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Effect of Geogrid and Bamboo-Grid Reinforcement in Soil Subgrade Using Dynamic Cone Penetration Test

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Abstract— ***Weak subgrade soils generally lead to excessive settlement, rutting, and unseasonable pavement failure. This study examines the effect of geogrid and bamboo-grid reinforcement on the performance of sandy soil subgrade using the dynamic cone penetration test (DCPT). The primary objective was to evaluate and compare the improvement in strength and penetration resistance of reinforced and unreinforced soil. Laboratory model tests were conducted on unreinforced soil as well as soil reinforced with geogrid and bamboo-grid layers at 50 mm and 100 mm depths within the soil, using DCP testing to measure depth penetration and subgrade performance. The dynamic cone penetration test was used to assess the dynamic cone penetration index and improvement in subgrade strength. The geogrid and bamboo-grid reinforced soft subgrade shows an increase approximately 300 percent cone resistance is achieved at 50 mm depth, and geogrid reinforced 200 percent cone resistance while 202.87 percent resistance achieved using bamboo-grid reinforced at 100 mm when compared to unreinforced soil section. The results show that both reinforcement materials significantly increased the load-bearing capacity and stiffness of the soil compared to unreinforced soil. The findings show up the reinforced subgrade systems in improving pavement foundation performance, reducing maintenance requirements, and sustainable ground improvement practices in transportation and geotechnical engineering applications.***

Index Terms— ***Bamboo-grid, DCPT, Geogrid, Reinforcement***

I. INTRODUCTION

Dynamic cone penetrometer (DCP) is a simple and effective test used to evaluate the strength and engineering properties of soil. It helps engineers quickly understand soil behaviour and suitability for construction work [1]. Bamboo grid reinforcement is an effective and eco-friendly method used to improve the strength and settlement behaviour of weak soil. It helps in increasing soil stability and reducing deformation under loading conditions [2]. Cone penetration testing (CPT) is an important method used to study the strength and dynamic behaviour of sandy soil under loading conditions. It helps in understanding soil stability, bearing capacity, and the response of soil during foundation and pavement construction [3]. Bamboo grid is a sustainable and effective reinforcement material used to improve the stability and strength of weak subgrade soil. It helps in reducing settlement and enhancing the overall performance of soil in construction works [4]. Peat soil is a weak and highly compressible soil that creates difficulties in construction due to its high-water content and low strength. bamboo reinforcement is considered an effective and eco-friendly method to improve the stability and performance of peat soil [5]. Geogrid reinforcement is an effective technique used to improve the performance and stability of flexible pavements under repeated traffic loading. It helps in reducing permanent deformation and increasing the strength of pavement layers [6]. Geosynthetic reinforcement is an effective technique used to improve the strength and stability of unpaved roads built on weak soil. It helps in reducing deformation, improving load distribution, and enhancing the overall performance of pavement layers [7]. Geosynthetic reinforcement is an effective method used to improve the strength and stability of weak soil in pavement construction. It helps in increasing load carrying capacity, reducing settlement, and enhancing the overall performance of the road structure [8]. Geogrid reinforcement is an effective technique used to improve the strength and stability of soft subgrade soil. The placement depth and number of reinforcement layers play an important role in reducing deformation and increasing the load carrying capacity of the soil [12 -13].

II. MATERIALS

This study used sandy soil in a steel tank shown in Figure 2.1, geogrid (shown in Figure 2.2) and bamboo-grid (shown in Figure 2.3) as reinforcement materials.

