Role of Geogrid on Stiffness Capacity of Loose Cohesionless Geomaterial

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March 28, 2025

Role of the geogrid reinforcement on stiffness capacity of loose cohesionless geomaterial

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Abstract

The present study has been conducted to examine the variation in stiffness capacity with the penetration factor in loose, cohesionless geomaterial under both reinforced and unreinforced conditions using California Bearing Ratio (CBR) testing. Stiffness capacity, a non-dimensional parameter, is conceptualized to quantify the resistance offered by the geomaterial to penetration. The reinforcement was introduced in the form of a geogrid, incorporated at three different depths proportional to the total depth of the CBR mold. Preliminary testing of the geomaterial indicated that the sample is well-graded sand, with a specific gravity of 2.63, an optimum moisture content of 12.32%, and a maximum dry density of 19.57 kN/m³. The inclusion of geogrid reinforcement significantly enhances the stability and strength of the geomaterial, as reflected in improved stiffness capacity. Among the tested reinforcement depths, the placement at h/4 proved to be the most effective in maintaining stiffness capacity. Additionally, jute reinforcement demonstrated some improvement in stiffness capacity compared to unreinforced sections. However, it was less effective than geogrid, particularly at greater penetration levels. Geogrid reinforcement at h/4 depth consistently resulted in reduced penetration, highlighting its superiority as a stabilization material. These findings indicate towards the advantages of geogrid over jute reinforcement, the importance of optimal reinforcement placement depth, and the overall effectiveness of reinforcement in enhancing soil stiffness capacity.

Keywords: Geogrid; Cohesionless geomaterial; CBR test; Stiffness capacity; Penetration factor

1. Introduction

The mechanical behavior of geomaterials plays a pivotal role in the stability and performance of geotechnical structures. Loose cohesionless geomaterials, such as sands and gravels, are often characterized by low stiffness and high deformability, making them unsuitable for bearing significant loads without excessive settlement or failure. To address these limitations, geosynthetic reinforcement has emerged as an effective technique for improving soil stiffness, strength, and overall structural integrity [1]. Among various geosynthetics, geogrid reinforcement is widely used due to its ability to interlock with soil particles and provide enhanced mechanical stability. Geogrids are polymeric materials characterized by an open-grid structure that facilitates soil interlocking and improves load distribution. The reinforcement mechanism of geogrids is governed by factors such as aperture size, tensile strength, and placement depth, all of which influence the stiffness capacity of reinforced soils [2]. The introduction of geogrids into loose cohesionless geomaterials leads to improved load-bearing capacity, reduced lateral displacement, and increased resistance to deformation under loading conditions. This makes geogrid-reinforced soils highly suitable for applications such as road pavements, embankments, retaining walls, and foundation systems [3].

Stiffness capacity is a critical geotechnical parameter that determines a soil's resistance to deformation under applied loads. It directly affects the performance of structures such as pavements, railways, and foundations, where excessive settlement or deflection can lead to structural failure [4]. In the case of loose cohesionless geomaterials, the lack of cohesion and weak interparticle bonding result in low initial stiffness and high susceptibility to deformation. The integration of geogrid reinforcement significantly enhances stiffness by providing lateral confinement, reducing particle displacement, and improving load transfer mechanisms [5].

Several studies have investigated the effect of geogrid reinforcement on soil stiffness and load-bearing capacity. Research has shown that the placement depth of geogrids plays a crucial role in optimizing stiffness improvement. For instance, reinforcement positioned at h/4 depth has been found to be more effective compared to placements at h/2 or h/3 depth, as it provides better confinement and stress distribution within the soil matrix [6]. Additionally, the effectiveness of geogrid reinforcement is influenced by soil type, loading conditions, and reinforcement configurations, making it essential to conduct experimental investigations to optimize these parameters [7].

The primary mechanism by which geogrid reinforcement enhances stiffness in loose cohesionless geomaterials is through soil-geogrid interaction. When a load is applied to unreinforced soil, individual particles undergo excessive movement, leading to settlement and loss of stiffness. However, when a geogrid is introduced, the interlocking between soil particles and geogrid apertures restricts lateral displacement, thereby increasing confinement and improving overall stiffness [8]. This interaction reduces the rate of stiffness degradation as loading increases and enhances the soil's ability to withstand applied forces.

