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ABSTRACT

Weak and soft subgrade soils often cause excessive settlement, rutting, deformation, and premature pavement failure under repeated traffic loading. Enhancing engineering properties of such soil is therefore essential to improve effectiveness and long-term durability of pavement system. Among various ground improvement techniques, the use of geosynthetic and natural reinforcement materials has emerged as a reliable and eco-friendly method for improving soil strength and enhancing its load-carrying capacity. A comparative evaluation of sandy soft subgrade soil with geogrid and bamboo grid was carried out using SCPT and DCPT. Laboratory investigations were performed on unreinforced and reinforced soil sections by placing geogrid and bamboo-grid layers at depths of 50 and 100 mm inside the developed soil bed. Experiments were conducted to evaluate the improvement in penetration behavior, soil stiffness, cone resistance and overall performance of the reinforced soil subjected to loading. The experimental findings indicate that both reinforcement materials significantly improved the behavior of the soft subgrade in comparison to the untreated soil. The penetration depth was reduced, while cone resistance and stiffness were enhanced in the reinforced soil sections. In the SCPT analysis, at 50 mm penetration depth, the geogrid-reinforced soil exhibited an increase of about 225% in cone resistance, while the bamboo-grid reinforced soil showed nearly 232.87% improvement in cone resistance compared to the unreinforced soil. Similarly, at 100 mm penetration depth, the geogrid reinforcement showed an increase of about 61.36% in cone resistance, whereas the bamboo-grid reinforcement achieved nearly 90.05% improvement compared to the unreinforced soil. Similarly, the DCPT results demonstrated substantial enhancement in penetration resistance, with improvements reaching approximately 300% at 50 mm reinforcement depth. At 100 mm depth, geogrid and bamboo-grid reinforcement achieved nearly 200% and 202.87% improvement, respectively. The study concludes that geogrid and bamboo-grid reinforcement techniques effectively improve bearing capacity & overall behaviour of soft subgrade soil. Moreover, bamboo-grid reinforcement can serve as an economical, eco-friendly, and locally available alternative to conventional reinforcement materials for sustainable pavement and geotechnical engineering applications.

LIST OF CONFERENCES/PUBLICATIONS

1. Roy, P., Gaur, K., and Trivedi, A. (2026). Effect of geogrid and bamboo-grid reinforcement in soil subgrade using static cone penetration test. In 5th *International Conferences on Advances in Science, Engineering & Technology (ICASET).*
2. Roy, P., Kumar, N., Gaur, K., and Trivedi, A. (2026). Effect of geogrid and bamboo-grid reinforcement in soil subgrade using dynamic cone penetration test. In *International Conference on Geotechnical Engineering and Civil Engineering Solutions (ICGECE)*.

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LIST OF SYMBOLS, ABBREVIATIONS, AND NOMENCLATURE

G_s: Specific gravity

W_s: Weight of solids

V_s: Volume of solids

Υ_w: Unit weight of water

C_u: Coefficient of uniformity

C_c: Coefficient of curvature

c: Cohesion

ϕ: Internal friction angle

μ: Micron

kg: Kilogram

kN: Kilo Newton

Fig.: Figure

mm: Milli meter

IS: Indian standard

cc: cubic centimeter

cm: Centimeter

m: Meter

g: Gram

H: Tank depth

m^2: Square meter

SP: Poorly graded sand

SW: Well graded sand

CBR: California bearing ratio

UCS: Unconfined compressive strength

SCPT: Static cone penetration test

DSCPT: Digital static cone penetration test

MDD: Maximum dry density

LVDT: Linear variable displacement transducer

OMC: Optimum moisture content

DCPI: Dynamic cone penetration index

USB: Universal serial bus

MD: Machine direction

CMD: Cross – machine direction

Lab.: Laboratory

DCPT: Dynamic cone penetration test

ITS: Intelligent transportation system

DCP: Dynamic cone penetrometer

APT: Accelerated pavement testing

M. Tech: Master of Technology

DTU: Delhi Technological University

CHAPTER 1

INTRODUCTION

This study focuses on understanding how geogrids improve the behavior of flexible pavements by strengthening the base layer. By through full-scale APT, the study compares reinforced and unreinforced sections to observe changes in deformation and structural behavior under repeated traffic loads (Han et al., 2020). This study explores how the depth and number of geogrid layers can enhance the strength of soft subgrade soil by enhancing its resistance to penetration under load (Boban et al., 2024). This study explains how using geosynthetic materials like geotextiles and geogrids can strengthen unpaved roads by improving load resistance and reducing damage on weak soil subgrades (Singh et al., 2020). This study examines how placing geogrids within inverted pavement layers can improve pavement strength and reduce surface damage under heavy traffic loads (Jiang et al., 2024). This study looks at how geogrids help strengthen weak pavement subgrades by improving load distribution and reducing surface rutting. Through laboratory tests and accelerated pavement studies, it shows that the performance of geogrids mainly depends on their mechanical properties and interaction with surrounding soil and aggregates (Tang et al., 2008). This study evaluates how geogrid reinforcement can enhance the performance of flexible pavements by reducing rutting and spreading traffic loads more effectively, leading to longer pavement life and possible reduction in base layer thickness(Sharbaf and Ghafoori, 2021). This study investigates how geosynthetic materials, such as geogrids and geotextiles, can develop the behavior of unpaved roads constructed on weak soils. Large-scale laboratory investigations were conducted to understand how reinforcement reduces rutting, lowers stress on the subgrade, and decreases maintenance needs. The results clearly show that reinforced roads perform better and last longer than unreinforced ones (Palmeira et al., 2010). This study focuses on how geogrid reinforcement can enhance the strength and stability of unbound aggregate layers applied in roads, railways, and pavements. Through laboratory testing subjected to static and cyclic load applications. it shows that position and number of geogrid layers play a key role in minimizing settlement and increasing bearing capacity (Raymond and Ismail, 2003). This study examines how geocell reinforcement enhances the behavior of unpaved roads through providing better lateral confinement to sand bases. Accelerated pavement testing shows that reinforced sections experience much less rutting and behave similarly to thicker aggregate layers (Yang et al., 2012).

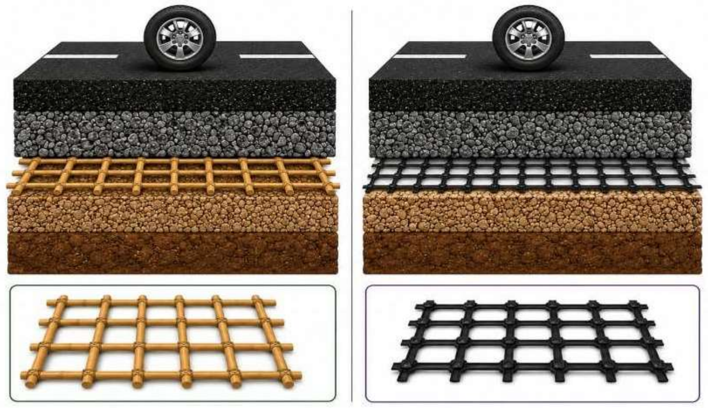

Fig.1.1 Schematic illustration of pavement structure with bamboo-grid and geogrid reinforced

This study investigates how geogrid reinforcement enhances the performance of unbound granular pavement granular layers under repeated traffic loading. Laboratory tests using a loaded wheel tester and cyclic plate loading show that geogrids significantly reduce rutting and enhance load resistance. The results confirm that proper geogrid selection can lead to longer-lasting and more stable pavement structures (Wu et al., 2015) . This study explores how adding geogrids to the base layer of flexible pavements can reduce rutting and improve overall pavement performance. Through laboratory cyclic plate load tests, it shows that geogrids help spread traffic loads more evenly and strengthen weak subgrades (Abu et al., 2011). This study shows that reinforcing thin flexible pavements with geogrids helps reduce rutting and improves pavement performance under repeated traffic loading (Jersy et al.,2012). This study explains how reinforcing airport flexible pavements with geogrids helps reduce cracks and stresses caused by heavy aircraft loads, leading to improved pavement strength and longer service life (Abdessemed et al., 2015). This study shows that using geogrids in unpaved roads helps reduce deformation and improves load distribution by providing better confinement to the base layer over weak subgrade soils (Sun et al., 2015). This study explains how numerical modelling and large-scale testing are used to examine the response characteristics of geogrid reinforced flexible pavement systems & evaluate their effectiveness in reducing rutting and improving pavement performance (Gu et al., 2016). This study presents an easy and practical approach to understand how geogrids influence the behavior of flexible pavement was improved through better load distribution and reduced rut formation under traffic loads (Gu et al., 2017). The study focuses on bamboo as a sustainable alternative to steel reinforcement material in concrete slabs and shows that properly treated bamboo can significantly improve flexural strength and load carrying capacity (Mali et al., 2018). This study shows that bamboo grid reinforcement is a simple, low cost & ecofriendly method to increase soil bearing capacity while significantly reducing settlement under load (Ahirwar et al., 2021). This review shows the capability of bamboo as a low cost & eco-friendly alternative to steel in ferrocement panels, focusing on its ability to improve flexural strength and structural performance in construction (Banger et al., 2024). This study shows that bamboo grid reinforcement is an effective and eco-friendly way to reduce settlement and provide better strength performance to peat soil under cyclic loading conditions (Waruwu et al., 2018). His research investigates effect of bamboo reinforcement on flexural performance of concrete beam subjected to bending loads. Bamboo was identified as a cost effective and environmentally substitute for steel in construction applications (Qaiser et al., 2020). This study examines how bamboo can be used as an environmentally friendly substitute for steel in concrete beams, focusing on its effect on strength and structural behaviour under load (Jahami et al., 2023). This study evaluates bamboo as an economical and eco-friendly alternative to conventional steel reinforcement by examining its tensile strength and performance in bamboo-reinforced concrete beams (Usidamen et al., 2024). Geosynthetics like geotextile and geogrid are commonly applied to strengthen unpaved roads by improving stability and reducing damage caused by weak soil conditions. (Singh et al., 2020).

CHAPTER 2

LITERATURE REVIEW

5 Performance of geogrid as a reinforced soil was examined by static and repeated loading conditions. The findings showed improvements in bearing capacity, resilient modulus, and strength parameters due to geogrid inclusion. An optimum geogrid placement depth of approximately 72–76% from the upper portion of the subgrade layer was identified for maximum benefit. The study further showed notable reductions in permanent and resilient strains, confirming the effectiveness of geogrid reinforcement in delaying rut formation and enhancing pavement durability (Kamel et al., 2004). Examined the role of geogrid mechanical and physical properties for stabilizing weak pavement subgrades. The study established that junction strength and tensile stiffness at low strains, and aperture size significantly influence pavement performance. Correlations between laboratory interface tests and accelerated pavement testing showed that geogrid stiffness affects rutting resistance and compaction quality. The research provides a systematic framework for selecting geogrids based on performance-related properties, although the analysis was limited to a single subgrade soil type (Tang et al., 2008). The results indicated substantial improvement in traffic benefit ratio and rutting resistance, particularly when geogrids were placed in upper one third portion of subgrade layer. Reinforcement redistributed applied stresses, thereby reducing permanent subgrade deformation. The study further showed that geogrids with higher tensile modulus provide greater performance benefits, supporting the need for proper material selection and placement for effective pavement reinforcement (Abu-Farsakh and Chen, 2011). Examine possibility of using bamboo instead of steel reinforcement in concrete beams, with emphasis on tensile and flexural performance. Experimental investigations included tensile strength tests on bamboo sticks with varying node numbers and flexural tests on plain, singly reinforced, and double reinforced bamboo concrete beams. The findings showed that bamboo possesses adequate tensile strength and deflection behaviour of beams when compared with plain concrete (Rahman et al., 2011). This laboratory-based investigation assessed effectiveness of geogrid reinforced flexible pavement through plate load testing. The results indicated that geogrid reinforcement enhanced load distribution, increased bearing capacity and reduced rutting, particularly when installed over weak subgrades. The effectiveness of reinforcement was found to depend strongly on geogrid stiffness and placement depth. While the study confirms the beneficial role of geogrids in pavement structures, it also identifies the need for