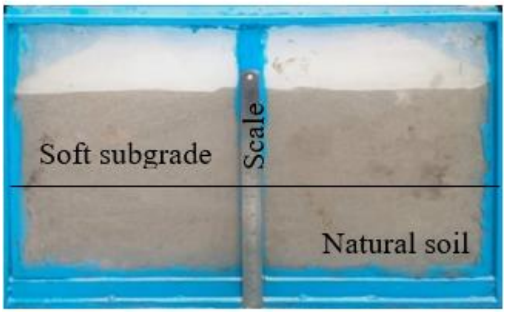

Fig. 2.1 Steel tank filled with sandy soil

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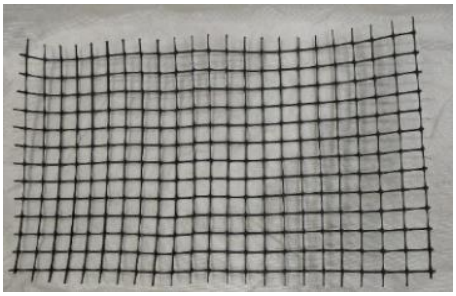

Fig. 2.2 Bi-axial geogrid used in this study

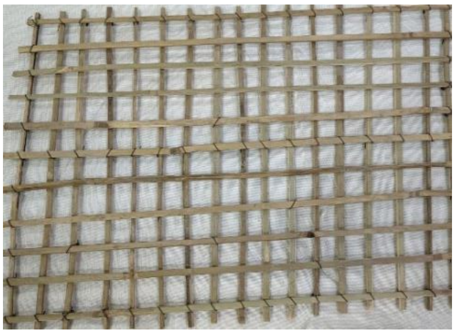

Fig. 2.3 Bamboo – grid used in this study

A steel test tank measuring 650 mm in length, 450 mm in width, and 300 mm in depth was used for the experimental study. In the tank setup, the upper 150 mm layer was treated as the unpaved road section, whereas the lower 150 mm layer treated as the natural soil subgrade.

In the present study, geogrid and bamboo grid were used as reinforcing materials and embedded within sandy soil at depths of 50 mm and 100 mm. The main purpose of providing reinforcement was to increase the load-bearing capacity of the soil and reduce the lateral displacement of soil particles. The biaxial geogrid used in this investigation was made from perforated polypropylene sheets having interconnected ribs. This grid-shaped structure provides confinement to the granular soil and improves the interaction between soil and reinforcement by increasing friction at the interface. Due to this effect, the lateral movement of sand particles is restricted, which ultimately enhances the strength and stability of the soil layer. The properties of the geogrid are presented in Table 2.2 [8].

Bamboo grid was adopted as a natural and eco-friendly reinforcing alternative. It was prepared using mature bamboo strips that were cut, treated, and woven into a grid form. Bamboo is a renewable material well known for its high tensile strength, flexibility, and biodegradable nature. To improve its durability, the bamboo strips were treated with preservative solutions to protect against moisture, insects, and microbial attack. When placed inside the soil, the bamboo grid acts as a reinforcing framework that helps in distributing the applied load and limiting excessive deformation of the soil mass. The properties of the bamboo grid are shown in Table 2.1.

Table 2.1 Properties of Bamboo-Grid Used in This Study

Property	Values
Structure	Bi-axial bamboo -grid
Size(mm)	650× 450 × 6
Color	Natural bamboo color
Weight (g/m^2)	1552.02
Shape	Quadrangular
Material	Natural
Aperture size (mm)	3.5× 3(MD×CMD)
Rib width (mm)	≈ 3
Rib thickness(mm)	≈6
Junction thickness(mm)	≈12

MD Machine direction, CMD cross-machine direction

Table 2.2 Properties of geogrid used in this study

Category	Parameter	Values
Physical Features	Geogrid structure	Bi-axial geogrid
	Color	Black
	Aperture shape	Quadrangular
	Polymer type	Polypropylene
Mechanical Features	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 (mm)	0.26
	Longitudinal rib thickness (mm)	0.38
	Junction thickness (mm)	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. METHODOLOGY

A series of laboratory tests were conducted to evaluate the engineering properties of the soil. These tests included sieve analysis, pycnometer test, Standard Proctor compaction test, and direct shear test. Dynamic cone penetration tests were performed in the ITS and Soil Dynamics Laboratory under both reinforced and unreinforced soil conditions to examine the strength of the soil, locate weaker layers at different depths, and determine the adequacy of the subgrade for pavement construction and design.

