Stablization of Subgrade Using Geosynthetics

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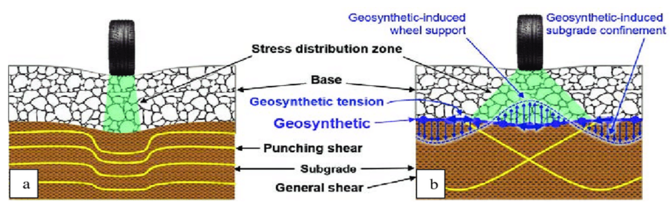
Abstract- *A wide range of reinforcing materials, such as metal strips, bar mats, Geotextile sheets, Geo Grids, etc., have been created and emerged for use in construction. The building of earth dams, retaining walls, highway embankments and railway formation has made widespread use of reinforced soil technologies over the last few decades. Geo synthetics are widely utilized in engineering practice as a reinforcing material to enhance various structures such as roads, pavement, slopes, crushed-stone columns, etc. In order to provide a uniform surface for cars, a hard crust known as pavement is built over the natural soil. When it comes to pavement building, soil stabilization also deals with the construction methods used on highways, dams, bridges, and railroad facilities. It illustrates the numerous methods by which the stabilization responses of several soil types can be determined.The mechanical strength of subgrade soil and the density of soil sample were determined by the CBR test using four different types of soils reinforced with geo-composit materials. This research provides the features of the soil-geo-synthetic interaction.*

I. INTRODUCTION

The performance and lifetime of civil engineering projects like highways, railroads, airports, and embankments depend critically on the stability of subgrade soils. Often facing difficulties including low bearing capacity, too much settlement, and insufficient shear strength resulting from natural soil qualities or unfavourable environmental circumstances, the subgrade forms the basis upon which these buildings are erected. Effective addressing of these issues is essential to guarantee the safety and longevity of built facilities.

Improving subgrade stability has long been accomplished using techniques including mechanical compaction, chemical stabilisation, and soil replacement. These approaches, meanwhile, could be expensive, time-consuming, and environmentally disruptive. Geo-synthetic use has become a feasible and sustainable substitute for improving subgrade performance in recent years. By changing the mechanical behaviour of soils and enhancing their engineering qualities, geo-synthetic materials—including geotextiles, geo-grids, geo-cells, and geo-membranes—offer flexible options to address the above described problems.

Ground improvement techniques utilizing geo-synthetics reinforcing materials have improved dramatically over the recent few decades, notably those applied in foundation engineering. These geo-synthetics reinforcement materials are produced in various forms such as planer form (woven and nonwoven geotextile), planer form with different aperture (uniaxial geo-grid, biaxial geo-grid, and tri-axial geo-grid), and three-dimensional form (geo-cell) and specially used for reinforcement of soil or any other granular fill under the footing. This technique is ideally suited for spread footings, including isolated and continuous footings especially when these footings are constructed on soft/weak soil strata. One of the areas where geo-synthetic materials are employed to the reinforcing of soil for long term stability of foundation is designated as a reinforced soil foundation system. This technique could be employed extremely well in bearing capacity increase (Vidal, 1966).



II. LITERATUREREVIEW

Numerous studies have been conducted to assess reinforced soil pavements and foundations during the preceding forty years. Previous study has demonstrated that the installation of geo-synthetics in weak soils enhances the bearing capacity and minimizes the footing settlement. Numerous investigators have sought to quantify the benefits of reinforced soil foundations by measuring the bearing capacity ratio (BCR). Numerous research have been undertaken to quantify the variables that influence the BCR value. The researchers studied the following fixed and variable parameters: (1) reinforcement depth of the first layer (u), (2) number of reinforcement layers (N) (3) total depth of reinforcing layer (d) (4) vertical spacing between reinforcement (h), (5) width and length of reinforcement (l × b), (6) tensile strength of reinforcement, (7) type of fill, (8) depth of embedded footing (Df). A geo-grid reinforced foundation bed is represented in Figure 2.1.

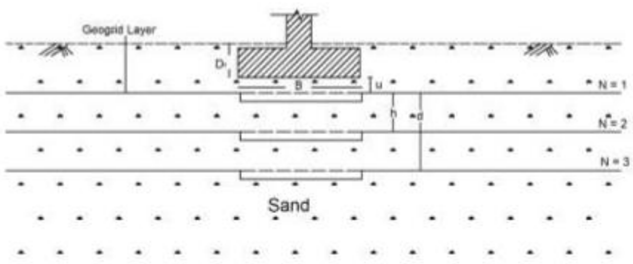


Figure 2.1 Geo-synthetics reinforced soil foundation system.