better correlation between laboratory findings and real field performance (Yang et al., 2012). The results confirmed that geogrid as a reinforcement substantially enhances rutting resistance and decreases surface deflection in sand and gravel bases. The study also validated the loaded wheel tester as a reliable laboratory tool, as its results closely matched cyclic plate loading outcomes. Performance was influenced by geogrid type and base material, indicating the need for material-specific reinforcement selection in pavement applications (Wu et al., 2015). The flexural behaviour of bamboo reinforced concrete slabs was experimentally assessed as a sustainable substitute for traditional steel reinforcement. Investigation focused on improving bamboo–concrete bonding behaviour by surface treatment and the development of a semicircular grooved bamboo strip. Results showed that treated and grooved bamboo reinforcement significantly improved load bearing capacity, flexibility, and energy dissipation. The flexural performance of grooved bamboo-reinforced slabs was comparable to, and in some cases exceeded, that of conventional reinforced concrete slabs (Mali and Datta (2018). Investigated the performance of bamboo – grid reinforcement improving engineering behavior of peat soils under repeated loading conditions. Laboratory tests were performed to unreinforced peat & reinforced peat with different layer of bamboo grid layers to evaluate settlement reduction, bearing capacity, modulus of subgrade along with shear modulus. (Waruwu et al., 2018). The study revealed that geosynthetic reinforcement substantially improved in-situ strength and reduced penetration depth compared to unreinforced sections. While geotextiles contributed more effectively to shear strength improvement, geogrids enhanced lateral restraint and load distribution. The research emphasizes the practical benefits of placing geosynthetics at the subgrade -based interface, although the limited test section size restricts large-scale applicability (Singh et al., 2020). The study demonstrated that placing geotextile and geogrid within the subgrade base interface zone significantly enhanced penetration resistance and in-situ strength compared to unreinforced sections. A substantial reduction in DCPI values and notable improvement in CBR were observed, with geotextile-reinforced sections showing superior performance. The findings confirm that geosynthetic reinforcement is a reliable and practical solution for enhancing strength, durability, and serviceability of unpaved road structures (Singh et al., 2020). Analyze the structural behavior of reinforced beams containing including bamboo strips as shear reinforcing material through experimental testing and numerical modeling. Five beams with varying bamboo strip spacing and configurations were subjected to four-point bending to evaluate load–deflection behavior, shear capacity, strain distribution, and crack patterns. The results demonstrated that bamboo strips significantly enhanced shear resistance, with up to 30% improvement in load-carrying capacity compared with conventional steel stirrups. Inclined bamboo strips showed superior performance over vertical arrangements. Finite element analysis using ABAQUS closely matched experimental results, confirming ability, bamboo as a sustainable and ecofriendly material (Jahami et al., 2023). The study clarified that adequate tensile strain development is essential for geogrid activation (Jiang et al., 2024). Results showed that geogrid reinforcement significantly enhanced subgrade strength and stiffness, with stiffness improvement reaching nearly 98%. Single-layer reinforcement performed best at shallow depth, while double- and triple-layer systems provided superior resistance under boundary effects, indicating that optimal placement and number of layers are critical for improving load–displacement behavior of soft subgrades (Boban et al., 2024). A detailed review on the flexural behavior related to bamboo-reinforced ferrocement panels, focusing on the capability of bamboo as a sustainable substitute for conventional steel wire mesh. The review study synthesized findings from previous experimental investigations on ferrocement panels reinforced with bamboo meshes of varying layers, spacing, and configurations (Bangar and Kawade, 2024). Investigated the behaviour of unpaved road sections reinforced with different geosynthetics under repeated loading conditions. The study demonstrated that geogrids, geotextiles, and geocells significantly reduced permanent settlement while improving elastic response. Among the reinforcements, geocells provided superior confinement when optimal height and placement were used. Excessive geocell height, however, reduced performance due to inadequate granular cover. The research highlights that reinforcement type, geometry, and placement depth collectively govern unpaved road performance (Nair and Latha, 2015). Conducted full-scale APT to evaluate NPA geocell reinforced constructed on soft subgrades. Study found that geocell reinforcement significantly reduced rut depth and improved load distribution, even when thinner base layers were used. Among different infill materials, recycled asphalt pavement (RAP)-filled geocells exhibited the best performance. The findings confirm that geocell reinforcement can effectively extend service life and reduce base thickness requirements for low-volume roads on weak soils (Pokharel et al., 2011). Examined the behaviour of unpaved roads reinforced with novel polymeric alloy (NPA) geocells using accelerated pavement studies. The study showed that geocell-reinforced sand bases significantly reduced rutting and enhanced structural stability under repeated wheel loading. A thinner geocell-reinforced sand layer performed equivalently to a much thicker conventional aggregate base, highlighting material efficiency. However, insufficient geocell thickness led to structural failure due to cell bursting, emphasizing the importance of adequate geocell integrity and base thickness in pavement design (Yang et al., 2012). The authors conducted full-scale accelerated traffic testing to observe that behaviour of triaxial geogrid reinforcement in thin pavement structure. The obtained geogrid-reinforced section demonstrated delayed rutting initiation and significantly higher traffic capacity compared to unreinforced control sections with similar or greater asphalt thickness. Despite early termination of testing due to flooding, the reinforced pavement showed clear structural benefits and maintained base stiffness for longer durations. The study confirms that geogrid reinforcement can enhance service life and reduce dependence on increased asphalt thickness, supporting more cost-effective pavement designs (Jersey et al., 2012).

2.1 Research gaps

Based on the previous studies of the published literature, the following research gaps have been observed:

1) Earlier studies have established that geogrid and bamboo grid reinforcement can enhance pavement and soil performance; however, a comprehensive understanding of their behaviour under repeated and traffic-induced loading conditions is still limited, particularly for weak subgrade soils.
2) The literature reports inconsistent findings regarding the optimum depth, configuration, and number of reinforcement layers, indicating the need for systematic experimental investigation to achieve reliable design recommendations.
3) Most available research is restricted to laboratory-scale or short-term studies, while long-term performance and field-representative loading conditions remain inadequately explored.
4) Limited attention has been given to the combined effect of soil reinforcement and dynamic traffic parameters, such as cyclic loading and vehicle-induced vibrations, which are crucial for realistic pavement behaviour assessment.

2.2 Objective

The objectives of current study were prepared based on research gaps identified in earlier investigations.

1) Evaluate the behaviour of reinforced soil pavement systems in comparison with unreinforced conditions.
2) To evaluate how different reinforcement materials, such as geogrid and bamboo grid, influence load deformation behavior of soil subgrade.

3) To analyse influence of reinforcement depth and layering on strength and settlement characteristics.
4) To examine the behaviour between soil & reinforcement materials contributing to improved stiffness and stability.
5) To analyse the response of reinforced systems under repeated and traffic-induced loading conditions.

CHAPTER 3

MATERIALS AND METHODOLOGY

3.1 Materials and Methods

Present study investigates, sandy soil sample along with geogrid & bamboo-grid as reinforcement material. Various laboratory test was conducted for the characterization of soil. Properties of soil was determined through sieve analysis, pycnometer bottle method, standard proctor test, and direct shear test (DST). Finally, SCPT as well as DCPT were conducted in Soil Dynamics & ITS laboratory under both reinforced and unreinforced conditions.

3.2 Particle Size Analysis

Particle size analysis of soil was performed in Soil Mechanics Laboratory at DTU in accordance with IS: 2720 (Part 4) – 1985. A 1 kg soil sample was sieved through sieves sizes 4.75 to 0.075 mm shown in Figure 3.1 schematic illustration of sieve analysis. The weight retained on every sieve was noted, and the percentage finer was calculated. Gradation curve obtained from curve as shown in Figure 3.2. From curve value of D_{10} , D_{30} , and D_{60} were find 0.29, 0.36, and 0.45 mm respectively. Using these values C_u and C_c were determined 1.55 and 0.99, respectively. Based on results, soil was identified as poorly graded sand. The parameters were calculated using standard equations (Ranjan and Rao ,2011). The grain size properties of soil were obtained from sieve analysis result and were presented in Table 3.1.

The gradation curve was plotted with grain size (log scale) on the x-axis and percent passing along the y-axis. This curve helps to determining C_u and C_c.

$$C_u = \frac{D_{60}}{D_{10}} \quad \text{......} \quad (3.1)$$

$$C_c = (D_{30})^2/(D_{60} * D_{10}) \quad \text{......} \quad (3.2)$$

Where, D_{10}, D_{30} and D_{60} are the diameter of the grain size corresponding to 10, 30 and 60 percent finer, respectively.

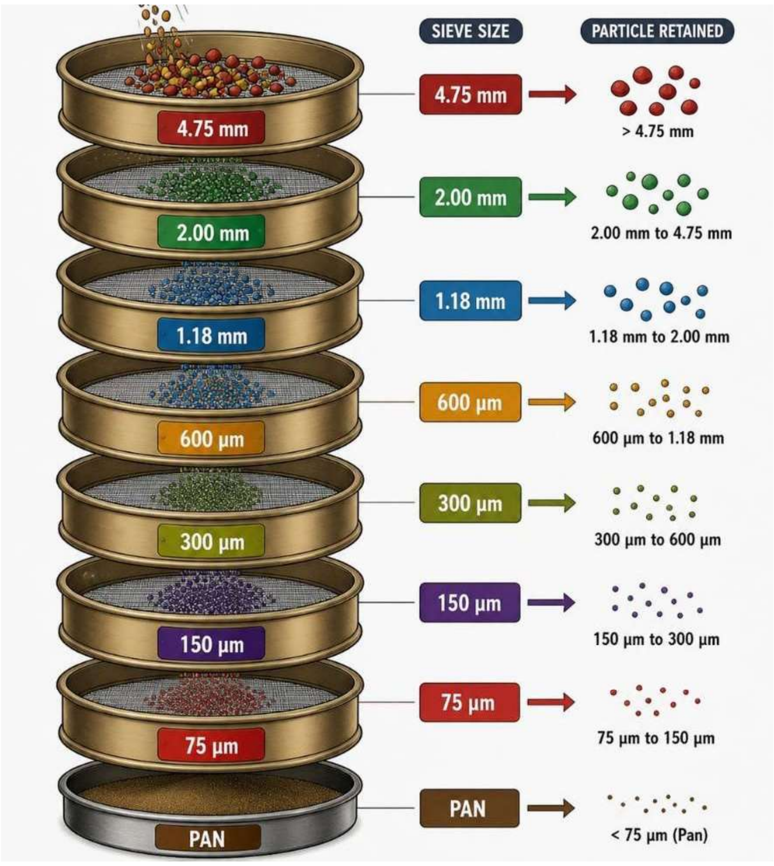

Fig. 3.1 Schematic representation of grain size analysis setup

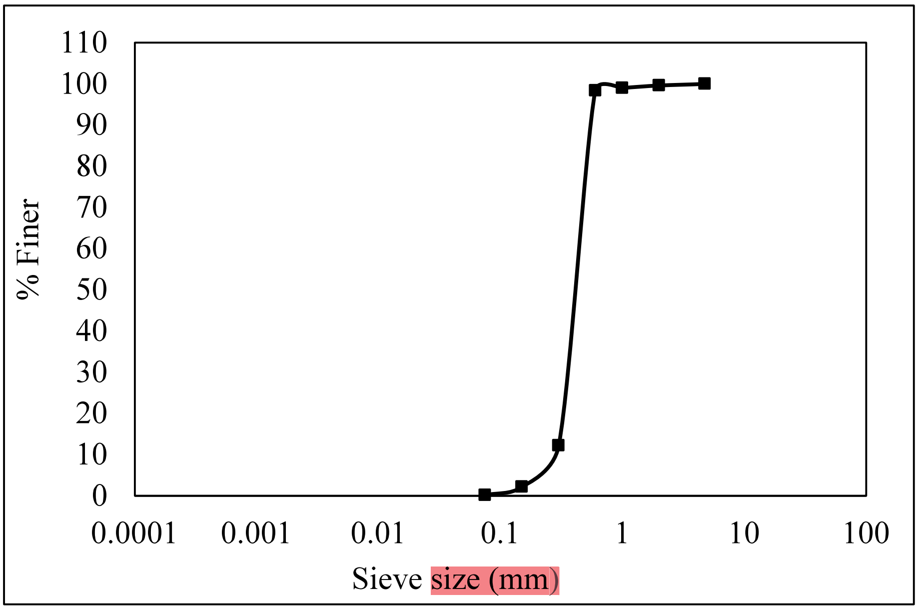

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Fig. 3.2 Grain size distribution curve

Table 3.1 Summary of particle size distribution parameters obtained from sieve test

Parameter	Value
D_{10}	0.45
D_{30}	0.36
D_{60}	0.29
C_c	0.99 ≈1
C_u	1.55

3.3 Pycnometer Bottle Method

The pycnometer bottle method was carried out in accordance with IS: 2720 (Part 3) – 1980 using sandy soil passing through a 4.75 mm sieve. Specific gravity of the soil, influenced by the mineral characteristics of soil particle, represents ratio between weight of soil solids and weight of an equal volume of water at 4°C (Ranjan and Rao, 2011). Specific gravity value of sandy soil obtained from pycnometer bottle test was found to be 2.66. Shown in Table 3.2 observation and calculation.