3.1 Sieve Analysis

Sieve analysis was carried out in the Soil Mechanics Laboratory at DTU in accordance with IS: 2720 (Part 4) – 1985 [16]. For the test, a 1 kg soil sample was passed through a series of sieves of sizes 4.75 mm, 2.00 mm, 1.18 mm, 600 μm, 300 μm, 150 μm, and 75 μm. The weight of soil retained on each sieve was measured and the percentage passing was determined. The grain size distribution curve obtained from the test is presented in Figure 3.1. From the curve the particle sizes D_{10}, D_{30}, and D_{60} were found to be 0.29 mm, 0.36 mm, and 0.45 mm, respectively. Using these values the coefficient of uniformity (C_u) and coefficient of curvature (C_c) were calculated as 1.55 and 0.99. Based on the obtained results the soil was classified as poorly graded sand (SP). The coefficients were evaluated using standard equations 3.1, 3.2, 3.3, and 3.4 [15].

$$\text{Percentage retained} = \frac{\text{weight retained}}{\text{total sample weight}} \times 100 \quad (3.1)$$

$$\text{Percentage passing} = 100 - \text{cumulative \% retained} \quad (3.2)$$

$$C_u = D_{60}/D_{30} \quad (3.3)$$

$$C_c = (D_{30})^2/(D_{60} * D_{10}) \quad (3.4)$$

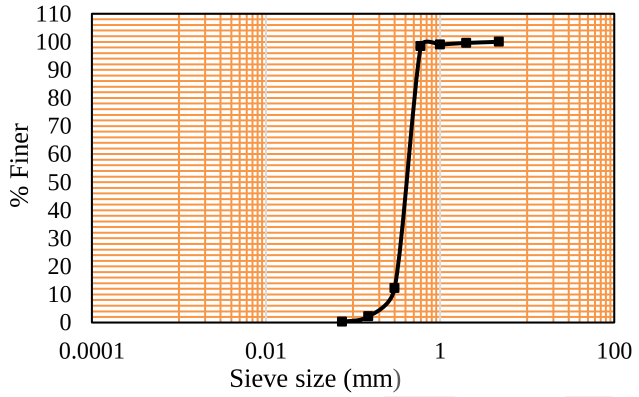

Fig. 3.1 Particle size distribution curve

3.2 Pycnometer Bottle Method

The pycnometer test was carried out in accordance with IS: 2720 (Part 3) – 1980 [17] to determine the specific gravity of the soil sample. For this test, sandy soil passing through the 4.75 mm sieve was used. Specific gravity represents the ratio between the weight of soil solids and the weight of an equal volume of water at 4°C, and it mainly depends on the mineral composition of the soil particles [15]. Based on the test results the specific gravity of the sandy soil was determined to be 2.66.

3.3 Standard Proctor Test

The Standard Proctor compaction test was performed in accordance with IS: 2720 (Part 7) – 1980 [18] to determine the compaction characteristics of the soil. For the test 3 kg of oven-dried soil was taken and mixed with different water contents varying from 2% to 10%. The prepared soil was compacted in a mould in three equal layers with each layer receiving 25 blows from a 2.6 kg rammer dropped freely from a height of 310 mm. After compaction, the weight of the compacted soil in the mould was measured to calculate the dry density. The same procedure was repeated for different moisture contents and the corresponding compaction curve was plotted as shown in Figure 3.2. From the obtained curve the maximum dry density (MDD) and optimum moisture content (OMC) were determined as 17.854 kN/m³ and 8%, respectively.

