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Improvement of Soft Subgrade Using Geosynthetics: A Dynamic Cone Penetration Test Investigation

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Abstract— ***Unpaved roads constructed on weak subgrade soil, rural areas, semi urban areas and mining areas generally face problems such as rutting, differential settlement, and reduced service life under repeated traffic loading. Improving the strength and stability of these roads are an important challenge in pavement construction. The present study investigates the effect of geosynthetic reinforcement on the performance of unpaved road using the dynamic cone penetration test. This research focuses on estimate the improvement in penetration resistance and load-bearing capacity of reinforced soil compared to unreinforced soil. In this study poorly graded sand (SP) was used as the subgrade and Geotextile and geogrid were selected as reinforcement. Laboratory model tests were conducted in a steel tank. Reinforcement layer was placed at 50 mm and 100 mm depth, within the soil, and DCPT was carried out to measure the penetration characteristics of the soil. The geogrid reinforced subgrade shows an increase of 300 % cone resistance while 200 % resistance is achieved using geotextile reinforced at 50 mm and 200 % cone resistance while 166.67 % resistance is achieved using geotextile reinforced at 100 mm when compared to unreinforced section. The results show that the addition of geosynthetic reinforcement significantly improved the strength and stiffness of the subgrade soil. Reinforced sections show lower penetration values and better resistance against the unreinforced section. The study highlights the potential of geosynthetic reinforcement as a practical and economical solution for enhancing the stability and durability of unpaved roads.***

Index Terms— ***Dynamic Cone Penetration Test (DCPT), Dynamic Cone Penetrometer (DCP), Geosynthetic Reinforcement, Subgrade, Unpaved Roads***