Fig. 3.3 Pycnometer bottle (Soil Mechanics laboratory ,DTU ,Delhi)

$$G_s = \frac{W_s}{V_s \gamma_w} \quad (3.3)$$

$$G_s = \frac{\gamma_s}{\gamma_w} \quad (3.4)$$

$$G_s = \frac{w_2 - w_1}{(w_2 - w_1) - (w_3 - w_4)} \quad (3.5)$$

Where, G_S = Specific gravity, W_1 = Initial weight of pycnometer bottle

W_2= Measured weight of pycnometer containing oven-dried soil, W_3 = Weight of pycnometer bottle after adding soil and water, W_4= Weight of the water filled pycnometer bottle

Table 3.2 Experimental data obtained for specific gravity test (Pycnometer method)

Particulars	Recorded value in g
Initial weight of the pycnometer bottle	698
Measured weight of pycnometer containing oven-dried soil	1160
Weight of pycnometer bottle after adding soil and water	1868
Weight of the water-filled pycnometer bottle	1580
G_S	2.66

3.4 Standard Proctor Test

Standard proctor test was carried out according to IS: 2720 (part 7) – 1980 For this test, 3 kg of oven dried soil was taken & mixed with different water contents ranging from 2% to 10%. Soil was compacted inside a mold in three uniform layer and every layer compacted 25 no. of blows with 2.6 kg rammer was dropped freely from a height of 310 mm above. After compaction, weight of the soil inside mold was determine soil density.

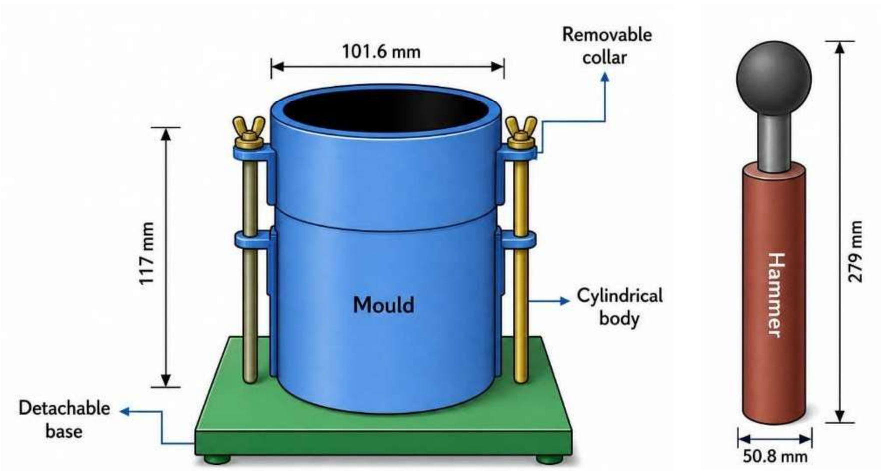

Fig. 3.4 Schematic diagram of standard proctor test

The procedure repeated for different water content, and compaction curve presented in Figure 3.5. From curve, MDD and OMC was determined as 17.854 kN/m³ and 8%, respectively. Observation and data collect summarized in Table 3.3.

Table 3.3 Compaction test data using standard proctor method

Water Content, w (%)	2	3	4	5	6	7	8	9	10
Mass of empty mould, W_1					3780 g				
Volume of mould, V					944 cc				
Mass of Mould +soil, W_2 (g)	5246	5282	5358	5430	5520	5590	5644	5610	5560
$W_2 - W_1$, g	1466	1502	1578	1650	1740	1810	1864	1830	1780
$Y_b = W_2 - W_1 / V$ (g/cc)	1.55	1.59	1.67	1.75	1.84	1.91	1.97	1.94	1.89
$Y_d = Y_b / 1 + w$ (g/cc)	1.52	1.54	1.61	1.67	1.74	1.79	1.82	1.77	1.71
Y_d (kN/m³)	14.9	15.1	15.8	16.4	17.1	17.6	17.9	17.4	16.8

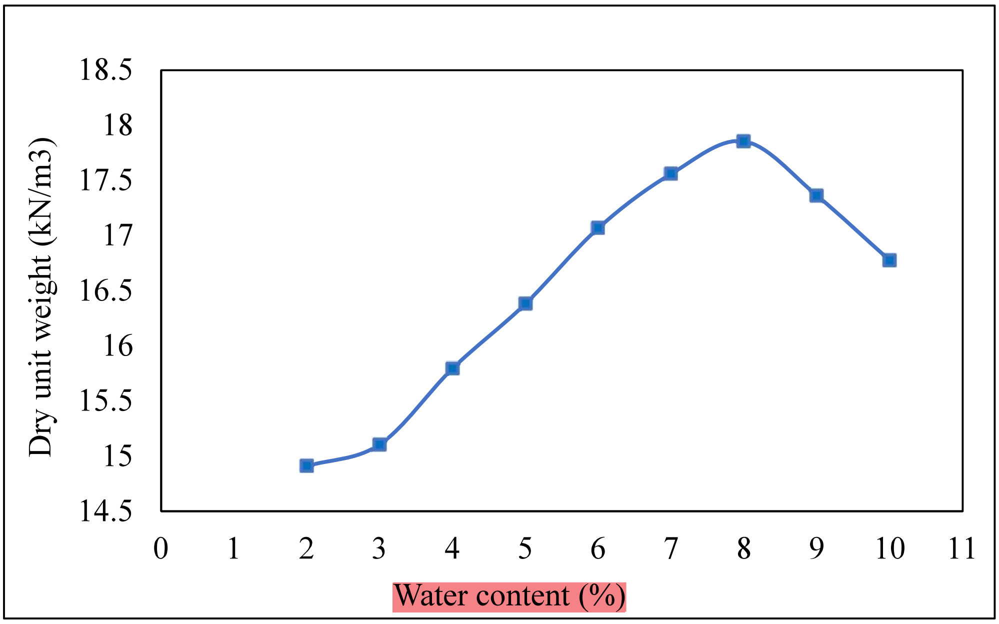

Fig. 3.5 Dry unit weight v/s moisture content curve

3.5 Direct Shear Test

DST was conducted according to IS: 2720 (Part 13) – 1986 to determine shear strength of soil. Soil sample was compacted in shear box size of 60 mm × 60 mm, which consisted of a porous stone, base plate, grid plates, and other accessories. After assembling the apparatus, normal stress of 0.5 kg/cm² was provided, and horizontal shear force was gradually increased up to failure occurred. During the experiment shear force and corresponding horizontal displacement were monitored. The procedure was further carried out under increased normal stresses of 1 and 1.5 kg/cm². Cohesion (c) and angle of internal friction (ϕ) were determined from test results. DST setup shown in Figure 3.6.

Fig. 3.6 Direct shear testing system consisting of test setup

Fig. 3.7 Experimental setup of DST subjected to a normal stress of 0.5, 1 and1.5 kg/cm² (Soil Mechanics Laboratory, DTU, Delhi)

A direct shear test to evaluate shear strength characteristics of soil. DST was conducted on sandy soil samples within normal stresses of 0.5, 1, and 1.5 kg/cm², as illustrated in Figure 3.7. Each specimen was exposed to horizontal shearing until either failure occurred or a maximum horizontal displacement of 20% was achieved. The shear load and corresponding displacement readings recorded during testing were utilized to prepare a shear versus normal stress graph. Based on failure envelope (Figure 3.8) shear strength of soil was determined. Soil exhibited a cohesion and angle of internal friction value of 2.6 kPa and 26° respectively. The fundamental properties of soil considered in experimental study presented in Table 3.4.

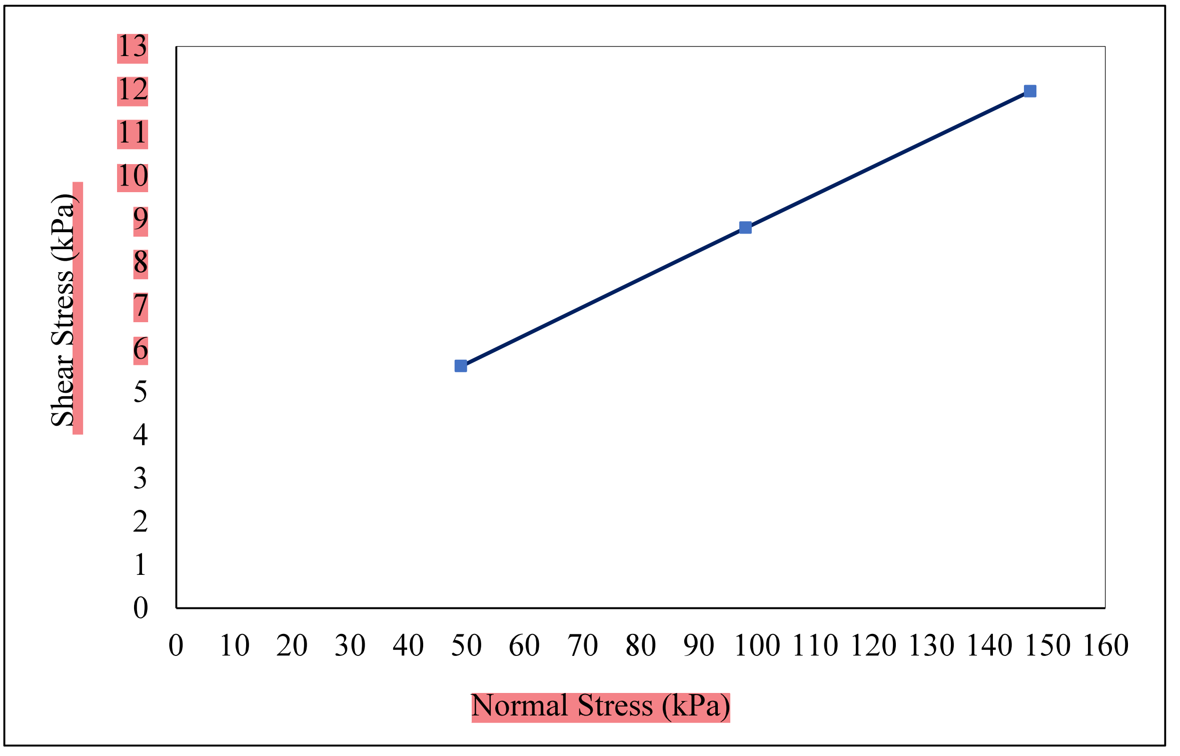

Fig. 3.8 Normal stress v/s shear stress curve

Table 3.4 Basic properties of soil

Property	Result
Soil type	Sandy soil
Gradation of soil	Poorly graded sand (SP)
G_s	2.66
MDD	1.82 g/cc (17.854 kN/m³)
OMC	8%
Cohesion (c)	2.6 kPa
ϕ	26°

The Table 3.5 presents the observed value of applied normal stress during DST along with the corresponding maximum shear stress developed at failure.