A brief literature review of the investigations with planar sheets is presented in this section. The first part deals with the 2D planar inclusions in the sand, while the second part reviews 2D planar placed at the clay/backfill interface and the third part describes reviews related to 3D reinforcement system.

Research on Geo-synthetics in Airport Pavements

1. **Effectiveness of Geo-synthetics**
   - **Research**: Ewais et al. (2020)
   - **Date**: 2020
   - **Summary**: Studied the effectiveness of geo-synthetics in improving mechanical properties and durability of airport pavements, enhancing stability and load-bearing capacity under heavy traffic.
2. **Impact on Maintenance**
   - **Research**: Wang et al. (2018)
   - **Date**: 2018
   - **Summary**: Analyzed how geo-synthetics reduce maintenance costs and extend service life by mitigating reflective cracking and moisture-induced damage in airport pavements.
3. **Case Studies**
   - **Research**: Liu et al. (2019)
   - **Date**: 2019
   - **Summary**: Documented successful applications of geo-synthetics in airport runway, taxiway, and apron pavements, highlighting improvements in structural integrity and operational efficiency.

Research on Geo-synthetics in Normal Pavements

1. **Reinforcement in Highway Pavements**
   - **Research**: ASTM (2017)
   - **Date**: 2017
   - **Summary**: Reviewed geo-synthetics' role in reinforcing highway pavements, reducing rutting, improving fatigue resistance, and extending service life while optimizing life cycle costs.
2. **Environmental Impact**
   - **Research**: Li et al. (2021)
   - **Date**: 2021
   - **Summary**: Assessed the environmental sustainability of geo-synthetics in urban pavement applications, highlighting reductions in construction waste, carbon emissions, and material usage.
3. **Application in Rural Roads**
   - **Research**: Kwon and Park (2019)
   - **Date**: 2019

Summary: Investigated geo-synthetics' effectiveness in enhancing subgrade stability and reducing maintenance needs in rural road pavements, improving durability in low-traffic environments.

Key Findings

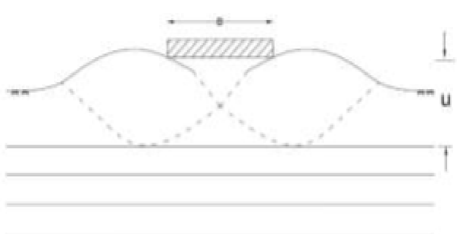
1. **Improvement in Load-Bearing Capacity**: Smith (2018) found that the inclusion of geo-grids in subgrade layers significantly improved the load-bearing capacity. The study demonstrated a 30% reduction in rutting for pavements reinforced with geo-grids compared to non-reinforced sections.
2. **Reduction in Differential Settlements**: The study highlighted that geotextiles effectively reduced differential settlements by distributing loads more uniformly. This was particularly beneficial in areas with high moisture content, where soil stability is compromised.
3. **Economic Benefits**: Smith (2018) also conducted a cost-benefit analysis, concluding that while the initial cost of using geo-synthetics is higher, the overall lifecycle cost of the pavement is reduced due to lower maintenance and extended pavement life.

III. IMPLEMENTEDMETHOD

MODEL STUDIES ON REINFORCED SOIL BED.

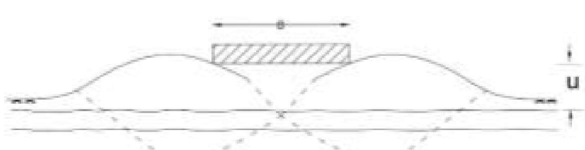
Model plate stress tests on circular, strip, square, and rectangular footings were done by various researchers with varied reinforcement configurations are reported as follows. Binquet and Lee (1975a) performed several strip footing load tests to imitate actual foundation conditions, such as deep homogenous sand beds and sand atop soft clay. The footing load testing were done in a rectangular tank of size 1500 mm × 510 mm × 330 mm. A 76 mm-wide strip plate served as the model footing. The test findings suggested that by fortifying the soil foundation, the bearing capacity may be improved by a factor of two to four. The authors reported that increasing the number of reinforcing layers will virtually surely increase performance in terms of bearing capacity improvement and footing settlement decrease. In their investigation, the placement depth of reinforcement below the effect depth is roughly two times the footing width. According to their model simulations, u/B = 0.3 below the footing resulted in the greatest significant improvement. Binquet and Lee (1975b) observed that there are three separate failure modes of bearing capacity for the isolated strip footing installed on reinforced sand and corresponding to a particular settlement. Three different ways of failure were detailed in Figures 2.2(a)-2.2 (c), depending upon the positioning and tensile strength of strips. These modes of failures are as follows:

(1) Shear failure above the topmost reinforcement layer (u/B greater than 2/3, where u = reinforcement depth, B = width of footing.



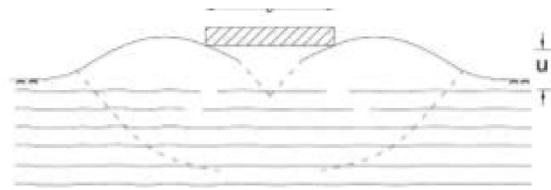
U/B > 2/3:Shear above reinforcements

(2) Tie pullout failure, which is likely for shallow and light reinforcement or in the case where reinforcing ties are short to mobilize the required friction (u/B < 2/3 and N > 3, where N = number of layers).



U/B <2/3 and N < 2 or 3, or short ties: Ties pull out

(3) Ties break failure, which occurred with long, shallow and heavy reinforcement (u/B < 0.67, N > 3). In this type of failure, ties always broke under the edge. The uppermost tie broke first, followed by the next deep tie.



U/B <2/3, Long ties & N > 4: Upper ties break

Figure. 2.2 Failure mechanism for reinforced bed assumed by Binquet and Lee (1975b).

Latha and Somwanshi (2009a) analyzed the results of footing load tests and validated these results by conducting numerical simulations (FLAC3D) of reinforced sand beds under square footings. The effect of various reinforcement parameters such as quantity, geometry and tensile strength of reinforcement on the performance of reinforced beds wereanalyzed. It was reported by the authors that the geometry and configuration of reinforcements have a significant effect on bearing capacity. It was also found that the beneficial depth of geo-grid = 2B, the optimal spacing between geo-grids layer = 0.4B and optimal size of geo-grid = 4B are sufficient for maximum bearing capacity improvement. Further studies have been reported (Latha and Somwanshi, 2009b) on the comparative performance of geo-net and geo-grid in three different forms (planar, cellular, randomly distributed mesh) in sand beds, as shown in Figure 2.14. The amount of reinforcement was set equal in all tests with varying forms. The reinforcement in the pattern of randomly oriented grid size utilized in the experiments was observed to somehow be weaker compared to planar or geo-cell structures due to the overall confinement action being reduced due to the tiny size of the mesh. Geo-cell is the most advanced reinforcement of the ground improvement techniques examined, assuming that the material does not rupture during loading. The geo-cell layer enhances footing capacity by transmitting applied load to deeper strata, reducing stresses and strains beneath the footing and eliminating surface heave near to the footing.

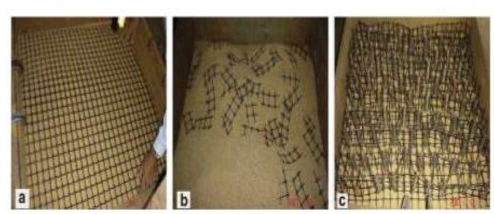


Figure 2.9 Different reinforcement forms used by Latha and Somwanshi (2009b)

Vinod et al. (2009) assessed the performance of coir rope to improve the strength and reduce footing settlement of weak sand beds by using the footing load test. The effect of braided coir rope (Figure 2.15) factors such as reinforcing embedment depth, length, layer count, and plies count were investigated. The findings of the model tests were indicated that using the proposed reinforcing approach could result in a strength increase of approximately 600% and a reduction of around 90% in the settlement. The optimum value of u/B was found to be 0.4.

Vinod and Bhaskar (2010) studied the performance of a hand-knotted coir netting (Figure 2.10) in the weak sand bed. It was concluded by the authors that coir netting with N =1 embedded at a depth between 0.25B and 0.4B results in a roughly threefold increase in strength. At N = 3, these parameters were obtained as 0.4 B to 0.6B. The most beneficial effect was obtained when the reinforcement length was 3B.

