials in many different contexts. It is a useful tool for environmental engineers working on landfill projects. Additionally, it has many applications in the building of railways, including protection, drainage, anti-seepage, antifiltration, and reinforcement. Subgrade filtering made use of needle punched staple fiber nonwovens.

Table 2: CBR Test

Penetration (mm)	CBR (plain soil)	CBR GG(40×40)	CBR (GT)
2.5	10.571	22.020	13.2145
5.0	9.9843	21.143	12.9200
7.5	9.6368	20.880	12.3900

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10.0	9.4880	20.115	12.1440
12.5	9.3870	19.780	12.0700

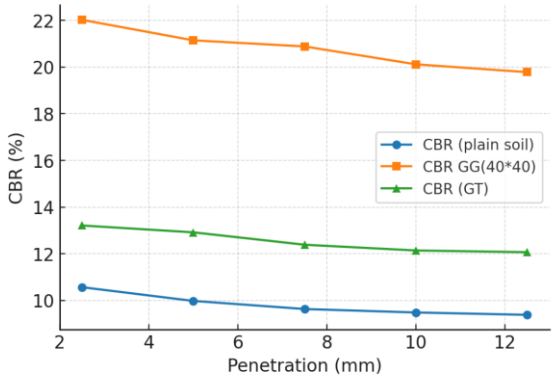

Figure 6: CBR-Peneteration graph

Figure 7 shows the cumulative blows with depth profiles (from one set of test locations) and the DCP-CBR profiles for all four sections three months after construction and in the spring. The results of the CBR testing conducted in October 2024 and April 2025 on the subbase and subgrade (top 12 in.) layers are shown in the figures. Figure 6 shows the average CBR of the subbase layer tested in October and April, based on three measurements per test segment. Prior research confirms the results, The study found that if the road is not maintained frequently due to budgetary concerns, the service and function of the road would be affected [38]. Pavements that incorporate geotextiles have a longer lifespan, need less maintenance, and have a thinner system overall. Because of their superior puncture resistance, woven geotextiles, when placed between a soft subgrade and a base course, enhance the performance of flexible pavements. The results of an experimental survey on vertical stress measurements were examined in this work [39]. Four different geotextile deployments, including horizontal and vertical ones, were employed in the research. It also measures the force that vehicles apply to virtual pavement layers. There were notable variations, but the horizontal treatment yielded the lowest pressure. Mittal Ayush and Shukla Shalinee Research by [40] found that the subgrade soil, which forms the pavement's base, has a significant impact on the pavement's performance. The environmental friendliness, uniformity across soils, cost- and time-saving benefits, and general attractiveness of geo synthetic material are driving its rising popularity. The research carried out compaction, soaking, and UCS experiments using biaxial geogrid and non-woven geotextile, both of which were authorized by the Indian Roads Congress.

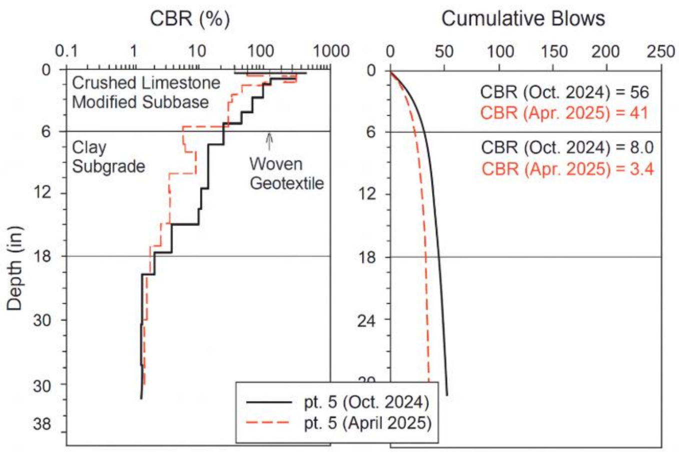

Figure 7: DCP-CBR and cumulative DCP blows with depth profiles

5. CONCLUSION

Using Geogrids for pavements in Granular soil may reduce the layer thickness by about half of the original depth, as the CBR values for Geogrids roughly doubled for penetrations of 2.5mm and 5mm in Granular Laterite soil. Granular soil has higher CBR values. Because sands tend to have a larger percentage of coarse grains compared to soils that are more fine-grained and clayey, this was the result. The use of Geogrids 2.5x3 to fortify laterite soil resulted in a tripling of the soil's strength. For the same amount of traffic, these Geogrids for Laterite Soils formats may be used to construct low-volume roads at a lesser cost. Red laterite, marine clay, and laterite soil are all clayey soil types that have shown positive responses to the Geotextile, in contrast to sandy soils. The non-woven Geotextile was compressed when the soils were subjected to the load. Soils that are clayey and have a high moisture content may be treated and reinforced using geotextile. The soils' high clay content made them stiff and boosted their load bearing capability, and the fact that the Geotextile absorbed water from the soils also had a role.

The CBR tests were carried out by positioning the geosynthetics at varying heights on the specimen. It was discovered that the ideal height for geotextiles was determined to be H/4 from the top of the specimen, while for geogrids, it was 3H/5 from the bottom. Therefore, it may be inferred that the soil's maximum strength was achieved with the geogrid placed 3H/5 from the specimen's base. Use of geogrids occurs when no other locally accessible economically viable soils are suitable. Additionally, when there is a buildup of moisture, the sand particles should not flow, therefore the soil around the sand layer should be harder and have a high fines content. This will provide the groundwork for future studies on how to economically build pavements utilizing different reinforcing technologies on subgrade, base, and sub-base soils that are weaker. We are planning to use Geocells to contain sands and look at ways to prevent clayey soil from expanding as part of our future study. Furthermore, woven Geotextiles will be used to evaluate how they stack up against Geogrids and non-woven Geotextiles in terms of cost-effectiveness and CBR value increase.

The goal of this study was to determine the relationship between the field performance of geosynthetics and their easily accessible features as a means of subgrade stabilization. Although this study did not aim to compare all material parameters that affected the performance of each test section, the empirical data suggests that tensile strength at 2% axial strain and, to a lesser degree, 5% axial strain (which indicates the geosynthetic's stiffness) in the cross-machine direction of the geogrids significantly reduces rut formation under these conditions. In order to determine which geosynthetic material qualities are most important for stabilizing poor subgrade soils, more study is required.

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