45

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Table 3.5 Summary of normal stress and peak shear stress

S.I No.	Applied Normal Stress	Normal Stress (kPa)	Peak Shear Stress (kPa)
1	0.5	49.033	5.60
2	1.0	98.067	8.80
3	1.5	147.10	11.96

3.6 Static Cone Penetration Method

SCP test used to evaluate strength of soil subgrade (Singh et al., 2020). Unlike conventional SCPT systems that use hydraulic jacks, the digital SCPT equipment employed in this study operates using manual push handles shown in Figure 3.9 (Singh et al., 2020). The soil sample was placed inside a steel tank, as shown in Figure 3.10. The testing system consisted of a 60° cone attached to a steel rod having16 mm diameter and 498 mm length, a load cell, and an LVDT. All measurements of force and penetration depth were captured using a data acquisition system connected via USB. The operator applied a uniform downward force using body weight, allowing the cone to penetrate the soil. The test was continued until further penetration was not possible despite additional load.

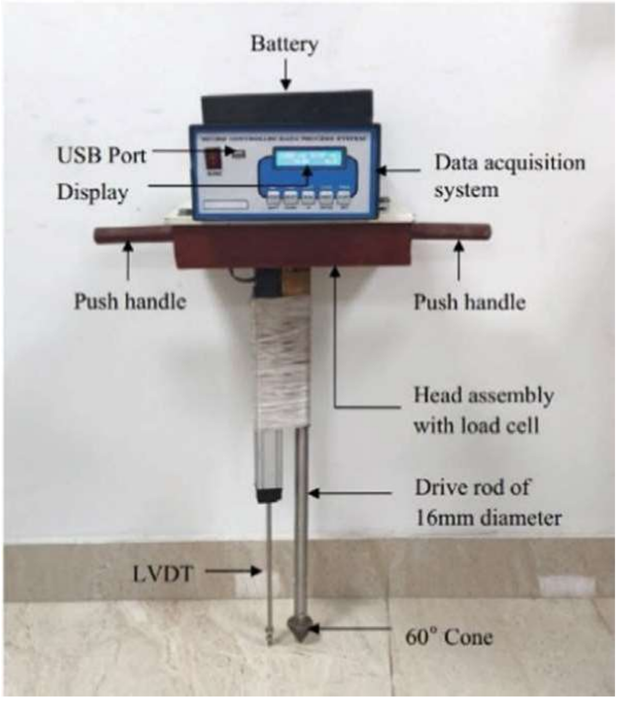

Fig. 3.9 Digital static cone penetrometer

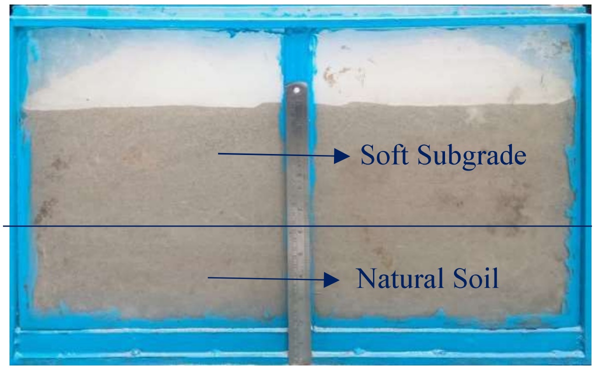

Fig. 3.10 Steel tank with soil sample (Soil Dynamics and ITS laboratory ,DTU ,Delhi)

The steel tank used for the test had dimension in length 650 mm, width 450 mm, and depth 300 mm. The top 150 mm layer was considered as the unpaved road layer, while the remaining 150 mm represented the natural soil. It is susceptible to shear fluidization under dynamic loading conditions (Das and Luo, 2016).

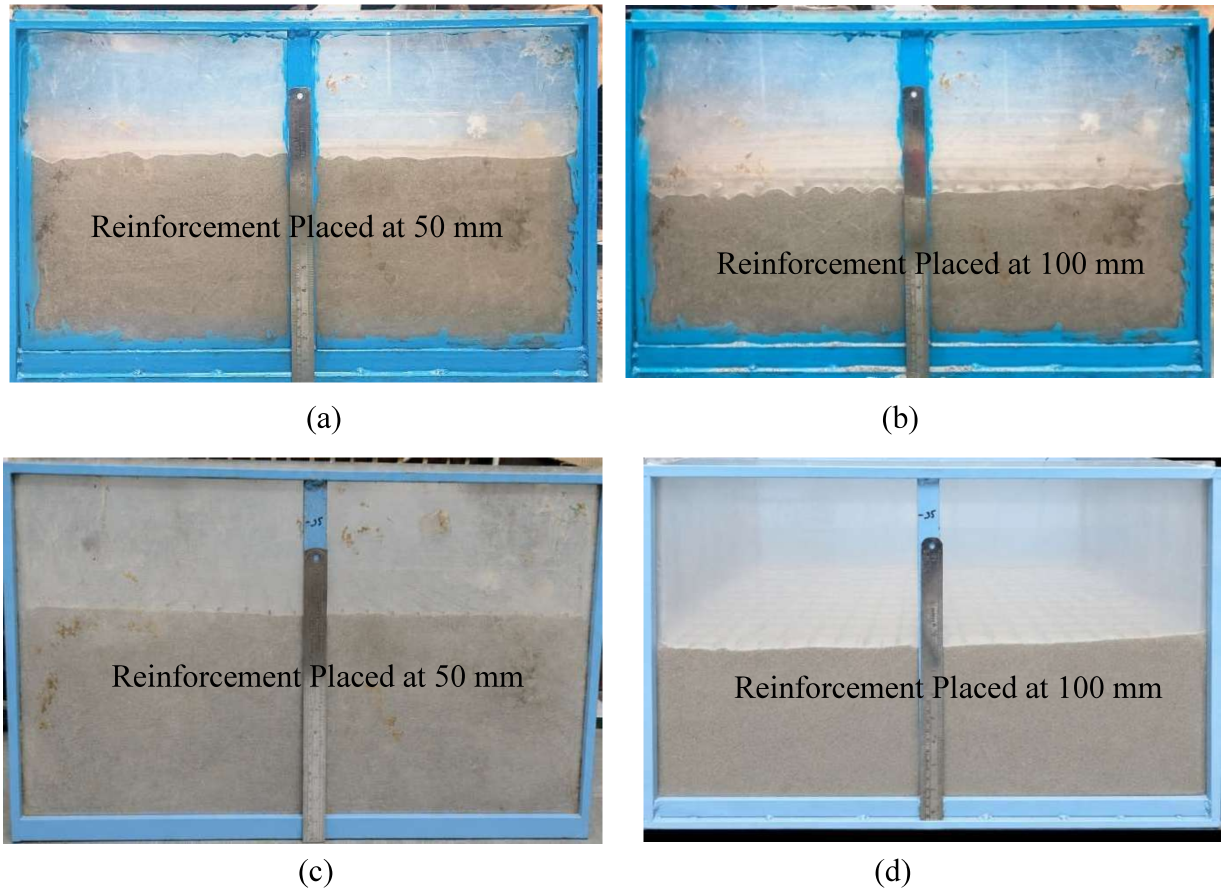

Fig. 3.11 Experimental steel tank showing placement of (a) Bamboo-grid reinforcement at 50 mm (b) Bamboo-grid reinforcement at 100 mm (c) Geogrid reinforcement at 50 mm (d) Geogrid reinforcement at 100 mm (Soil Dynamics and ITS lab ,DTU ,Delhi)

Previous studies recommend reinforcing soil within 0.25H to 0.5H of the total depth to reduce such effects (Boban et al., 2024). Accordingly, a reinforcement depth of 50 and 100 mm were adopted in this study. Test locations inside tank are illustrated in Figure 3.11. Tests were conducted under both unreinforced and reinforced conditions using geogrid and bamboo-grid layers placed at depths of 50 mm and 100 mm.

3.7 Dynamic Cone Penetration Test

DCP employed in the present study, as illustrated in Figure 3.12, conforms specifications outlined in ASTM D6951-03. Test was evaluating in-situ strength of compacted subgrade soil. DCP apparatus consisted of a steel cone having a cone angle of 60° along with a base diameter having 20 mm, rigidly connected with a rod of 16 mm diameter. During testing, the rod is maintained in a vertical alignment to ensure uniform penetration. A hammer weighing 8 kg was raised to fixed height of 575 mm and then allow to free fall onto anvil, thereby forcing the cone into the soil. Special attention was given to the handling of the hammer during testing procedure.

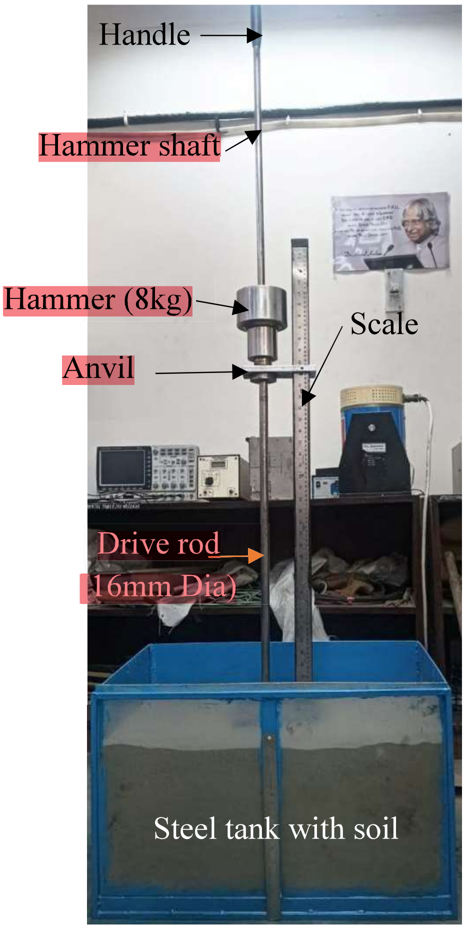

Fig. 3.12 Dynamic cone penetration test (Soil Dynamics and ITS Lab DTU, Delhi)

The hammer was raised only up to the designated lower stop without causing any upward displacement of the cone prior to release. Any improper handling during lifting or dropping may introduce significant errors in the recorded penetration values. The penetration corresponding to the initial hammer blow was disregarded, as the contact area of the cone tip is comparatively smaller during the first impact than in subsequent blows.

The cone diameter is intentionally designed to be larger than rod diameter to ensure that soil resistance is predominantly mobilized along cone surface. Penetration depth was recorded after every hammer blow. DCPI represents the penetration per hammer blow and is reported in mm/blow. It may be determined analytically using the following equation 3.8.

$$DCPI = \frac{P_{(i+1)} - P_{(i)}}{N_{(i+1)} - N_{(i)}} \quad \ldots\ldots (3.6)$$

Here, DCPI (mm/blow), $P_{(i+1)}$ and $P_{(i)}$ denote the penetration depths (in mm) at successive blows, and $N_{(i+1)}$ and $N_{(i)}$ correspond to the cumulative number of blows. Furthermore, DCPI values can also be obtained graphically by plotting penetration depth with cumulative number of blows and determining its slope of the best-fit line. The results obtained from DCP test were estimated representative DCPI values for subgrade soil, using the relationship in equation 3.7 provided (Chennarapu et al., 2018). In addition, the variation in slope of the penetration versus blow count curve was utilized to identify the boundaries between different soil layers. These variations provided a clear indication of changes in soil properties with depth.

$$DCPI_{avg} = \frac{\sum_{i}^{N} DCPI}{N} \quad \ldots\ldots (3.7)$$

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

3.8 Geosynthetic and Natural Reinforcement

In this study, geogrid and bamboo grid were used as reinforcement materials and placed within the sandy soil at depths of 50 & 100 mm below surface. These reinforcements were introduced to enhance load carrying capacity and minimize lateral movement of soil particles. Biaxial geogrid used in this work (shown in Figure 3.13) is manufactured from a perforated polypropylene sheet with a network of interconnected ribs.