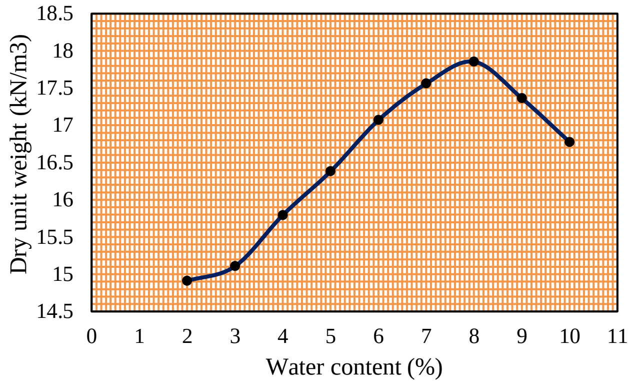

Fig. 3.2 Dry unit weight v/s water content curve

3.4 Direct Shear Test

The direct shear test was carried out in accordance with IS: 2720 (Part 13) – 1986 [14] to evaluate the shear strength characteristics of the soil. The soil specimen was compacted inside a shear box measuring 60 mm × 60 mm, equipped with a porous stone, base plate, grid plates, and other necessary components. After proper assembly of the apparatus, a normal stress of 0.5 kg/cm² was applied to the specimen, and the horizontal shear load was increased gradually until the soil failed in shear. During the test, both the shear load and horizontal displacement were recorded continuously. The same procedure was repeated under higher normal stresses of 1.0 kg/cm² and 1.5 kg/cm². From the obtained test data, the cohesion (c) and angle of internal friction (ϕ) of the soil were determined. Shown in Figure 3.3 shear stress v/s normal stress curve. Also shown in Table 3.1 summary of basic properties of soil.

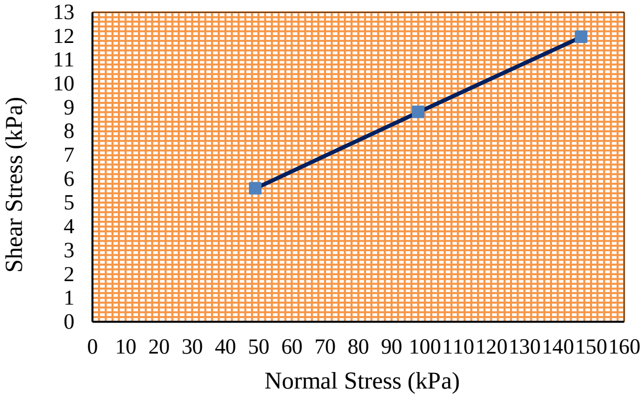

Fig. 3.3 Shear stress vs horizontal displacement curve for sandy soil

3.5 Dynamic Cone Penetrometer (DCP) Test

The dynamic cone penetrometer (DCP) used in the present investigation, shown in Figure 3.4 was operated in accordance with ASTM D6951-03 specifications. The test was carried out to assess the in-situ strength behavior of the compacted subgrade soil. The apparatus consists of a steel cone having a 60° apex angle and a base diameter of 20 mm, which is firmly attached to a rod of 16 mm diameter. During testing the rod was kept in a vertical position to ensure uniform and accurate penetration into the soil. An 8 kg hammer was raised to a standard height of 575 mm and allowed to fall freely onto the anvil causing the cone to penetrate the soil layer. Proper care was taken while handling the hammer throughout the testing process. The hammer was lifted only up to the specified lower stop ensuring that the cone did not move upward before release. Any improper lifting or dropping of the hammer could lead to errors in penetration measurements. The penetration recorded during the first hammer blow was neglected because the cone tip initially has a smaller contact area with the soil compared to the subsequent blows. The cone was designed with a slightly larger diameter than the rod so that the soil resistance developed mainly around the cone surface [9]. The penetration depth was noted after every hammer blow. The dynamic cone penetration index (DCPI) expressed in mm/blow represents the penetration per hammer blow and was calculated using Equation 3.1[10].

$$DCPI = \frac{P_{(i+1)} - P_{(i)}}{N_{(i+1)} - N_{(i)}} \qquad (3.1)$$

Where, DCPI denotes the dynamic cone penetration index expressed in mm/blow. The term $P_{(i+1)}$ and $P_{(i)}$ represent the penetration depths (mm) recorded at two successive blows while $N_{(i+1)}$ and $N_{(i)}$ indicate the corresponding cumulative number of blows. DCPI values can also be determined graphically by plotting penetration depth against the cumulative blow count and calculating the slope of the best-fit line obtained from the plot [11]. The results obtained from the DCP test were further analyzed to estimate the representative DCPI values of the subgrade soil using the correlation given in Equation 3.2 [10]. In addition, changes in the slope of the penetration depth versus blow count curve were used to identify the interfaces between different soil layers. These slope variations clearly reflected the changes in soil characteristics with increasing depth.

$$DCPI_{avg} = \frac{\sum_i^N DCPI}{N} \qquad (3.2)$$

Where N represents the total count of DCPI (mm/blow) readings obtained within a specified depth of penetration.