The reinforcement effect of geogrids also depends on the cyclic loading behavior of the geomaterial. Studies have shown that geogrid-reinforced soils exhibit lower deflections and better load-bearing characteristics under cyclic loads compared to unreinforced soils [9]. This is particularly significant in infrastructure projects where repeated traffic loading or seismic activity can cause progressive deterioration of soil stiffness [10].

Furthermore, the use of natural fibers such as jute in soil reinforcement has gained attention due to their environmental sustainability and mechanical effectiveness. Experimental investigations comparing geogrid and jute reinforcement indicate that jute reinforcement provides a moderate improvement in stiffness but is less effective than geogrids in long-term applications due to biodegradability concerns [11]. However, hybrid reinforcement systems combining geogrids and natural fibers have shown promising results in balancing mechanical performance and sustainability [12].

Various experimental studies have been conducted to assess the influence of geogrid reinforcement on stiffness capacity in loose cohesionless geomaterials. Moving wheel load tests and cyclic loading experiments have been widely used to evaluate the performance of reinforced soils under realistic loading conditions [13]. These studies indicate that geogrid-reinforced sections exhibit significantly lower penetration and higher stiffness retention compared to unreinforced sections [14].

Additionally, the dynamic properties of reinforced soils have been investigated using techniques such as resonant column tests and large amplitude oscillatory shear tests [15]. These studies highlight the role of geogrid reinforcement in improving soil damping characteristics and reducing vibration-induced deformations, which is particularly beneficial for railway and highway applications [16].

The application of geogrid reinforcement in loose cohesionless geomaterials presents a promising avenue for advancing sustainable and efficient ground improvement techniques. While current research has established the benefits of geogrids in enhancing soil stiffness, further investigations are needed to explore multi-layer reinforcement configurations, hybrid reinforcement systems, and long-term performance under extreme environmental conditions [17].

Moreover, the integration of machine learning techniques in geotechnical engineering can provide new insights into predicting the behavior of geogrid-reinforced soils under varying loading conditions [18]. Advanced computational modeling approaches, coupled with large-scale field studies, can further refine the design methodologies for optimized geogrid reinforcement applications [21].

2. Material and procedure

2.1. Geomaterial

In this study, a geomaterial was sourced from a local site in proximity to the institution and subsequently transported to the laboratory for analysis. The particle size distribution of the geomaterial was determined through sieve analysis. The test outcomes indicate that the soil conforms to the specifications outlined in IS: 2720 Part-4 (1985). The California Bearing Ratio (CBR) curve was analyzed under soaked conditions to evaluate the soil's load-bearing capacity under different moisture states. To determine the optimum moisture content (OMC) and maximum dry density (MDD) of the soil, a Standard Proctor compaction test was conducted in accordance with IS: 2720 Part-7 (1980).

Table 1. Properties of subgrade

Property of subgrade	Notation	value
Specific gravity	-	2.63
Optimum moisture content	OMC	12.32%
Maximum dry density	MDD	19.57KN/m^3
Type of soil	SW	-

2.2. Geogrid

A geogrid is a geosynthetic reinforcement material, typically manufactured as a sheet, as illustrated in Fig. 2. It is a cost-effective and environmentally sustainable material commonly employed in various geotechnical and environmental applications. Geogrids provide superior performance and long-term durability when compared to traditional natural fiber-based materials. The material properties of the geogrid are summarized in Table 2.