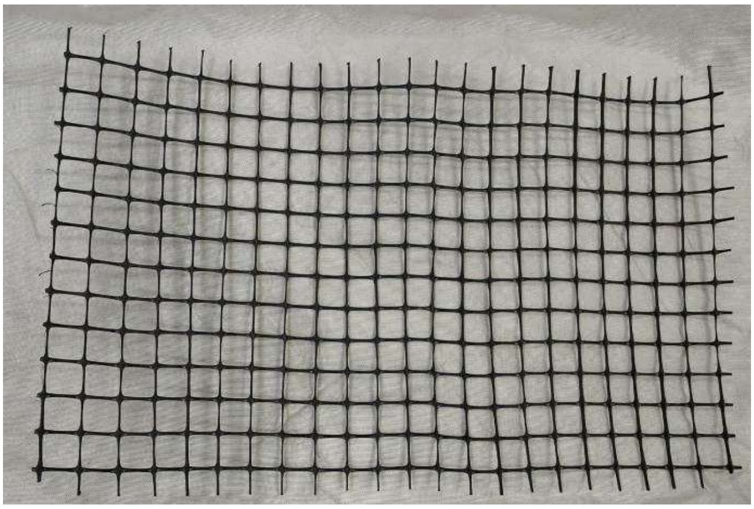

Fig. 3.13 Biaxial geogrid used for reinforcement

This geogrid-like structure provides confinement to granular soil and enhances soil reinforcement interaction by increasing interface friction. As a result, the sideways displacement of sand particles is effectively controlled, leading to enhanced strength & stability of soil layer. Geogrid properties shown in Table 3.6 (Singh et al., 2020).

Table 3.6 Properties of geogrid

Category	Parameter	Values
Physical Features	Geosynthetic type	Bidirectional geogrid
	Color of geogrid	Dark-colored
	Pattern shape of grid	Four-sided shape
	Type of polymer material	(PP) Polypropylene
Mechanical Features	Grid opening (mm)	30 × 30 (MD × CMD)
	Stiffness at 0.5% strain (kN/m)	550 × 350 (MD × CMD)
	Rib width (mm)	0.26
	Rib thickness (mm)	0.38
	Thickness of junction (mm)	0.6
Performance Features	Interface friction coefficient	1.78 at 10 kPa, 1.14 at 20 kPa
	Installation damage factor	1

Table 3.7 Properties of bamboo-grid adopted in the present study

Property	Value
Grid type	Natural bamboo -grid
Size (mm)	650×450×6
Color	Natural bamboo-color
Weight (g/m^2)	1552.02
Shape	Quadrangular
Material	Natural
Aperture dimensions (mm)	35×30 (MD×CMD)
Rib width	≈3
Rib thickness(mm)	≈6
Junction thickness(mm)	≈12

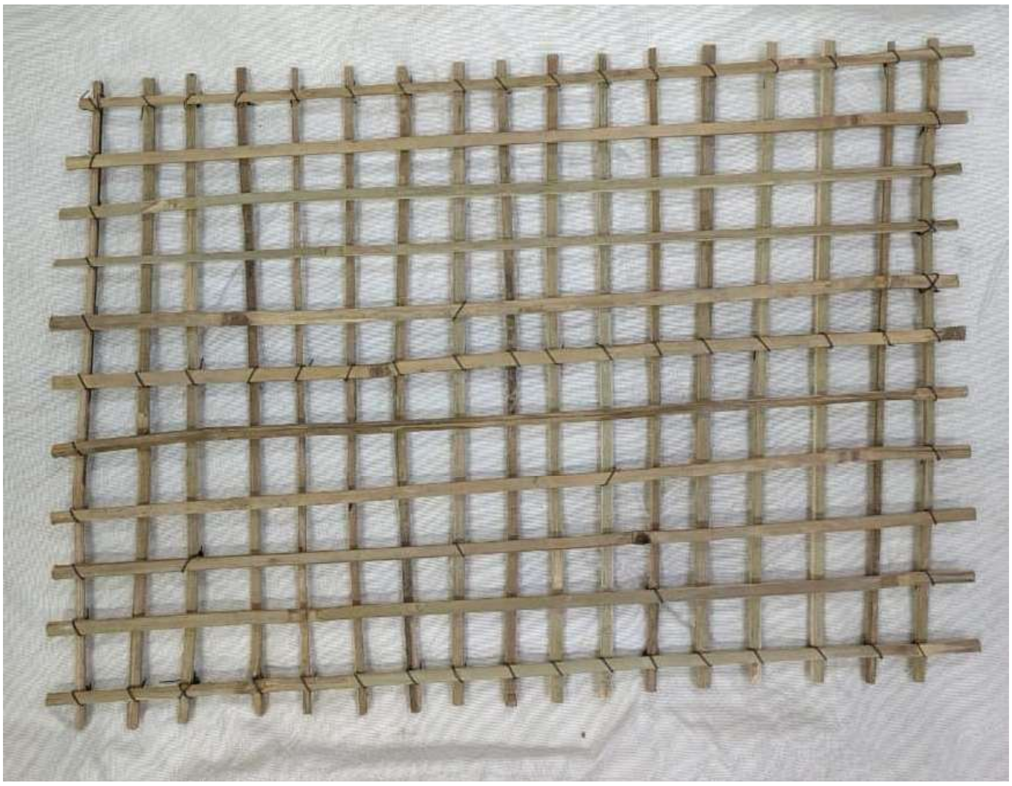

Fig. 3.14 Bamboo grid used for reinforcement

The bamboo grid above shown in Figure 3.14, used as a natural and eco-friendly alternative, is fabricated from mature bamboo strips that are cut, treated, and woven into a grid pattern. Bamboo is a natural and renewable material well known for its high tensile strength, flexibility along with biodegradability. The bamboo strips are typically treated with preservative solutions to improve resistance against moisture, insects, and microbial attack. When placed within soil, the bamboo grid acts as a reinforcing framework that distributes applied loads and restricts excessive deformation of the soil mass. Bamboo-grid properties presented in Table 3.6.

CHAPTER 4

RESULTS AND DISCUSSIONS

4.1 Digital Static Cone Penetration Method

DSCPT was carried out using poorly graded sand to evaluate effect of reinforcement on penetration resistance of soil. Reinforcement was installed at two different embedded at 50 mm and 100 mm beneath the top sand surface . When the cone was positioned near the soil surface, it penetrated easily under its own weight, indicating that the loose sandy soil provided very low resistance to penetration. Shown in Figure 4.1 3D schematic representation of the steel tank containing soft subgrade soil reinforced

The DSCPT was carried out under the following two conditions:

- Without reinforcement
- With reinforcement using geogrid and bamboo- grid

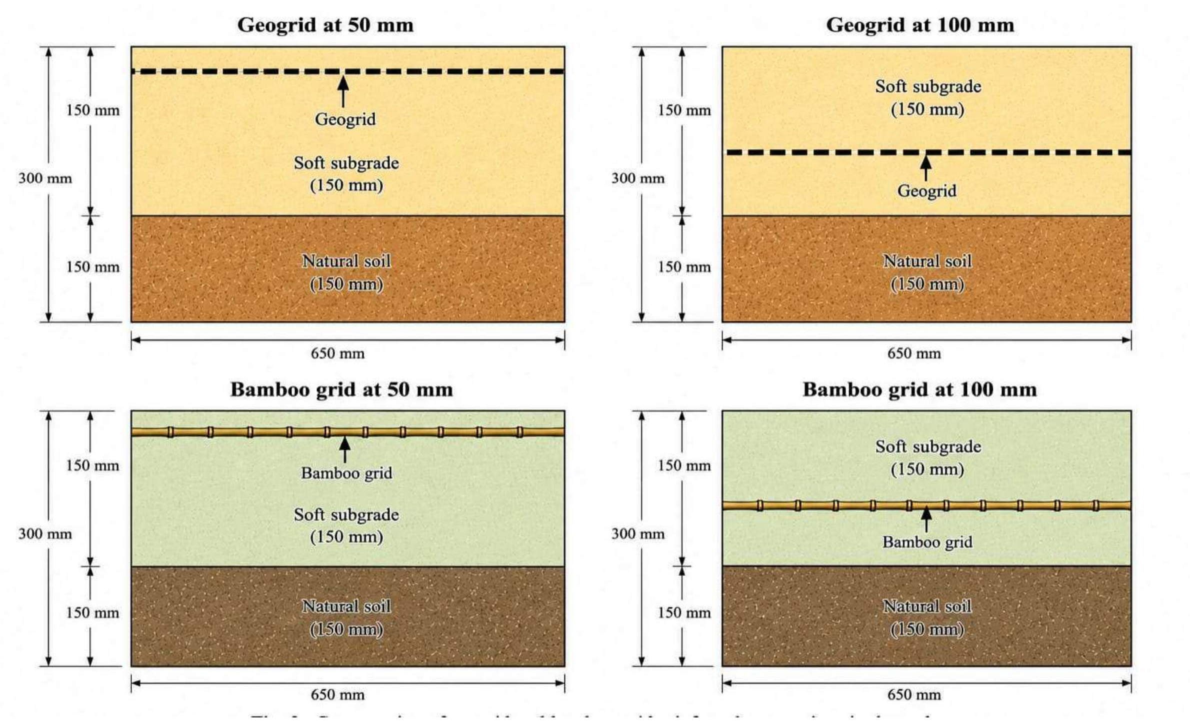

Fig 4.1 2D schematic representation of the steel tank containing soft subgrade soil reinforced with reinforcement layers installed at 50 mm and 100 mm.

In the unreinforced condition, the cone penetrated into the soil subgrade with minimal resistance, reflecting the weak nature of the loose sand. As the penetration depth increased, the resistance gradually improved because of soil densification produced by overburden pressure. The results clearly highlight the beneficial role of reinforcement influence on the performance of soft subgrade soil. Without reinforcement, soil experienced rapid penetration even under minimum loads, resulting in higher displacement and lower bearing resistance.

4.1.1 The Reinforcement Layers of Geogrid and Bamboo – Grid were Positioned 50 mm Below the Surface

The load -displacement curve (presented in Figure 4.2) behavior of sandy soil was studied for three cases: untreated soil, geogrid -reinforced soil, and soil strengthened using a bamboo-grid, both placed at a depth of 50 mm.