I. INTRODUCTION

Unpaved roads built on weak subgrade soils frequently face issues such as rutting, excessive settlement, and poor load-bearing performance under repeated traffic loads. Enhancing the strength and stability of these roads remains a major concern in pavement engineering. In recent years, geosynthetic materials such as geotextiles and geogrids have been widely adopted to improve pavement performance by providing reinforcement, separation, and better stress distribution within the soil structure. These materials contribute to minimizing surface deformation and increasing the service life of roads. One of the various evaluation methods, the dynamic cone penetrometer (DCP) test is considered a simple, cost-effective, and dependable field technique for determining the strength characteristics of pavement layers and weak subgrade soils. Likewise, the California bearing ratio (CBR) test is extensively used in laboratory investigations to assess soil strength. In the present study, the behavior of unpaved road sections reinforced with geotextile and geogrid materials is investigated through DCP test. The reinforcement layer is positioned at the interface between the aggregate layer and the subgrade soil to study its influence on penetration resistance and the overall performance of the pavement system [1]. Geosynthetic reinforcement plays an important role in improving the performance of unpaved roads constructed over weak subgrade soil. This study investigates the effect of different geosynthetic layers placed at varying depths on the California bearing ratio of subgrade soil. Laboratory CBR tests showed that the inclusion of geogrids and geomats significantly enhances soil strength, reduces deformation, and improves load-carrying capacity [2]. Geotextile and geogrid reinforcement are widely used to improve the stability and performance of unpaved roads constructed on weak subgrade soil. This study evaluates the effectiveness of geosynthetic reinforcement through dynamic cone penetrometer (DCP) and direct shear tests. The results showed that reinforced sections provide better penetration resistance, improved shear strength, and enhanced load distribution compared to unreinforced sections. The study highlights the importance of geosynthetics in increasing pavement durability, reducing deformation, and supporting sustainable road construction practices [3]. This study evaluates the performance of coir geotextile reinforced subgrade under static loading conditions through field tests on reinforced and unreinforced pavement sections. Results showed significant improvement in stiffness, elastic modulus, and load-bearing capacity of reinforced sections. The study highlights that coir geotextiles can effectively reduce pavement deformation and aggregate thickness, thereby improve pavement durability and promote sustainable road construction practices [4]. Geogrids are widely used in pavement engineering to improve the stability and performance of weak subgrade soils. This study evaluates the effectiveness of different geogrids through laboratory tests and accelerated pavement testing. The research highlights how properties such as tensile strength, junction strength, and aperture size influence rutting resistance and pavement durability. The findings demonstrate that proper geogrid selection can significantly reduce deformation and enhance the load-carrying capacity of flexible pavements built on weak soils [5]. Geocell reinforcement has become an effective technique for improving the performance of unpaved roads constructed on weak subgrades. This study evaluates the behaviour of geocell-reinforced sand bases using accelerated pavement testing under repeated wheel loading. The results show that geocells significantly reduce rutting, improve load distribution, and enhance the stability of pavement sections [6]. The reinforcement of weak subgrade soil using geosynthetics has become an effective solution for improving pavement performance and durability. This study investigates the combined use of geotextile and geogrid to enhance the strength characteristics of clayey soil through compaction, CBR, and UCS tests. The results show significant improvement in load-bearing capacity, reduction in pavement thickness requirements, and better resistance against deformation, making geosynthetic reinforcement a sustainable and economical technique for road construction [7]. Geosynthetic reinforcement has emerged as an effective technique for improving the performance of pavements constructed on weak subgrade soils. This study examines the behaviour of geogrid and geotextile reinforced pavements under both static and dynamic loading conditions. Laboratory plate load tests revealed that the inclusion of geosynthetics significantly increases bearing capacity, reduces settlement, and enhances pavement life. The combined use of geogrid and geotextile showed the best performance, making it a reliable and economical solution for unpaved road construction on soft soils [8]. Geotextile reinforcement plays an important role in improving the performance of unpaved roads constructed on weak subgrade soils. This study investigates the behavior of reinforced and unreinforced unpaved roads using full-scale accelerated pavement testing under repeated axle loading. The results showed that geotextile reinforcement significantly reduced vertical stress and subgrade deformation while improving stress distribution and pavement stability. The study also confirmed a reduction in base course thickness, highlighting the economic and sustainable benefits of geotextile application in pavement engineering [9]. Geogrid reinforcement is widely used to improve the stability and load-bearing capacity of weak subgrade soils in pavement engineering. This study investigates the effect of geogrid placement depth and multiple reinforcement layers on soft subgrade performance using a digital static cone penetration test [10]. The study develops a cross hole-type dynamic cone penetrometer (DCP) to evaluate the strength and stiffness of railway track substructures through DCPI and shear wave velocity measurements. Laboratory and field investigations confirmed that the DCP can effectively estimate the maximum shear modulus and identify variations in ballast, sub-ballast, and subgrade conditions. The results showed a strong correlation between DCPI and shear wave velocity, demonstrating the usefulness of DCP as a reliable, economical, and practical tool for railway track assessment [11]. Vehicle loads play a major role in the performance and durability of pavement structures. This study examines the effect of static and dynamic vehicle loads on road surfaces and evaluates pavement strength using modern testing equipment. The research highlights how repeated traffic loading causes stress, deformation, and early pavement deterioration. By analyzing elastic modulus and deflection behavior, the study emphasizes the importance of proper pavement evaluation and maintenance for improving road safety and extending pavement service life [12].

II. MATERIALS AND METHODS

The materials used in this study included sandy soil, geosynthetic like geotextile and geogrid. Some laboratory tests were performed on the sandy soil to determine its engineering properties. Poorly graded sand (SP) was selected for the dynamic cone penetration test (DCPT). Grain size analysis was carried out to classify the soil as poorly graded sand (SP) or well graded sand (SW). A pycnometer test was conducted to determine the specific gravity of the sandy soil. The Standard proctor test was performed to find the maximum dry density and optimum moisture content. A direct shear test was determining the cohesion (c) and angle of internal friction (ϕ) of the sandy soil. Finally, DCPT was conducted to evaluate soil strength, identify weak zones at different depths, and assess the suitability of the subgrade for pavement design.