Table 2. Properties of Geogrid

Geogrid	Values
Aperture size	30×30mm
Ultimate tensile strength	38.1kN/m
Yield strain	16.7%
Secant modulus at 2% strain	588kN/m
Mass per unit area	530g/m^2

2.3.Test procedure

The geomaterial properties for the sample under investigation are presented in **Table 1**, derived from tests conducted in the laboratory. To evaluate the desired characteristics of the soil, a California Bearing Ratio (CBR) test was performed. Initially, the CBR test was conducted under unsoaked conditions, followed by testing under soaked conditions. In accordance with IS: 2720 Part-6 (1987), standard apparatus and dimensions were employed. The cylindrical mold used for the CBR test has a diameter of 15 cm and a height of 17.5 cm, with an attached base plate. The collar height is 5 cm. The compaction rammer, with a weight of 2.5 kg and a diameter of 14.7 cm, has a net capacity of 2250 cm^3. CBR values for both unreinforced and geogrid-reinforced soil samples were determined based on plunger penetration measurements at 2.5 mm and 5 mm. The testing procedure involved applying a load to the top surface of the sample via a plunger at a constant rate of penetration (1.25 mm/min). A soaked sample is shown in Figure 1, which is soaked for 72 hours. This test is essential for determining the strength and bearing capacity of the soil, which are critical factors in geotechnical engineering applications.

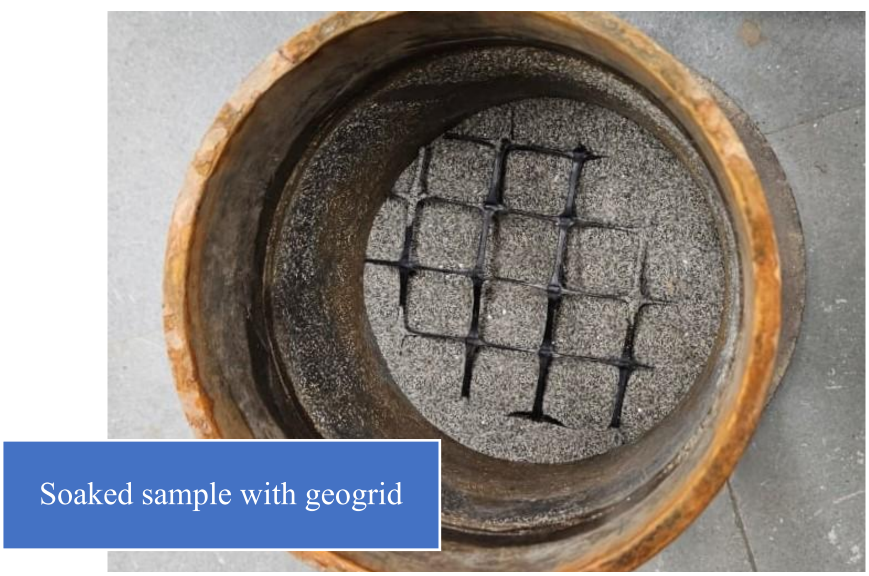

Figure 1. Geogrid reinforced in CBR mould after soaked for 72 hours

In this experimental setup, geogrid layers are strategically placed within the mold to assess its impact on the strength characteristics of the material under various conditions. The mold, with geogrid layers incorporated, is subsequently submerged in water for a duration of 72 hours. This soaking period is intended to simulate conditions that may affect the geogrid's performance, particularly in terms of its strength retention under saturated conditions.

The test is conducted under five distinct conditions, categorized as follows:

a) Unreinforced condition,
b) Geogrid at h/2 depth,
c) Geogrid at h/3 depth, and
d) Geogrid at h/4 depth as shown in Fig. 2.