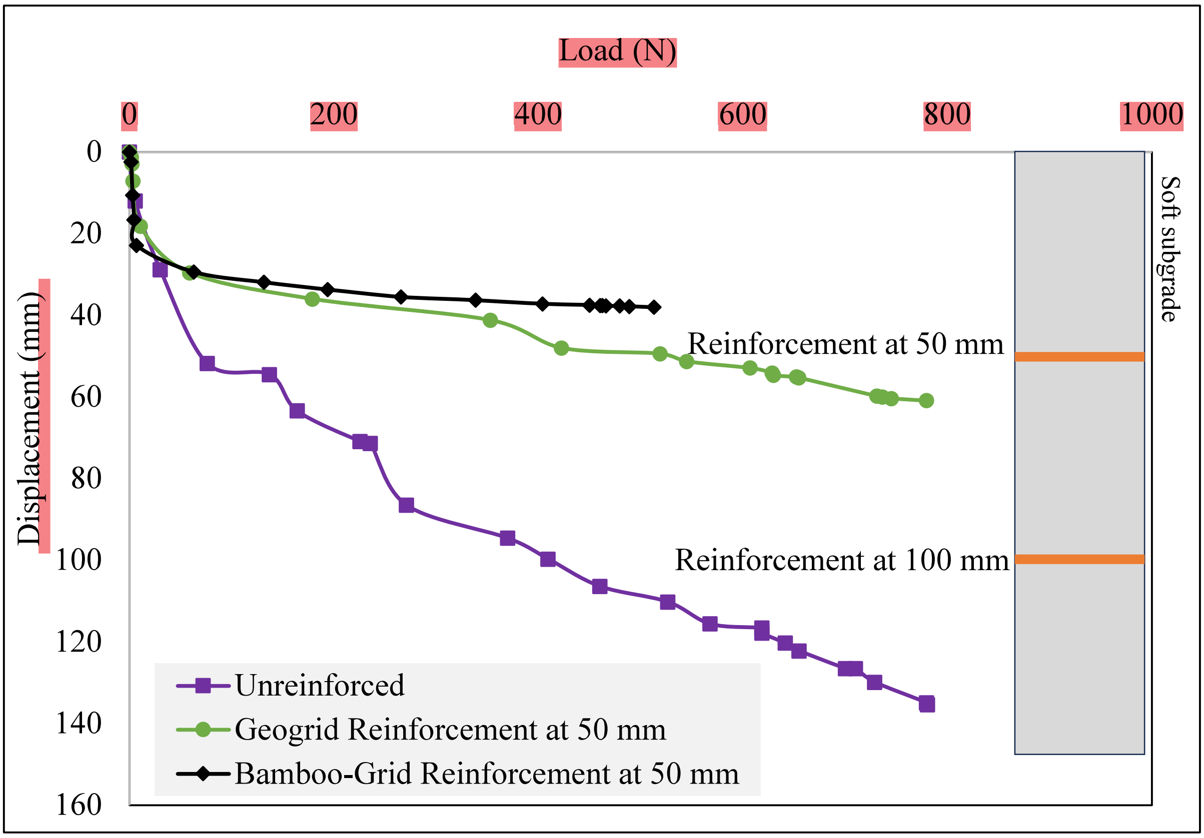

Fig. 4.2 Load displacement curve without and with reinforced at 50 mm depth

The Digital Static Cone Penetration Test (DSCPT) results indicate that the inclusion of reinforcement at 50 mm depth significantly influenced the penetration resistance behaviour of the soil. The load–penetration curves obtained for unreinforced soil, geogrid reinforcement, and bamboo-grid reinforcement showed noticeable differences throughout the penetration process.

Table 4.1 Observation and data collection with and without reinforcement at 50 mm depth

	Without reinforcement		With Geogrid at 50mm		With bamboo-grid at 50mm	
S.I No.	Load (N)	Disp. (mm)	Load (N)	Disp. (mm)	Load (N)	Disp. (mm)
1	0	0	0	0	0	0
2	5.5	12	2	1.3	01.5	2.4
3	30	28.8	2.5	2.9	3	10.6
4	76	51.8	3.5	7.1	2.5	16.6
5	137	54.5	10.5	18.2	7	22.9
6	164	63.4	59	29.6	63	29.4
7	225.5	70.9	179	36	131.5	31.9
8	235.5	71.4	353	41.2	194	33.7
9	271	86.5	422.5	48	265.5	35.5
10	370	94.6	519	49.4	338.5	36.3
11	409.5	99.7	545	51.3	404	37.2
12	460	106.4	607	52.9	450	37.5
13	526.5	110.2	628.5	54.1	460.5	37.6
14	568	115.6	630	54.7	459.5	37.6
15	618.5	116.6	652.5	55.1	466	37.7
16	618.5	117.8	654.5	55.3	479.5	37.7
17	641.5	120.3	731	59.8	489	37.8
18	655	122.2	736.5	60	513	38
19	700.5	126.5	745	60.4	---	---
20	710	126.5	779.5	60.9	---	---
21	729	129.9	---	---	---	---
22	779.5	134.9	---	---	---	---
23	780.5	135.4	---	---	---	---

In the initial stage of penetration, all sections exhibited nearly similar behaviour under low loading conditions. However, as the penetration depth increased, the unreinforced soil showed rapid penetration under comparatively lower load values. The curve for untreated soil remained lower throughout the test, indicating weaker resistance against cone penetration and lower stiffness characteristics of the soil mass.

For the geogrid reinforced layer positioned at 50 mm depth, the penetration resistance increased gradually with increase in applied load. From the graph, it can be observed that a penetration of nearly 20–25 mm occurred at approximately 150–170 N load, while penetration increased to around 45–50 mm at nearly 300–320 N load. Beyond this stage, the curve shifted upward compared to the untreated soil, indicating improved resistance against cone movement. The geogrid-reinforced section exhibited nearly 225% improvement in penetration resistance compared to the unreinforced condition at 50 mm depth. The gradual slope of the curve indicates controlled deformation and effective confinement of soil particles around the reinforcement layer. The soil reinforced with the bamboo- grid also Showed a significant improvement in capacity to withstand load related to untreated soil. Geogrid as well as bamboo-grid reinforced soils demonstrated better performance than the unreinforced soil by improving stiffness and reducing settlement under loading conditions. The bamboo grid helped in mobilizing resistance inside the soil layer by functioning as a tensile reinforcement layer. Both reinforcement techniques considerably reduced settlement & increased overall load bearing capacity of sand. The geogrid reinforcement showed almost same performance, while the bamboo grid provided comparable results. Bamboo-grid as an eco-friendly and sustainable alternative to synthetic reinforcement materials. Overall, both reinforcement techniques considerably reduced settlement and increased the ability of sandy soil to withstand loads .Geogrid-reinforced section exhibited comparable cone resistance and stiffness values as shown by bamboo grid reinforcement. The study concluded that bamboo-grid reinforcement may prove as a sustainable and locally available alternative compared to other reinforcement types. Observation and data collection in above Table 4.1.

4.1.2 The Reinforcement Layers of Geogrid and Bamboo – Grid were Positioned 100 mm Below the Surface

The load–displacement curve of sandy soil was determined for three conditions: unreinforced soil, soil reinforced with a bamboo grid and geogrid both installed at 100 mm depth. The curves shown in Figure 4.3 clearly show influence of reinforcement depth on the settlement behaviour and load response of the soil. Observations and recorded readings are presented in Table 4.2.

Table 4.2 Observation and recorded readings with and without reinforcement at 100 mm depth

	Without reinforcement		With geogrid at 100mm		With bamboo-grid at 100mm	
S.I No.	Load (N)	Disp. (mm)	Load (N)	Disp. (mm)	Load (N)	Disp. (mm)
1	0	0	0	0	0	0
2	5.5	12	1.5	1.6	3	0.5
3	30	28.8	12.5	8.2	2	5.8
4	76	51.8	34	15.4	2.5	13.4
5	137	54.5	57	18.3	4.5	27.2
6	164	63.4	85.5	25.6	20	36.2
7	225.5	70.9	96	34.7	55	43.9
8	235.5	71.4	137	39.4	125.5	50.1
9	271	86.5	174	48.7	183	54.2
10	370	94.6	209.5	56.4	229.5	57.5
11	409.5	99.7	255.5	66.1	294.5	58.8
12	460	106.4	338	68.7	334.5	60
13	526.5	110.2	406	76.3	360	61.7
14	568	115.6	498	83.2	429	63.3
15	618.5	116.6	505.5	85.5	467.5	63.4
16	618.5	117.8	528	89.3	478.5	63.8
17	641.5	120.3	567	91.05	480	64
18	655	122.2	580	93.45	484	64.4
19	700.5	126.5	594	96.7	490	64.5
20	710	126.5	600	97.6	488.5	64.5
21	729	129.9	625.5	99.2	490.5	64.5
22	779.5	134.9	631	100.3	490	64.6
23	780.5	135.4	645.5	100.6	497.5	64.6
24	---	---	676	101.8	502.5	64.7
25	---	---	709.5	102.6	501	64.8
26	---	---	---	---	518	64.8

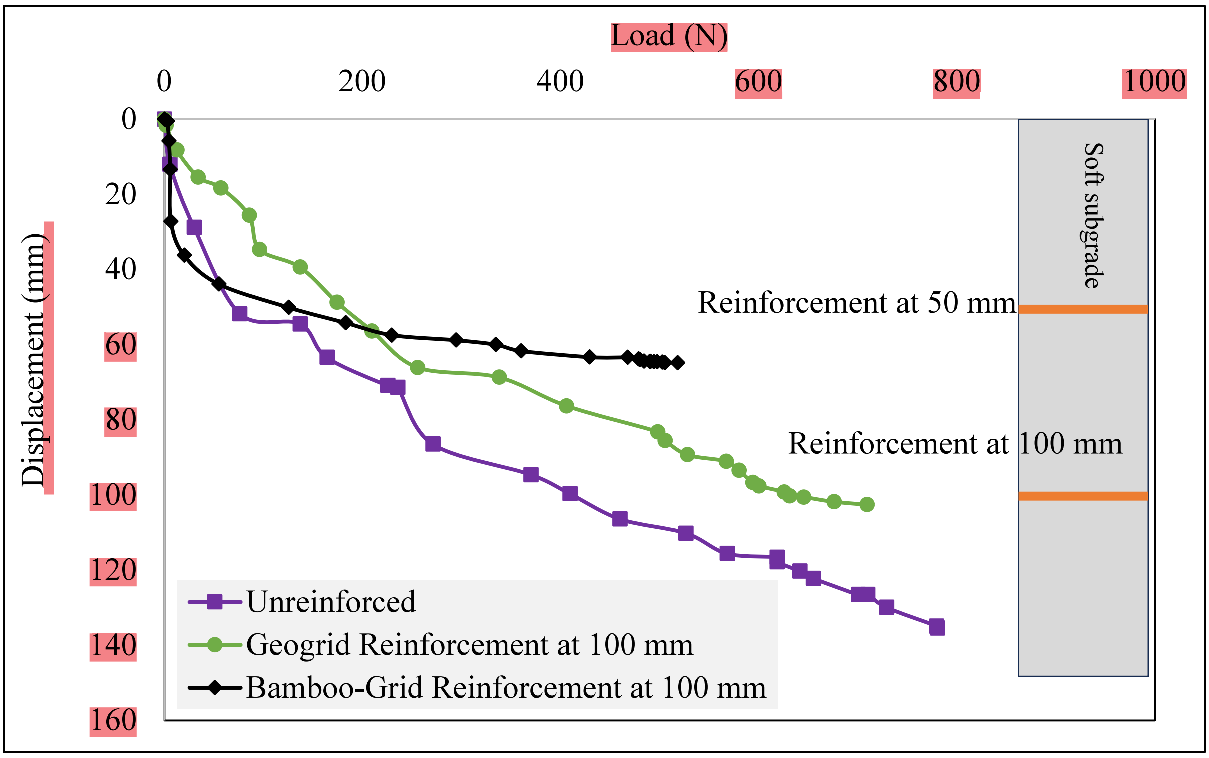

Fig. 4.3 Load displacement curve without and with reinforced at 100 mm depth

For unreinforced condition, the soil exhibited a uniform increase in load with increasing displacement, accompanied by large settlements. At higher load, the soil continued to deform significantly, indicating low stiffness and poor resistance to deformation.

The DSCPT results for reinforcement placed at 100 mm depth also indicate improved penetration resistance compared to the untreated soil condition. The load–penetration curves showed that both geogrid and bamboo-grid reinforcement reduced penetration and improved complete soil behaviour. Unreinforced soil exhibited rapid penetration with increase in applied load. The penetration depth increased continuously even under comparatively lower load levels, indicating lower stiffness and poor resistance against cone penetration. The geogrid-reinforced section at 100 mm depth demonstrated improved behaviour when compared with the unreinforced soil. According to the graph, penetration of nearly 40–45 mm occurred at approximately 220–240 N load, while penetration close to 80–90 mm required nearly 420–440 N load. The curve shifted upward relative to the untreated soil, indicating improved penetration resistance. The geogrid reinforcement exhibited approximately 61.36% improvement compared to the unreinforced condition at 100 mm depth. Although the improvement remained noticeable, the response was comparatively lower than that observed for reinforcement at 50 mm depth.