3.6 CBR – DCPI Relationship

The results obtained from the DCP test can be related to California Bearing Ratio (CBR) values through empirical correlations. One of the widely adopted relationships used for estimating CBR from DCP measurements is given in Equation 3.3 [8].

$$\text{CBR} = \frac{292}{(\text{DCPI})^{1.12}} \qquad (3.3)$$

Where CBR is California bearing ratio and DCPI is dynamic cone penetration index in mm/blow.

IV. RESULTS AND DISCUSSIONS

4.1 Dynamic Cone Penetration Test (DCPT)

In the present study, the dynamic cone penetration test (DCPT) was performed on poorly graded sand (SP) to evaluate the strength characteristics of the subgrade soil under different reinforcement conditions. The test provides a relationship between the number of hammer blows and the corresponding penetration depth, which helps in assessing the stiffness and resistance of the soil against impact loading. The behavior of the soil was investigated under three conditions:

a. unreinforced soil
b. Soil reinforced with geogrid and
c. Soil reinforced with bamboo-grid

To examine the influence of reinforcement location, the reinforcing layers were placed at depths of 50 mm and 100 mm within the soil bed. The experimental results indicated that the unreinforced soil exhibited the highest penetration depth. A sharp increase in penetration was observed during the initial loading stage, suggesting that the soil possessed comparatively low resistance to the applied impact energy.

4.1.1 Strength Comparison of Geogrid and Bamboo-grid Reinforced Soil at 50 mm Depth

Figure 4.1 illustrates the variation of penetration depth with the number of blows for three different conditions: unreinforced soil, soil reinforced with geogrid at 50 mm depth, and soil reinforced with bamboo-grid at 50 mm depth. In all the cases penetration depth increases as the number of blows increases indicating gradual deformation of the soil under repeated impact loading. The unreinforced soil shows the highest penetration among all the cases. A rapid increase in penetration is observed even at lower blow counts which reflects the low stiffness and poor load resistance of the untreated soil. This behavior indicates that the unreinforced soil is unable to distribute the applied stresses effectively. Both geogrid and bamboo-grid reinforced soils exhibit noticeably lower penetration depths demonstrating the positive influence of reinforcement on soil strength and stiffness. The inclusion of reinforcement improves the load-carrying capacity of the soil by restricting particle movement and enhancing confinement. Among the reinforced cases geogrid reinforcement performs slightly better as it records comparatively lower penetration values for most of the blow counts. This improved behavior may be attributed to the better interlocking mechanism and confinement provided by the geogrid structure. The bamboo-grid reinforcement also performs effectively and shows results close to those of geogrid reinforcement. Although the penetration values are marginally higher in certain cases, the difference remains relatively small. This suggests that bamboo-grid can serve as a sustainable and efficient alternative reinforcement material.

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Volume 13 Issue 02 February 2026

The results demonstrate that placing reinforcement at a depth of 50 mm significantly improves the performance of the soil by reducing deformation under repeated loading. The enhancement in behavior is mainly due to improved stress distribution, increased confinement, and greater resistance to soil particle displacement. While geogrid reinforcement provides slightly superior performance, bamboo-grid offers a more economical and environmentally friendly solution with nearly comparable effectiveness.