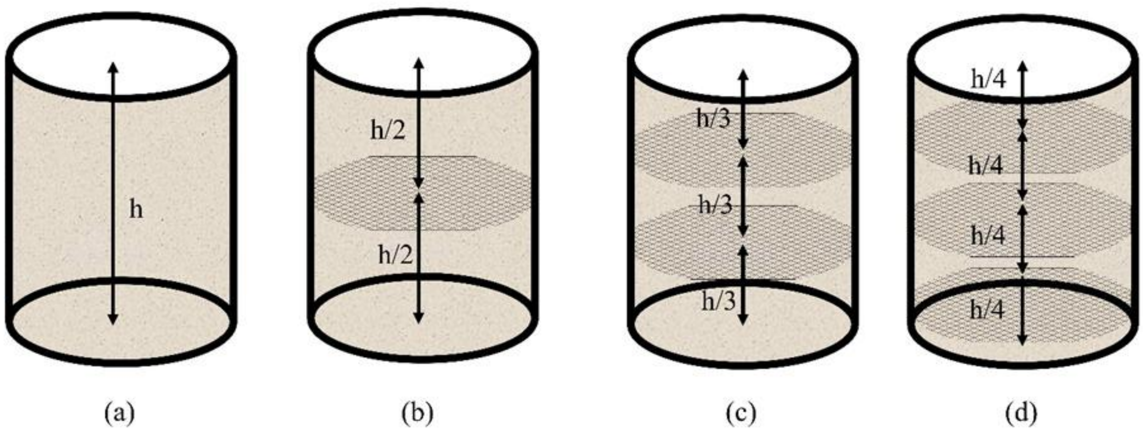

Figure 2. Alignment of geogrid in CBR mold with different height

3. Results and discussion

3.1. Stiffness capacity vs penetration factor

The graph illustrates the variation in stiffness capacity (k/ k_{max}) with respect to the penetration factor for different reinforcement conditions. The data includes results from the present study and the study by Kumar et al., [2] comparing unreinforced and reinforced sections using geogrid and jute at different depths. The trends in the graph highlight the effectiveness of reinforcement in resisting stiffness loss and the influence of reinforcement depth on performance as shown in the Figure 3.

The graph includes different sections which are mentioned as:

(a) Unreinforced section

Both the present work and Kumar et al., [2] show a significant reduction in stiffness capacity as the penetration factor increases. The present work's unreinforced section maintains a higher stiffness capacity compared to Kumar et al., [2]. This suggests improved material properties, soil composition, or experimental conditions in the present study. The initial stiffness for both studies starts at 1.0 (normalized value) but drops rapidly for lower penetration factors and then gradually stabilizes at higher penetration factors.