The bamboo-grid-reinforced section at 100 mm depth also showed favourable penetration resistance throughout the test. Initially, the curve followed behaviour similar to the geogrid-reinforced section; however, at higher penetration levels, the bamboo-grid curve remained comparatively stable with slower penetration progression. From the graph, penetration of nearly 40–45 mm occurred at approximately 260–280 N load, while penetration close to 80–90 mm required nearly 500–520 N load. The bamboo-grid reinforcement exhibited nearly 90.05% improvement compared to the untreated soil condition. The gradual slope of the curve indicates improved stiffness and effective stress distribution within the reinforced soil layer.

The comparison of all curves indicates that both reinforcement materials contributed positively to the penetration resistance characteristics of soil at 100 mm depth. The geogrid-reinforced section showed noticeable reduction in penetration, while the bamboo-grid-reinforced section displayed slightly better penetration control and comparatively stable behaviour under higher loading conditions. The results further indicate that reinforcement effectiveness was more noticeable at shallow embedment depth, although considerable improvement was still achieved at 100 mm depth compared to untreated soil.

4.2 Dynamic Cone Penetration Test

In this investigation DCPT was carried out on sandy soil. DCP test was to assess strength of subgrade soil under various reinforcement conditions. This test establishes a direct correlation between blow count and penetration depth , which is useful for evaluating the resistance and soil stiffness characteristics. The soil behaviour was studied under three different cases:

(a) Untreated soil
(b) Geogrid-treated soil
(c) Bamboo-grid treated soil

To further assess the influence of reinforcement placement, reinforcing layers were positioned at 50 mm and 100 mm, within soil layer. Untreated soil exhibited maximum penetration depth A rapid increase in penetration was observed during initial stage of loading, indicating that soil had relatively low resistance to the applied impact energy.

4.2.1 Effect of Reinforcement on Soil Penetration Behavior at 50 mm

The graph shows (presented in Figure 4.4) the variation of penetration depth with blow count for three cases: unreinforced soil, geogrid reinforcement at 50 mm, and bamboo-grid reinforcement at 50 mm. A clear trend is observed in all cases where penetration depth increases with the number of blows, indicating progressive deformation under repeated loading.

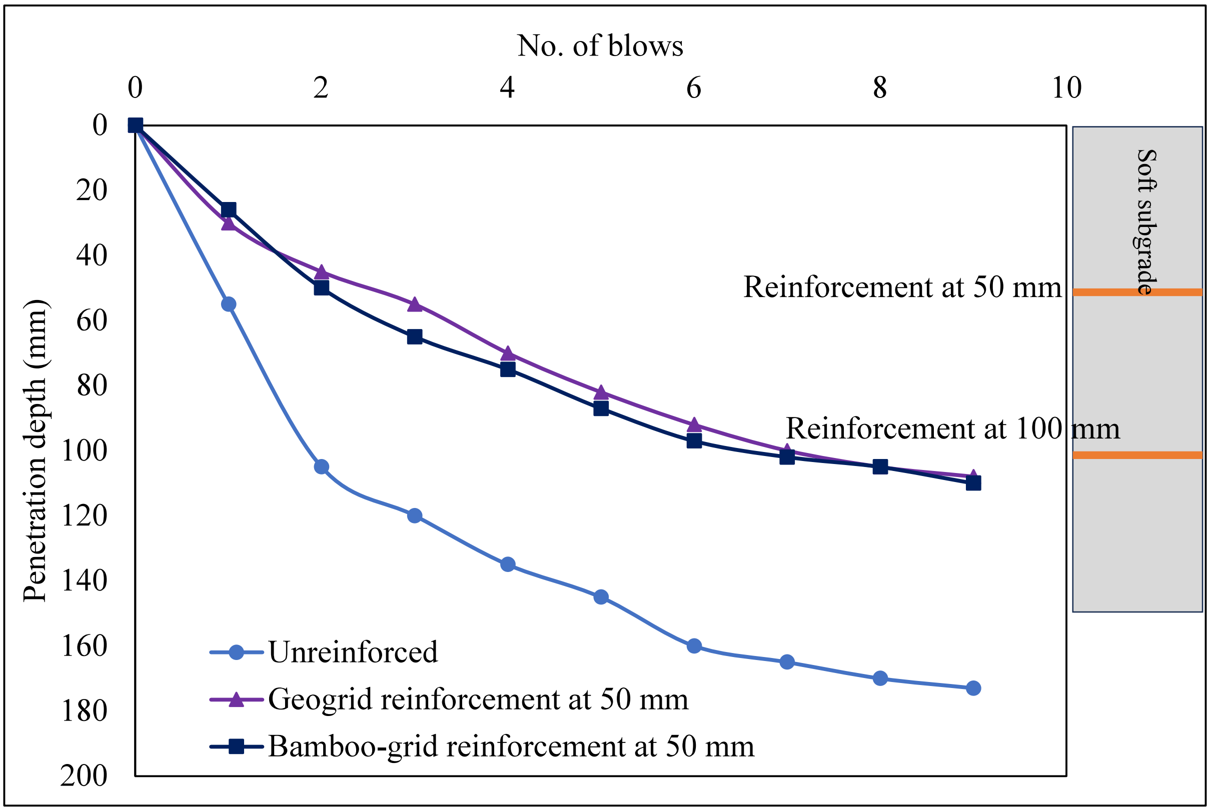

Fig. 4.4 Blow count versus penetration depth curve reinforced at 50 mm and unreinforced

The unreinforced soil exhibits significantly higher penetration compared to the reinforced cases. Even at a low number of blows, the penetration increases rapidly, showing its poor resistance to load and lower stiffness. This behaviour highlights the inability of untreated soil to effectively distribute applied stresses. Both geogrid and bamboo-grid reinforcements show a considerable reduction in penetration depth. This indicates that reinforcement increases the ability of the soil to sustain applied loads. Between both reinforcements, geogrid reinforcement material performs slightly better, showing marginally lower penetration values across most of the blow counts. This suggests that geogrids provide more effective interlocking and confinement of soil particles.

Table 4.3 Observation and evaluation of DCPI values with penetration depth for unreinforced and reinforced soil (Geogrid and Bamboo-grid at 50 mm)

Unreinforced			Reinforced geogrid at 50 mm		Reinforced bamboo-grid at 50 mm	
No. of blows	Depth (mm)	DCPI (mm/blow)	Depth (mm)	DCPI (mm/blow)	Depth (mm)	DCPI (mm/blow)
0	0	---	0	---	0	---
1	55	50	30	15	26	24
2	105	15	45	10	50	15
3	120	15	55	15	65	10
4	135	10	70	12	75	12
5	145	15	82	10	87	10
6	160	05	92	08	97	05
7	165	05	100	05	102	03
8	170	03	105	03	105	05
9	173	---	108	---	110	---
DCPI (avg.). = 14.75			DCPI (avg.). = 9.75		DCPI (avg.). = 10.5	

The bamboo-grid reinforcement also shows strong performance, closely following the geogrid results. Its penetration is slightly higher than geogrid in some cases, the difference is not very large. This indicates that bamboo grid can act as an efficient and sustainable alternative reinforcement material. The results confirm that introducing reinforcement at 50 mm depth significantly enhances soil performance by reducing deformation. The improvement is mainly because of improved stress distribution, increased confinement, along with resistance against particle movement. The findings also indicate that while geogrid offers slightly superior performance, bamboo grid provides a cost-effective and eco-friendly option with comparable efficiency.

4.2.2 Effect of Reinforcement on Soil Penetration Behavior at 100 mm

The graph shown in Figure 4.5 presents the change in penetration depth with increasing blow count for untreated soil together with geogrid and bamboo-grid reinforcement placed at depth of 100 mm. In all three cases, penetration depth increases as the number of blows increases, which reflects the cumulative effect of repeated loading on soil deformation.

Table 4.4 Observation and evaluation of DCPI values with penetration depth for unreinforced and reinforced soil (Geogrid and Bamboo-grid at 100 mm)

	Unreinforced		Reinforced geogrid at 100 mm		Reinforced bamboo-grid at 100 mm	
No. of blows	Depth (mm)	DCPI (mm/blow)	Depth (mm)	DCPI (mm/blow)	Depth (mm)	DCPI (mm/blow)
0	0	---	0	---	0	---
1	55	50	32	20	29	40
2	105	15	52	18	69	20
3	120	15	70	15	89	10
4	135	10	85	13	99	05
5	145	15	98	07	104	06
6	160	05	105	10	110	05
7	165	05	115	10	115	05
8	170	03	125	05	120	02
9	173	---	130	---	122	---
	DCPI (avg.). = 14.75		DCPI (avg.). = 12.25		DCPI (avg.). = 11.63	

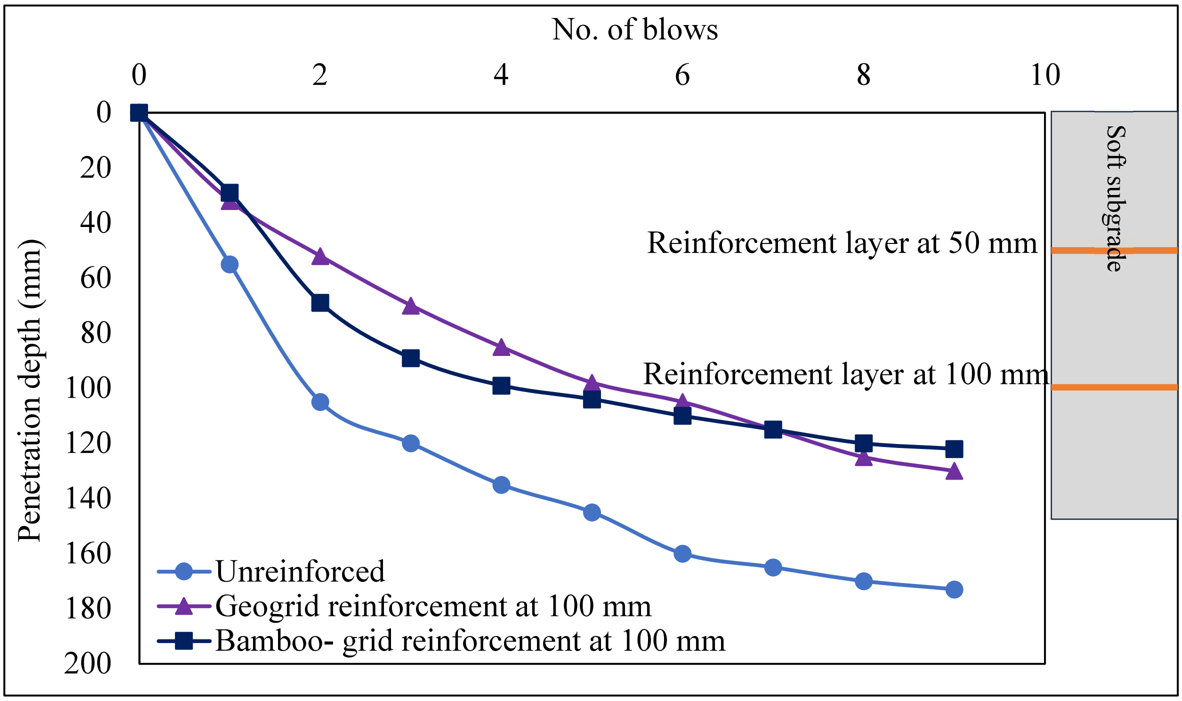

Fig. 4.5 Blow count versus penetration depth curve reinforced at 100 mm and unreinforced

The unreinforced soil shows the highest penetration throughout the test. The penetration increases rapidly even at the initial stages, indicating low resistance to impact loading and poor load distribution capacity. This behaviour confirms that untreated soil is more susceptible to deformation under repeated blows. Both geogrid and bamboo-grid reinforcements significantly reduce the penetration depth. The improvement is noticeable from the early stages and continues consistently with increasing blows. This reduction in penetration demonstrates that reinforcement enhances soil stiffness and improves its ability to resist deformation.