2.1 Grain Size Analysis

According to IS: 2720 (Part 4)–1985[13], a grain size analysis test was carried out in the Soil Mechanics Laboratory at DTU to determine the particle size distribution of the sandy soil. For the test, 1 kg of sandy soil was sieved through 4.75 mm, 2.00 mm, 1.18 mm, 600 µm, 300 µm, 150 µm, and 75 µm sieves. The weight of soil retained on each sieve was measured, and the percentage finer was calculated. The grain size distribution curve is presented in Figure 2.1. From the curve, the values of D_{10}, D_{30}, and D_{60} were found to be 0.290 mm, 0.360 mm, and 0.450 mm, respectively. The coefficient of uniformity (C_u) and coefficient of curvature (C_c) were calculated as 1.55 and 0.99, respectively. Based on these results, the soil was classified as poorly graded sand (SP). The equations used for calculating C_u and C_c are given below [14].

$$C_u = \frac{D_{60}}{D_{10}} \tag{2.1}$$

$$C_c = \frac{(D_{30})^2}{D_{60} * D_{10}} \tag{2.2}$$

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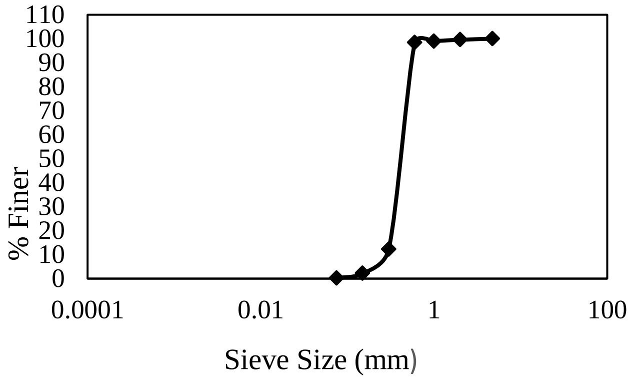

Fig. 2.1 Sieve analysis curve of sandy soil

2.2 Pycnometer Test

According to IS:2720 (Part 3) – 1980, the pycnometer test was performed to determine the specific gravity of the soil sample [15]. The sandy soil used in the test was first passed through a 4.75 mm sieve. The specific gravity of soil depends mainly on the density of the minerals present in the soil particles. It is expressed as the relationship between the weight of soil particles and the weight of an equal volume of water. at 4°C [14]. The specific gravity of the tested soil sample was found to be 2.66.

2.3 Standard Proctor Test

The Standard Proctor Test was carried out in accordance with IS:2720 (Part 7) – 1980 [16]. For the test, 3 kg of oven-dried soil passing through the required sieve was used. Different percentages of water content, namely 2%, 3%, 4%, 5%, 6%, 7%, 8%, 9%, and 10%, were mixed thoroughly with the soil to obtain a suitable moisture range.

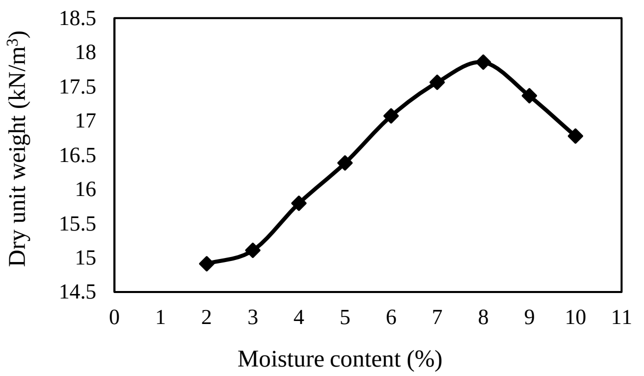

Fig. 2.2 OMC and MDD determination curve

The prepared soil was compacted in a mould in three equal layers. Each layer was compacted by giving 25 blows using a 2.6 kg rammer dropped freely from a height of 310 mm. The test was conducted to determine the maximum dry density (MDD) and optimum moisture content (OMC) of poorly graded sand (SP). By repeating the test at different moisture contents, the MDD and OMC obtained from Figure 2.2 were found to be 17.854 kN/m³ and 8%, respectively.