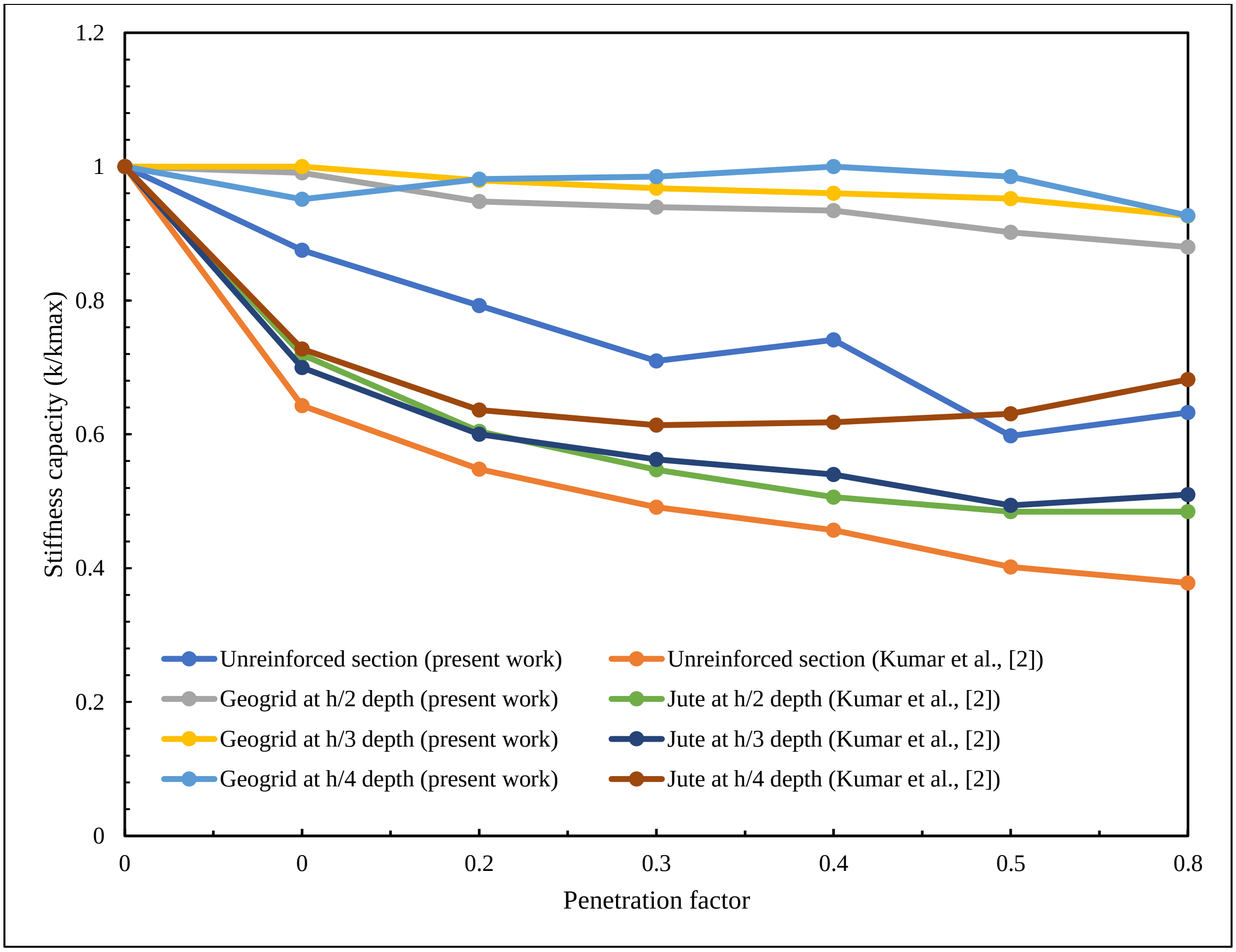

Figure 3. Comparison of geogrid and jute reinforcement in terms of stiffness capacity and penetration factor

(b) Effect of geogrid reinforcement (present work)

Geogrid reinforcement effectively mitigates the loss of stiffness capacity as penetration increases. Among the different placement depths, geogrid at h/2 depth experiences a gradual decline in stiffness capacity but still outperforms the unreinforced section. Geogrid placed at h/3 and h/4 depths demonstrates even better performance, with h/4 maintaining the highest stiffness capacity throughout. This trend suggests that placing geogrid reinforcement at multiple levels, particularly at h/3 and h/4, enhances load distribution and improves resistance to stiffness loss caused by penetration.

(c) Effect of jute reinforcement (Kumar et al., [2])

Jute reinforcement enhances stiffness retention compared to unreinforced sections, though it remains less effective than geogrid. Among the different placement depths, **h/2** exhibits a sharp decline in stiffness, performing only slightly better than the unreinforced section. **H/3** placement offers improved performance over **h/2**, but it still falls short of the stiffness retention achieved by geogrid reinforcement. The

h/4 placement retains the highest stiffness capacity among the jute-reinforced sections, reinforcing the trend that deeper reinforcement placement leads to better structural performance. Compared to geogrid, jute reinforcement exhibits a faster reduction in stiffness capacity, indicating that natural fibers may degrade more quickly or provide less overall structural resistance.

3.2. Penetration vs Load intensity

This graph illustrates the relationship between penetration (mm) and load intensity (kg/cm²) for different reinforcement conditions. The x-axis represents load intensity, which ranges from 0 to 12.5 kg/cm², while the y-axis represents penetration, measured in millimeters (mm). The dataset includes results from both the present study and Kumar et al.,[2], comparing the performance of unreinforced sections and reinforced sections using geogrid and jute placed at different depths as shown in the Fig. 4.