Comparing the two reinforcement types, geogrid initially performs slightly better by showing lower penetration values at intermediate blow counts. At higher numbers of blows, the bamboo-grid performs nearly equal or slightly better than the geogrid. This suggests that bamboo-grid provides comparable long-term resistance and may even offer better performance under prolonged loading conditions. The inclusion of reinforcement at 100 mm depth effectively enhances the mechanical response of soil through increasing confinement and minimizing particle movement. While geogrid shows strong performance, bamboo-grid proves to be an efficient and sustainable alternative with nearly similar effectiveness.

4.5 CBR and DCPI Correlation

Table 4.5 Average DCPI and corresponding CBR values for unreinforced, geogrid reinforced, and bamboo- grid reinforced soil sections

Test section	Average 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 show the impact behaviour of reinforcement on subgrade performance. The untreated soil exhibited an average DCPI reading of 14.75 mm/blow and lowest CBR value of 14.33%, indicating lower penetration resistance and strength. The addition of geogrid and bamboo-grid reinforcement reduced the DCPI values and increased the CBR values relative to the untreated section. Among all cases, the reinforcing geogrid embedded at a depth of 50 mm exhibited best performance with a DCPI value of 9.75 mm/blow and a corresponding CBR value of 22.79%. This indicates higher rigidity and improved ability of the soil to withstand loads. Bamboo-grid reinforcement at 50 mm depth also showed observable improvement, with the DCPI reducing to 10.5 mm/blow and the CBR increasing to 20.97%. The reinforced sections at 100 mm depth also performed better than the unreinforced soil, although the improvement was comparatively lower than the 50 mm reinforced sections. Overall, the results indicate that reinforcement placed near the top layer was more effective in improving penetration resistance and subgrade strength.

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CHAPTER 5

CONCLUSION AND FUTURE SCOPE

5.1 Conclusions

This study examined poorly graded sand (SP) to evaluate how geogrid and bamboo-grid reinforcement improve the performance of subgrade soil. Response of unreinforced soil was compared with reinforced soil by placing the reinforcement at depths of 50 mm and 100 mm below the surface. Soil behavior was evaluated through DSCPT and DCPT testing , and the important findings obtained from the investigations are presented below:

- The load–displacement behaviour clearly indicates that reinforcement significantly enhanced the mechanical strength and rigidity properties of sandy subgrade soil when comparison with the unreinforced condition. Both geogrid and bamboo-grid reinforcement reduced settlement and enhanced penetration resistance, resulting in improved resistance of the soil to applied loads. Reinforced soil sections showed comparatively smaller displacement under higher applied loads, whereas the unreinforced soil exhibited excessive deformation even under lower loading conditions.
- The DSCPT results demonstrated that reinforcement placed at shallow depth was more effective in improving soil performance. At 50 mm depth, geogrid reinforcement showed an improvement of about 225% in cone resistance, while bamboo-grid reinforcement showed approximately 232.78% improvement compared to the unreinforced soil. This significant enhancement confirms that reinforcement placed closer to the loading surface provides better confinement and improves stress distribution within the soil mass.
- At 100 mm reinforcement depth, both reinforcement systems continued to improve the penetration resistance and bearing behaviour of the soil compared to the untreated condition. However, the observed improvement was comparatively lower than that observed at 50 mm depth. The geogrid reinforcement showed nearly 61.36% improvement, while bamboo-grid reinforcement exhibited approximately 90.05% improvement in cone resistance. This indicates that reinforcement effectiveness gradually decreases as the reinforcement layer is placed deeper below the surface.
- 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. Reinforcement installed at 100 mm depth resulted in comparatively higher DCPI values than reinforcement provided at 50 mm depth, confirming that shallow reinforcement placement is more effective for improving subgrade behaviour.

- 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.
- 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 resistance and overall engineering behaviour of weak sandy subgrade soil.
- A comparative evaluation of DSCPT and DCPT results showed a consistent trend in behaviour between reinforced and unreinforced soil sections. In both testing methods, the reinforced soil exhibited considerably higher resistance against penetration and deformation relative to the untreated soil. The results further confirmed that reinforcement installed at 50 mm depth resulted in the highest enhancement in subgrade behaviour. Both geogrid and bamboo-grid reinforcement performed better than unreinforced case.
- Overall, the findings confirm that geogrid and bamboo-grid reinforcement are highly effective in enhancing the bearing 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 be used as a sustainable, economical, and eco-friendly substitute for conventional geogrid reinforcement systems for pavement and geotechnical engineering applications.

5.2 Future Scope

1. The long-term behaviour and durability of bamboo - grid reinforcement should be evaluated under varying environmental factors including moisture changes, biodegradation, as well as cyclic loading.
2. Detailed studies on preservation and treatment techniques of bamboo are required to enhance its strength, lifespan, and resistance to decay in geotechnical applications.
3. Further research can be extended to different soil types (clayey, silty, and mixed soils) to evaluate reinforcement suitability under different field conditions.
4. The influence of multiple reinforcement layers, varying spacing, and different embedment depths should be investigated to identify the most efficient design configuration.
5. Advanced numerical modeling and simulation studies can be conducted to better understand soil–reinforcement interaction and to develop reliable design guidelines.
6. Large-scale field studies and in-situ testing are necessary to validate laboratory results and assess real-time performance under actual loading conditions.
7. Comparative economic and environmental analysis between bamboo grid and synthetic geogrid should be carried out to promote sustainable and cost-effective solutions. Future work may also focus on integrating bamboo reinforcement with other ground improvement techniques to further enhance soil performance and broaden its practical applications.

APPENDIX – I

Acceptance Letter 1st Conference

Paper Acceptance Confirmation – ICASET 2026
1 message

ICASET Conference <info@icaset.in> Mon, 23 Feb, 2026 at 12:24
To: Puja Roy <proy13124@gmail.com>

Dear PUJA ROY,

Greetings from **ICASET 2026**.

Congratulations! We are pleased to inform you that your paper titled **"Effect of Geogrid and Bamboo Grid Reinforcement in Soil Subgrade Using Static Cone Penetration Test (Paper ID**:ICASET_CHE_1034)**"** has been **accepted for Oral/Poster Presentation** at the **5th International Conference on Advances in Science, Engineering & Technology (ICASET)**, accredited by **Continuous Professional Development (CPD), India**, scheduled on **22–23 March 2026**.

This is a significant milestone in your research journey, and we are delighted to have you join the conference. Your submission has successfully passed our **double-blind peer review and plagiarism check**, demonstrating the quality and relevance of your research.

Indexing & Publication

Your paper will be submitted for evaluation and indexing in **Web of Science (BkCI) and SCOPUS** *(terms and conditions apply)*, enhancing the visibility and impact of your work.
Alternatively, you may opt for **Scopus-indexed journal publication** based on your preference.

Session Allocation

This conference supports **global sustainable development** initiatives by encouraging innovative research, technological advancements, and interdisciplinary collaboration that contribute to industrial growth and societal progress.

CPD Benefits

As an accepted presenter, you will receive:

- **CPD Certificate** for participation
- **Eligible CPD points**
- **1-year free iCPD membership**, providing access to exclusive professional development resources

Next Steps – Registration Required

To confirm your participation, kindly complete your registration **on or before 25 Feb 2026** using the link below:

Registration Link: https://icaset.in/conference-registration.php

Once registered, please **share your payment receipt** with us to confirm your slot allocation.

If you need any assistance with registration, publication options, or presentation guidelines, please feel free to contact us.

Gomathi
Web:https://icaset.in/
Email: info@icaset.in
Contact Number: +91 8015999748

5th International Conference on Advances in Science,Engineering & Technology (ICASET)

Payment Receipt 1st Conference

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RECEIPT

M/s. Technoarete Research & Development Association. Rais Towers, 2054/B, 2nd Floor, West block, 2nd Ave, Anna Nagar, Chennai, Tamil Nadu 600040 Contact: +91 9944046574 **GSTN: 33AAFCT7109P2ZX** **CIN : U80221TN2016NPL104388**	**DATE:** 2026-02-23 15:10:04 **Payment MODE:** Online Payment **Order I'D** 699c6c475a5bc
BILL TO: Puja Roy Delhi Technological University, Delhi, Shahbad Daulatpur, MAin Bawana Road, Delhi, 110042	

Sr.No	DESCRIPTION	Amount	
1	ICASET_ 2026	4720	
		Internet Handling Charges (2.5%)	118
		Total	4588.00

Amount in Words: Four Thousand Five Hundred and Eighty Eight Rupees

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THANK YOU FOR YOUR REGISTRATION!

APPENDIX – II

Acceptance Letter 2nd Conference

INRI

Acceptance Letter

Date: 13-05-2026

Conference Name	: **International Conference on Geotechnical Engineering and Civil Engineering Solutions (ICGECE-26)**
Conference Venue	: **Lucknow - India**
Authors Name	: **Puja Roy, Nitish Kumar, Kshitij Gaur, Ashutosh Trivedi**
Paper Title	: **Effect of Geogrid and Bamboo-grid Reinforcement in Soil Subgrade Using Dynamic Cone Penetration Test**
Paper ID	: **INRI_62108**

Dear Authors,

We are pleased to inform you that your paper has been accepted by the review committee for Oral Presentation at the **International Conference on Geotechnical Engineering and Civil Engineering Solutions (ICGECE-26) which will be held in 24th May 2026 Lucknow - India**

Your paper will be published in the conference proceeding and well reputed journal after registration.

Please register as soon as possible in order to secure your participation:

Conference Link: https://inrinetwork.org/conf/fee-details.php?id=101018203

You are requested to release the payment and mail us the screen of successful payment release with your name and title of paper to confirm your registration.

Sincerely,

International Network for Research & Innovation INRI

Organizing Committee Head
International Network for Research & Innovation (INRI)

+91-96770 07228
info@inrinetwork.org
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Payment Receipt 2nd Conference

Online Payment Receipt

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International Conference on Geotechnical Engineering and Civil Engineering Solutions (ICGECE-26)

24th May 2026 | Lucknow - India

Reference ID	114508824011
Received on	14th May 2026
Amount Paid	5650 .INR

Name	Puja Roy
Email	proy13124@gmail.com
Address	Delhi Technological University, India

Invoice / Items	Unit Price	Quantity	Amount
Registration for Online Presentation with Publication Paper ID: INRI_62108 Paper Title: Effect of Geogrid and Bamboo-grid Reinforcement in Soil Subgrade Using Dynamic Cone Penetration Test	5650.INR	1	5650.INR
		Sub Total	5650.INR
		Net Amount	5650.INR

**This is computer generated online receipt, no signature required*

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www.inrinetwork.org

List of Conferences / Publications and their proofs

1. Roy, P., Gaur, K., and Trivedi, A. (2026). Effect of geogrid and bamboo-grid reinforcement in soil subgrade using static cone penetration test. In 5^{th} *international conferences on advances in science, engineering & technology (ICASET).*
2. Roy, P., Kumar, N., Gaur, K., and Trivedi, A. (2026). Effect of geogrid and bamboo-grid reinforcement in soil subgrade using dynamic cone penetration test. In *International Conference on Geotechnical Engineering and Civil Engineering Solutions (ICGECE).*

Conference Certificate

Fig. 1 First conference certificate

Google Scholar

CERTIFICATE
OF PRESENTATION

INRI

International Conference on Geotechnical Engineering and Civil Engineering Solutions (ICGECE-26)
24th May 2026 | Lucknow - India

THIS IS TO CERTIFY THAT

Puja Roy

affiliated with Delhi Technological University, Delhi, India has presented a paper titled
"Effect of Geogrid and Bamboo-grid Reinforcement in Soil Subgrade Using Dynamic Cone Penetration Test"
at the conference organized by the International Network for Research & Innovation held on **24th May 2026** at **Lucknow - India.**

OPEN ACCESS

Organizing Committee Head
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Authorizing Signature
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Fig. 2 second conference certificate