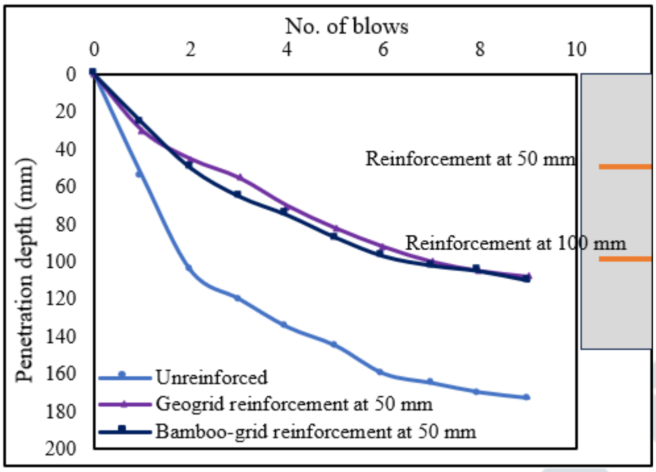

Fig. 4.1 No. of blows versus penetration depth curve at 50 mm

4.1.2 Strength Comparison of Geogrid and Bamboo-grid Reinforced Soil at 100 mm Depth

Figure 4.2 presents the relationship between penetration depth and the number of blows for unreinforced soil, geogrid reinforced soil, and bamboo-grid reinforced soil with the reinforcement placed at a depth of 100 mm. In all the cases, the penetration depth gradually increases with an increase in the number of blows, indicating the progressive deformation of soil under repeated impact loading. The unreinforced soil records the maximum penetration during the entire test. A steep rise in penetration is observed from the initial stages itself, which indicates the low impact resistance and weak load distribution capability of the untreated soil. This behavior clearly shows that unreinforced soil is more vulnerable to deformation under repeated loading conditions.

The inclusion of geogrid and bamboo-grid reinforcement considerably decreases the penetration depth compared to the unreinforced condition. The beneficial effect of reinforcement becomes evident from the early stages of loading and remains consistent throughout the test. When comparing the two reinforcement materials, geogrid exhibits slightly lower penetration values during the intermediate stages of loading indicating better initial performance. However, at higher blow counts the bamboo-grid shows performance almost equal to and in some cases slightly better than the geogrid. This behavior suggests that bamboo-grid is capable of providing effective long-term resistance under repeated loading conditions. The placement of reinforcement at 100 mm depth significantly enhances the engineering behavior of the soil by improving confinement and restricting soil particle displacement. Although geogrid demonstrates strong reinforcing performance bamboo-grid also proves to be a reliable sustainable, and cost-effective alternative with nearly comparable efficiency.

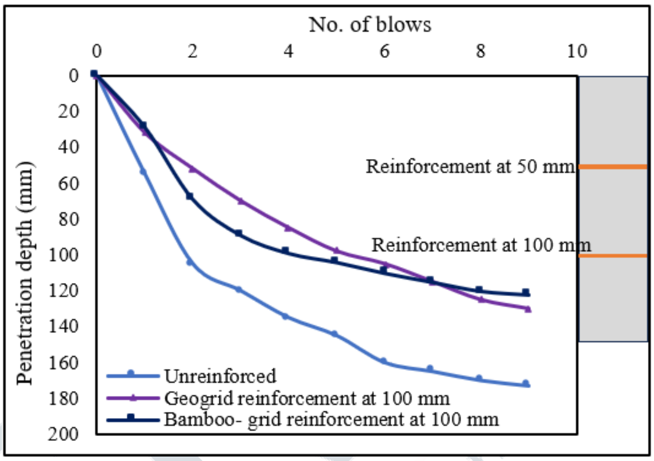

Fig. 4.2 No. of blows versus penetration depth curve at 100 mm

4.2 California Bearing Ratio (CBR)

The CBR and DCPI result summarized in Table 4.1.