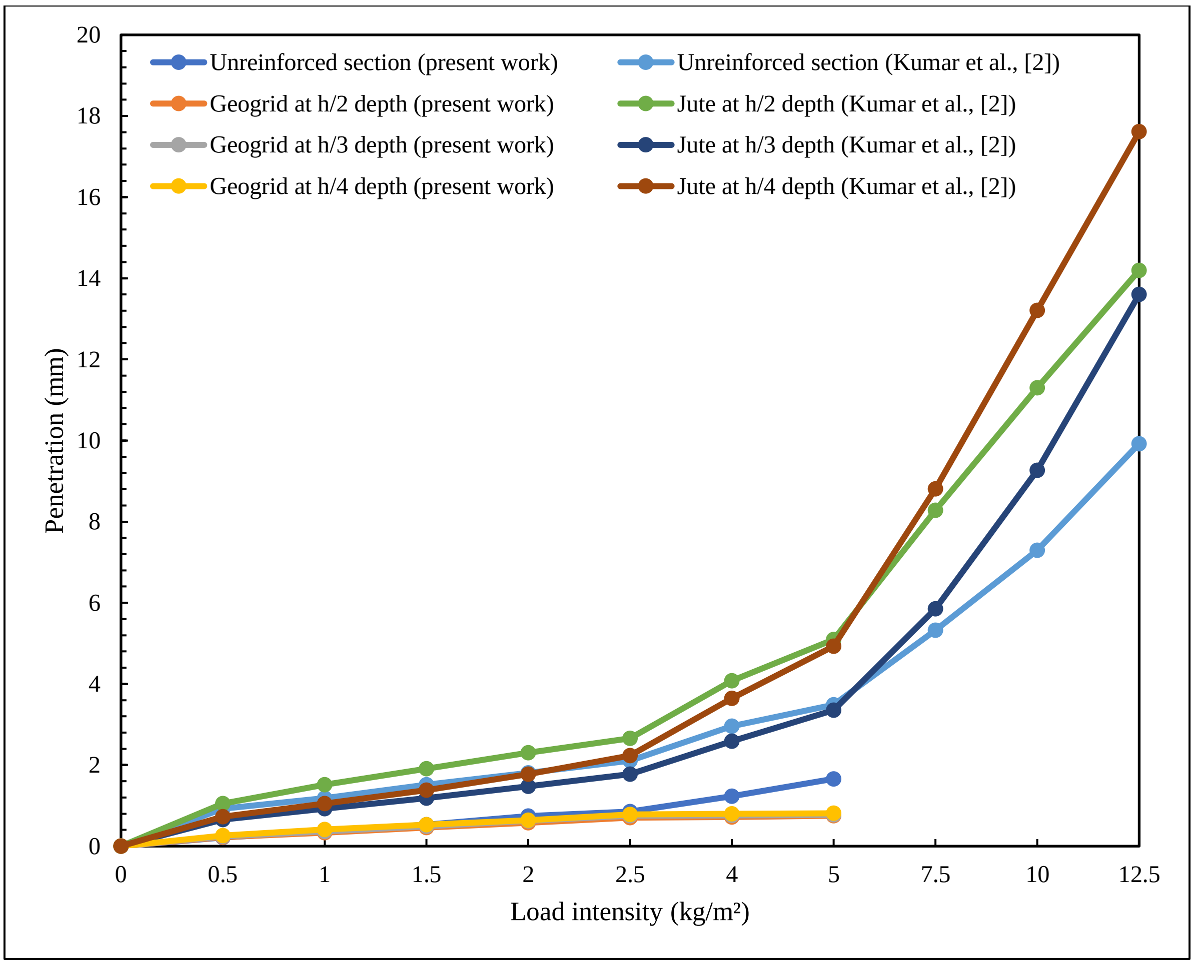

Figure 4. Comparison between geogrid and jute in terms of penetration and load intensity

The graph includes different conditions which are specified as:

(a) Unreinforced section

The unreinforced section from the present work and Kumar et al., [2], exhibits the highest penetration values among all test conditions. As load intensity increases, penetration increases more steeply in the unreinforced sections, especially beyond 5 kg/cm^2, indicating that soil without reinforcement experiences greater deformation under load. The present work's unreinforced section consistently exhibits lower penetration values than Kumar et al. [2] suggesting better soil strength, improved compaction, or different material properties in the present study.