2.4 Direct Shear Test

The direct shear test was carried out in accordance with IS:2720 Part 13 (1986) [17]. In this test, sandy soil was placed and compacted inside a shear box of size 60 mm × 60 mm. The setup included a porous stone at the bottom, along with a base plate, grid plate. After placing the top grid plate the shear box was mounted on the loading frame. Initially, a normal stress of 0.5 kg/cm² was applied to the soil specimen. Horizontal shear force was then gradually applied until failure occurred. During the test, the shear load and horizontal displacement were continuously recorded to evaluate the cohesion and angle of internal friction of the soil. The same procedure was repeated under higher normal stresses of 1.0 kg/cm² and 1.5 kg/cm². The direct shear test result is illustrated in Figure 2.3.

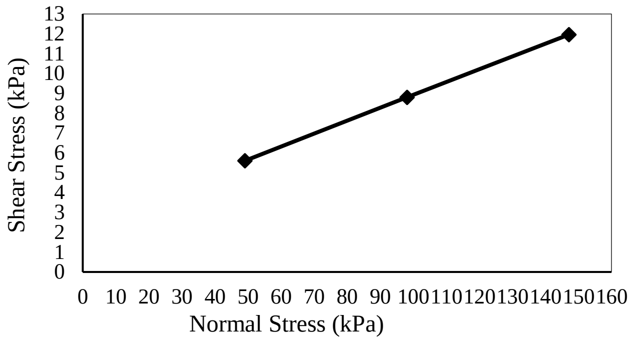

Fig. 2.3 Shear strength parameter curve

2.5 Dynamic Cone Penetration Test

The dynamic cone penetrometer (DCP) used in this study, shown in Figure 2.4, was designed in accordance with ASTM D6951-03 standards.

Fig. 2.4 Dynamic cone penetrometer

The equipment consists of a cone having a 60° apex angle with a base diameter of 20 mm, connected to a rod of 16 mm diameter. During the test, the rod was kept in a vertical position, and an 8 kg hammer was raised to a height of 575 mm and allowed to fall freely to penetrate the compacted subgrade soil. Proper care was taken while lifting the hammer to ensure that it touched the lower stop of the handle without disturbing the cone position before release. Incorrect handling during lifting or dropping may affect the accuracy of the DCP readings. The penetration corresponding to the first hammer blow was neglected because the cone tip initially has a smaller contact area compared to the later blows. The cone diameter was intentionally kept slightly larger than the rod diameter so that most of the soil resistance acts on the cone itself [18]. The penetration depth produced by each hammer blow was recorded throughout the test. The dynamic cone penetration index (DCPI) is defined as the penetration per hammer blow and is expressed in mm/blow. It can be calculated using Equation 2.3 [19]. Alternatively, DCPI may also be obtained from the slope of the best-fit line drawn between penetration depth and cumulative number of blows, which represents the penetration rate in mm/blow [20].

$$\mathrm{DCPI} = \frac{P_{(i+1)} - P_{(i)}}{N_{(i+1)} - N_{(i)}} \quad (2.3)$$

Where , DCPI = Dynamic cone penetration index (mm/blow), $P_{(i)}$ and $P_{(i+1)}$ = Cone penetration values at i and i + 1 hammer drops (mm), N(i) and N(i+1) = Number of blows counts corresponding to P(i) and P(i+1), respectively.

The results obtained from the DCP test were evaluated to determine the representative DCPI values of the soil subgrade using the correlation given in Equation 2.4 [19]. The test data also assisted in identifying the interfaces between different soil layers. These layer boundaries were identified from significant changes in the slope of the plot between cumulative blow count and penetration depth.

$$\mathrm{DCPI}_{avg} = \frac{\sum_{i}^{N} \mathrm{DCPI}}{N} \quad (2.4)$$

Where, N represents the total count of DCPI readings obtained within a specified depth of penetration.