Table 4.1 Average DCPI and corresponding CBR values for unreinforced, geogrid reinforced, and bamboo- grid reinforced soil sections

Test section	DCPI (mm/blow)	CBR (%)
Unreinforced	14.75	14.33
Geogrid reinforced at 50 mm	9.75	22.79
Geogrid reinforced at 100 mm	12.25	17.65
Bamboo-grid reinforced at 50 mm	10.5	20.97
Bamboo-grid reinforced at 100 mm	11.63	18.70

The DCPI and CBR results clearly demonstrate the influence of reinforcement on the performance of the soil subgrade. The unreinforced soil exhibited the highest average DCPI value of 14.75 mm/blow along with the lowest CBR value of 14.33%, indicating low penetration resistance and poor strength characteristics. The inclusion of geogrid and bamboo-grid reinforcement led to a noticeable reduction in DCPI values and a corresponding increase in CBR values when compared with the unreinforced condition. Among all the tested cases, geogrid reinforcement placed at a depth of 50 mm showed the most effective performance, recording a DCPI value of 9.75 mm/blow and a CBR value of 22.79%. These results indicate significant improvement in soil stiffness and load-carrying capacity. Similarly, bamboo-grid reinforcement at 50 mm depth also produced considerable improvement, reducing the DCPI value to 10.5 mm/blow and increasing the CBR value to 20.97%. Reinforcement placed at 100 mm depth also enhanced the soil performance relative to the unreinforced soil. However, the level of improvement was comparatively less than that observed for reinforcement at 50 mm depth. The findings suggest that placing the reinforcement closer to the upper layer of the soil is more effective in enhancing penetration resistance and improving the overall strength of the subgrade.

V. CONCLUSIONS

This experimental study was carried out on poorly graded sand (SP) to evaluate the effectiveness of geogrid and bamboo grid reinforcement in improving the performance of soil subgrade. The behavior of unreinforced soil was compared with reinforced soil by placing the reinforcement at depths of 50 mm and 100 mm from the surface. The performance was assessed using DCPT the main conclusions written from the study are summarized below:

i. The load–displacement behaviour clearly indicates that reinforcement significantly improved the strength and stiffness characteristics of sandy subgrade soil when compared with the unreinforced condition. Both geogrid and bamboo-grid reinforcement reduced settlement and enhanced penetration resistance, resulting in improved load-carrying capacity of the soil. The reinforced soil sections showed comparatively smaller displacement under higher applied loads, whereas the unreinforced soil exhibited excessive deformation even under lower loading conditions.

ii. The DCPT analysis also confirmed the strengthening effect of reinforcement on sandy subgrade soil. The average DCPI value decreased from 14.75 mm/blow for unreinforced soil to 9.75 mm/blow for geogrid reinforcement and 10.25 mm/blow for bamboo-grid reinforcement at 50 mm depth. Lower DCPI values indicate greater penetration resistance and improved soil stiffness. The reinforcement placed at 100 mm depth resulted in comparatively higher DCPI values than reinforcement placed at 50 mm depth, confirming that shallow reinforcement placement is more effective for improving subgrade behaviour.

iii. The improvement obtained from DCPT analysis further highlighted the beneficial effect of reinforcement. At 50 mm depth, geogrid reinforcement produced nearly 300% improvement in penetration resistance, while bamboo-grid reinforcement also showed substantial improvement compared to unreinforced soil. Similarly, at 100 mm depth, geogrid and bamboo-grid reinforcement showed improvements of about 200% and 202.87%, respectively, indicating considerable enhancement in soil resistance under repeated impact loading conditions.

iv. The California Bearing Ratio (CBR) values estimated from DCPI correlations also increased significantly due to reinforcement inclusion. The unreinforced soil exhibited comparatively lower bearing capacity, whereas reinforced sections showed substantial improvement. At 50 mm depth, the CBR values increased to 22.79% for geogrid reinforcement and 20.97% for bamboo-grid reinforcement. At 100 mm depth, the corresponding CBR values were found to be 17.65% and 18.70%, respectively. These results clearly indicate that reinforcement improves the bearing capacity and overall engineering performance of weak sandy subgrade soil.

v. Overall, the study concludes that both geogrid and bamboo-grid reinforcement are highly effective in improving the load-carrying capacity, penetration resistance, stiffness, and stability of weak sandy subgrade soil when compared with unreinforced soil. Reinforcement placed at shallow depth produced the best overall performance. The findings also establish that bamboo-grid reinforcement can serve as a sustainable, economical, and eco-friendly alternative to conventional geogrid reinforcement for pavement and geotechnical engineering applications.

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