(b) Effect of geogrid reinforcement (present work)

Geogrid-reinforced sections exhibit the lowest penetration values, demonstrating their effectiveness in resisting deformation. Among the different placement depths, geogrid positioned at h/4 depth performs the best, showing the lowest penetration values across all load intensities. While geogrid placed at h/3 and h/2 depths also significantly improve performance compared to unreinforced sections, the h/4 placement consistently provides superior support. The results indicate that utilizing geogrid at multiple depths enhances stability, as the reinforcement is more effectively positioned to distribute loads and resist soil displacement.

(c) Effect of jute reinforcement (Kumar et al., [2])

Jute-reinforced sections demonstrate improved performance over unreinforced sections but remain less effective than geogrid reinforcement. Among the jute-reinforced configurations, placement at **h/4** depth yields the best results, followed by **h/3** and **h/2** depths. However, when compared to geogrid reinforcement at the same depths, jute-reinforced sections exhibit higher penetration values, indicating that geogrid provides greater structural strength and is more effective in controlling deformation. The sharp increase in penetration beyond 5 kg/cm^2 in jute-reinforced sections indicates that jute may lose effectiveness under higher loads, possibly due to material deformation or biodegradability.

4. Conclusion

- The findings of this study indicate that geogrid reinforcement is highly effective in preserving stiffness capacity, with an optimal placement depth of h/4 yielding the best results. While jute reinforcement enhances stiffness compared to unreinforced sections, it is less effective than geogrid in maintaining stiffness capacity as penetration increases.
- The results emphasize on the significance of reinforcement depth, demonstrating that an increase in the number of geogrid layers further enhances stiffness retention and improves load-bearing performance.
- Geogrid reinforcement also proves to be effective in minimizing penetration, with the h/4 placement depth providing the most favorable outcomes. Although jute reinforcement contributes to some reduction in penetration, its effectiveness is notably lower than that of

geogrid, particularly under higher loads. The consistent reduction in penetration values observed with geogrid reinforcement at h/4 depth establishes it as a superior stabilization material.

Overall, this analysis highlights the superiority of geogrid over jute reinforcement, the benefits of deeper reinforcement placement, and the critical role of reinforcement in enhancing soil stiffness capacity. Furthermore, the enhanced performance of geogrid compared to jute underscores the importance of selecting appropriate reinforcement materials and optimizing placement depth to improve soil stability under diverse field conditions.

5. Future scope

The role of geogrid reinforcement in improving the stiffness capacity of loose cohesionless geomaterials is of significant importance in geotechnical engineering. By enhancing soil confinement, reducing settlement, and improving load distribution, geogrids contribute to more stable and durable soil structures. The effectiveness of geogrid reinforcement depends on various factors, including placement depth, soil type, and loading conditions, necessitating comprehensive experimental and numerical studies to optimize their application. Future research directions should focus on hybrid reinforcement strategies, cyclic load behavior, and sustainability aspects to further enhance the practical implementation of geogrid-reinforced systems in geotechnical engineering.

References

1. Singh, M., Trivedi, A., & Shukla, S. K. (2022). Evaluation of geosynthetic reinforcement in unpaved road using moving wheel load test. Geotextiles and Geomembranes, 50(4), 581-589.

2. Kumar, P., Kumar, Y., & Trivedi, A. (2023). Influence of Jute Reinforcement on the Stiffness Capacity of Cohesionless Pavement Geomaterials. In International Conference on Interdisciplinary Approaches in Civil Engineering for Sustainable Development (379-390). Singapore: Springer Nature Singapore.

3. Bajaj, M., & Padmanabhan, G. (2022). Experimental study on the factors influencing the performance of geogrid encased granular pile anchor installed in cohesionless soils. International Journal of Geosynthetics and Ground Engineering, 8(3), 39.

4. Kirtimayee, B., & Samadhiya, N. K. (2022). Performance of loosely skirted shallow foundation resting on reinforced sand under vertical loading. International Journal of Geosynthetics and Ground Engineering, 8(1), 17.

5. Pires, A. C., & Palmeira, E. M. (2021). The influence of geosynthetic reinforcement on the mechanical behaviour of soil-pipe systems. Geotextiles and Geomembranes, 49(5), 1117-1128.