2.6 Influence of Geosynthetic Reinforcement

In this study, geosynthetic materials such as geogrid and geotextile were used as reinforcement at different embedment depths of 50 mm and 100 mm. The geotextile used, shown in Figure 2.5 is a woven polypropylene multifilament fabric. It possesses good durability and provides resistance against chemicals and microorganisms commonly found in soil [1]. The properties of the geotextile are presented in Table 2.1. A biaxial geogrid, shown in Figure 2.6, was also used in the study. It is manufactured from a perforated polypropylene sheet with interconnected ribs, which helps reduce the lateral movement of granular soil by enhancing the interlocking and interface friction between soil particles [10]. The properties of the geogrid are listed in Table 2.2 [1].

Fig. 2.5 Geotextile

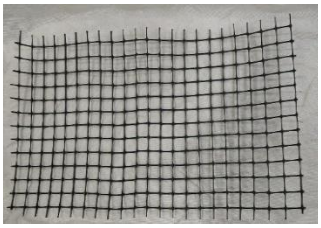

Fig. 2.6 Geogrid

Table 2.1 Properties of geotextile

Properties	Results/Values
Tensile strength (kN/m)	45 x 34 (MD x CMD)
Puncture strength (kN)	0.48
Apparent opening size (mm)	0.075
Mass per unit area of fabric (g/m^2)	200

MD Machine direction, CMD cross-machine direction

Table 2.2 Properties of geogrid

Characteristics	Properties	Results/Values
Physical	Geogrid shape	Bi-axial geogrid
	Color	Black
	Aperture shape	Quadrangular
	Polymer type	Polypropylene
Technical	Aperture size (mm)	30 x 30 (MD x CMD)
	Stiffness at 0.5% strain (kN/m)	550 x 350 (MD x CMD)
	Transversal rib width (cm)	0.26
	Longitudinal rib thickness (cm)	0.38
	Junction thickness (cm)	0.6
Performance	Aperture coefficient of friction (soil/geosynthetics)	1.78 at 10 kN/m^2 and 1.14 at 20 kN/m^2
	Installation damage factor	1

MD Machine direction, CMD cross-machine direction

III. RESULTS AND DISCUSSIONS

3.1 Dynamic Cone Penetration Test

In this study, the dynamic cone penetration test (DCPT) was carried out on poorly graded sand (SP). The test was performed to evaluate the strength and penetration resistance of the subgrade soil under different reinforcement conditions. The DCP test establishes a relationship between the number of hammer blows and the corresponding penetration depth, which is useful for assessing the stiffness and resistance characteristics of the soil. The performance of the soil was examined under the following three conditions:

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a. Unreinforced soil
b. Soil reinforced with geogrid
c. Soil reinforced with geotextile

The reinforcement layers were placed at depths of 50 mm and 100 mm to study the effect of reinforcement position on the behavior of the subgrade soil. Among all the cases, the unreinforced soil showed the maximum penetration depth. The penetration increased rapidly during the initial stages of loading, indicating that the soil had comparatively low resistance to the applied impact energy.

3.1.1 Influence of Geosynthetic Reinforcement on Soil Resistance at 50 mm Depth

The results of the dynamic cone penetration (DCP) test are presented in the form of penetration depth versus number of blows. The graph shown in Figure 3.1 indicates that the penetration depth increases with an increase in the number of blows for all testing conditions. All cases the unreinforced soil shows the highest penetration values throughout the test duration. At 9 blows, the penetration depth reaches 173 mm, which reflects the low resistance and weak strength of the subgrade soil. The soil samples reinforced with geogrid and geotextile at a depth of 50 mm exhibit a significant reduction in penetration depth compared to the unreinforced condition. For the same number of blows, the penetration depth was recorded as 108 mm for geogrid reinforcement and 102 mm for geotextile reinforcement. These results demonstrate that the inclusion of reinforcement improves the load-carrying capacity and overall performance of the soil. Geogrid-reinforced soil shows comparatively better performance, as it consistently records lower penetration values during loading.

The decrease in penetration depth in reinforced samples indicates an increase in soil stiffness and resistance against applied impact loads. In the case of unreinforced soil, penetration occurs more easily due to the absence of confinement and structural support. Geogrid reinforcement improves the soil behavior mainly through the interlocking mechanism developed between the grid structure and soil particles. This interaction restricts lateral particle movement and helps distribute the applied load over a larger area, resulting in reduced penetration. Geotextile reinforcement mainly acts as a separation and tension membrane layer. Although it enhances soil performance, its ability to distribute loads is relatively lower than that of geogrid. As a result, slightly higher penetration values are observed in the geotextile-reinforced soil. The difference between reinforced and unreinforced conditions becomes more noticeable with an increase in the number of blows, indicating that reinforcement is more effective under repeated or cyclic loading conditions such as pavement traffic loads.

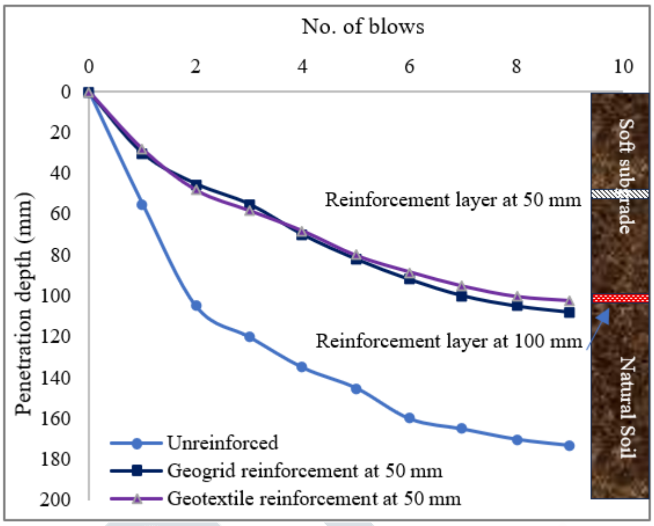

Fig. 3.1 Penetration depth versus number of blows for reinforced and unreinforced soil at 50 mm

3.1.2 Influence of Geosynthetic Reinforcement on Soil Resistance at 100 mm Depth

The DCP test results shown in Figure 3.2 illustrate the relationship between penetration depth and number of blows for three different conditions: unreinforced soil, soil reinforced with geogrid at 100 mm depth, and soil reinforced with geotextile at 100 mm depth. The plotted curves clearly demonstrate the improvement in subgrade performance due to the inclusion of reinforcement materials. In the case of unreinforced soil, the penetration depth increases rapidly with an increase in the number of blows. Even under a lower number of blows, higher penetration values are observed, indicating poor resistance and low shear strength of the soil. This behavior is typical for poorly graded sand, where limited particle interlocking results in lower resistance against penetration.

The soils reinforced with geogrid and geotextile show a considerable reduction in penetration depth for the same number of blows. This indicates that the reinforcement layers improve the stiffness and load-carrying capacity of the soil. The enhancement in performance is mainly due to the confinement effect provided by the reinforcement, which restricts the lateral movement of soil particles and improves interlocking within the soil mass. Among the two reinforcement types, geogrid reinforcement performs slightly better than geotextile reinforcement, particularly at higher blow counts. Another important observation is that the rate of increase in penetration depth is much lower in reinforced soils compared to the unreinforced condition. These results confirm the effectiveness of geosynthetic reinforcement in minimizing deformation and improving the durability and service life of unpaved roads.

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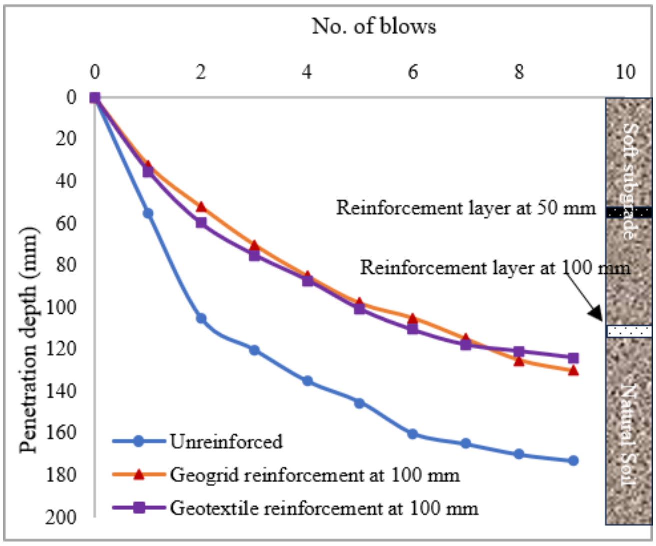