6. Prasad, P. S., & Ramana, G. V. (2016). Feasibility study of copper slag as a structural fill in reinforced soil structures. Geotextiles and Geomembranes, 44(4), 623-640.

7. Gao, J., Yang, Y., Bian, X., & Zhu, G. (2024). Study on dynamic shear properties of sulfate saline soil-geotextile interface with different salt content. Soil Dynamics and Earthquake Engineering, 183, 108807.

8. Shafiee, A., Fathipour, H., Payan, M., Jalili, J., & Chenari, R. J. (2024). Modulus reduction and damping characteristics of geotextile-reinforced sands. Soil Dynamics and Earthquake Engineering, 181, 108641.

9. Fernández-Lavín, A., Ovando-Shelley, E., & Chamorro-Zurita, C. (2024). Damping ratio on lacustrine soils using the wavelet transform. Soil Dynamics and Earthquake Engineering, 180, 108583.

10. Ibagón, L., Caicedo, B., Villacreses, J. P., & Yepez, F. (2023). Effect of the particle's shape on the dynamic shear modulus and compressibility of diatomaceous soils. Soils and Foundations, 63(6), 101374.

11. Kumar, Y., Trivedi, A., & Shukla, S. K. (2024). Deflections governed by the cyclic strength of rigid pavement subjected to structural vibration due to high-velocity moving loads. Journal of Vibration Engineering & Technologies, 12(3), 3543-3562.

12. Araz, O., Cakir, T., Ozturk, K. F., & Kaya, D. (2023). Effect of foundation embedment ratio in suppressing seismic-induced vibrations using optimum tuned mass damper. Soil Dynamics and Earthquake Engineering, 171, 107981.

13. Mei, X., Sheng, Q., Cui, Z., Zhang, M., & Dias, D. (2023). Experimental investigation on the mechanical and damping properties of rubber-sand-concrete prepared with recycled waste tires for aseismic isolation layer. Soil Dynamics and Earthquake Engineering, 165, 107718.

14. Wu, M., Tian, W., Liu, F., & Yang, J. (2023). Dynamic behavior of geocell-reinforced rubber sand mixtures under cyclic simple shear loading. Soil Dynamics and Earthquake Engineering, 164, 107595.

15. Wang, Y., Li, S., Duan, G., Yin, J., & Wang, Y. (2023). Study on dynamic properties of ultrasoft clay based on large amplitude oscillatory shear tests. Soil Dynamics and Earthquake Engineering, 172, 107989.

16. Heiland, T., Aji, H. D., Wuttke, F., Stempniewski, L., & Stark, A. (2023). Influence of soil-structure interaction on the dynamic characteristics of railroad frame bridges. Soil Dynamics and Earthquake Engineering, 167, 107800.

17. Baghbani, A., Choudhury, T., Samui, P., & Costa, S. (2023). Prediction of secant shear modulus and damping ratio for an extremely dilative silica sand based on machine learning techniques. Soil Dynamics and Earthquake Engineering, 165, 107708.

18. Zou, X., Yang, Z., & Wu, W. (2023). Horizontal dynamic response of partially embedded single pile in unsaturated soil under combined loads. Soil Dynamics and Earthquake Engineering, 165, 107672.

19. Peellage, W. H., Fatahi, B., & Rasekh, H. (2022). Experimental investigation for vibration characteristics of jointed rocks using cyclic triaxial tests. Soil Dynamics and Earthquake Engineering, 160, 107377.

20. Vrettos, C., & Banzibaganye, G. (2022). Effects of specimen size and inertia on resonant column tests applied to sands. Soil Dynamics and Earthquake Engineering, 155, 107136.

21. Tsai, C. C., Lin, C. Y., Dashti, S., & Kirkwood, P. (2021). Influence of centrifuge container boundaries and loading characteristics on evaluation of dynamic properties in dry sand. Soil Dynamics and Earthquake Engineering, 142, 106567.

22. Basas, V. G., Pantazopoulos, I. A., & Atmatzidis, D. K. (2020). Torsional and flexural resonant column testing of grouted sands. Soil Dynamics and Earthquake Engineering, 139, 106360.