Fig. 3.2 Penetration depth versus number of blows for reinforced and unreinforced soil at 100 mm

3.2 CBR-DCPI Correlation

The DCP results can be correlated with California bearing ratio (CBR) values using empirical relationships. A commonly used correlation is following equation 3.1 [1].

$$CBR = \frac{292}{(DCPI)^{1.12}} \quad (3.1)$$

Where, CBR = California bearing ratio and DCPI = Dynamic cone penetration index in mm/blow

3.2.1 CBR Result

CBR and DCPI calculation data from equation 2.3, 2.4 and 3.1 is shown in Table 3.1 summary of DCPI and CBR calculation.

Table 3.1 Summary of DCPI and CBR calculation

Particulars	DCPI mm/blow	CBR %
Unreinforced soil	14.75	14.33
Reinforced soil (geogrid) at 50 mm	9.75	22.79
Reinforced soil (geogrid) at 100 mm	12.25	17.65
Reinforced soil (geotextile) at 50 mm	9.25	24.17
Reinforced soil (geotextile) at 100 mm	11.13	19.65

The unreinforced soil exhibited a higher dynamic cone penetration index (DCPI) in mm/blow, which corresponds to lower California bearing ratio (CBR) values and indicates poor subgrade strength. In opposition the soil reinforced with geogrid showed the lowest DCPI values and consequently higher CBR values, demonstrating significant improvement in strength characteristics. The geotextile-reinforced soil also performed better than the unreinforced soil, although its CBR values were slightly lower compared to the geogrid reinforcement. The highest improvement in CBR was observed when the reinforcement layer was placed at a depth of 50 mm. The results also confirm that DCP-based estimation of CBR is an effective and practical method for evaluating subgrade performance.

IV. CONCLUSIONS

The present study investigated the effectiveness of geogrid and geotextile reinforcement in soft subgrade soil using the dynamic cone penetration test (DCPT). The performance of reinforced soil was compared with that of unreinforced soil by placing reinforcement layers at depths of 50 mm and 100 mm. Based on the experimental results and detailed analysis, the following conclusions were drawn:

I. In the DCPT results also confirmed the strengthening effect of reinforcement. The average DCPI value decreased from 14.75 mm/blow for unreinforced soil to 9.75 mm/blow for geogrid reinforcement and 9.25 mm/blow for geotextile reinforcement at 50 mm. Reinforcement at 100 mm depth showed comparatively higher DCPI values than reinforcement at 50 mm depth, confirming that shallow placement of reinforcement is more effective for improving subgrade behavior. Lower DCPI values indicate higher penetration resistance and improved soil strength. The improvement obtained from DCPT analysis showed that geogrid reinforcement at 50 mm depth produced nearly 300% improvement, while geotextile at 50 mm showed about 200% improvement. At 100 mm depth, geogrid reinforced and geotextile reinforced showed improvements of about 200% and 166.67%, respectively.

II. The California Bearing Ratio (CBR) values estimated from DCPI correlations also increased considerably due to reinforcement. The CBR value of unreinforced soil was 14.33%, whereas geogrid reinforcement at 50 mm increased the CBR to 22.79% and geotextile at 50 mm increased it to 24.17%. This confirms that geosynthetic reinforcement improve the engineering properties of weak subgrade soil.

III. Overall, the study shows that the use of geosynthetic reinforcement is an effective method for improving the strength and stability of weak subgrade soil. Reinforcement placed near the surface, particularly geogrid at 50 mm depth, was found to be the most efficient configuration for reducing penetration and improving load carrying capacity.

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