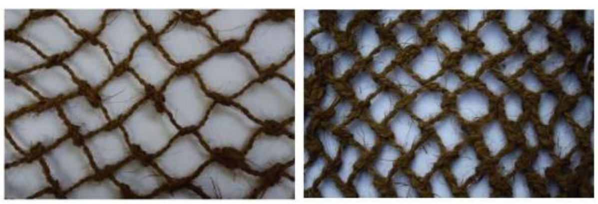


Figure 2.10 Hand knotted coir netting used by Vinod and Bhaskar (2010).

Soe et al. (2015) examined the load settlement response of reinforced bed and surface deformation features of geogrid-reinforced soil through small-scale plate load tests. As amodel footing, arigid circular steel plate was used. Triangular geo-grid reinforcement surpasses biaxial geogrid reinforcement of about equal unit weight in tests. The authors observed that the wider stress distribution could be achieved by using triangular geo-grid as the bending pattern of geo-grid presented (Figure 2.12) in this study.

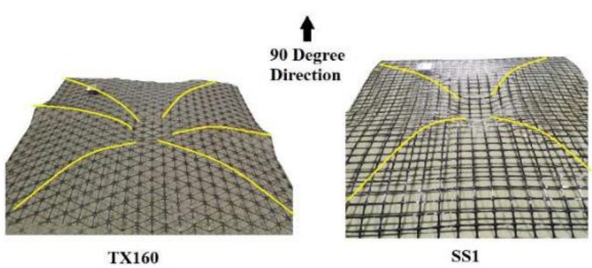


Figure 2.12 Bending pattern of triangle and biaxial geo-grids (soe et al., 2015).

The copper slag (CS) employed in the present experimental work, as illustrated in Figure 3.1, was supplied by Birla Hindalco Industries Limited, Dahej, Gujrat. Copper slag, sometimes termed black sand, is formed during the smelting and refining of copper. Copper slag is free draining material and granular non-cohesive glossy solid grains of black tint. The specific gravity value of CS was achieved at 3.62 as per IS: 2720 (Part 3). It consists mostly of Iron silicates, calcium oxide, alumina, and trace amounts of copper, lead, zinc, and other metals.

Figure 3.1 Copper slag used in the present study

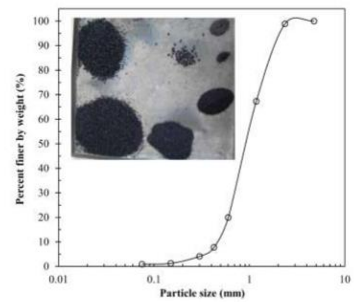


Figure 3.2 practical size distribution curve for copper slag

The sieve analysis test for copper slag was conducted as per IS: 2720 (Part 4) 1985 reaffirmed (1995) to determine particle size range. During the particle size analysis, most particles were angular in shape. It mainly contains sand-size particles (S = 98%) and silt size particles (M = 2%) and is categorized as a poorly graded sand-size (SP) material according to the IS:1498- 1970 reaffirmed (2002). The particle size analysis curve for copper slag is shown in Figure 3.2. The permeability test was performed as per IS:2720 (Part 17) 1986 reaffirmed (1997) by the constant head method, and the coefficient of permeability value is found to be 0.11 mm/sec. The relative density tests were conducted to determine the maximum and minimum dry unit weights of copper slag as per the IS 2720 (Part 14) 1983 reaffirmed (1995) and the values reported in Table 3.1.

Table 3.1 **: physical properties of copper slag sample.**

Property	Value
Specific gravity, Gs	3.62
Natural moisture content (%)	0.40
Effective grain size. D10 (mm)	0.46
Gravel size (%)	0.0
Coarse sand size (%)	1.0
Medium sand size (%)	91.0
Fine sand size (%)	6.0
Silt and clay size (%)	2.0
Average grain size, D50 (mm)	0.93
30% passing than size. D30 (mm)	0.70
60% passing than size. D60 (mm)	1.20
Coefficient of uniformity, Cu	2.61
Coefficient of curvature, C2	0.89
Maximum dry unit weight, Ydmax (kN/m2)	23.68
Minimum dry unit weight, Ydmin (kN/m3)	19.03
Coefficient of permeability (mm/sec)	0.11

IV. RESULTSANDANALYSIS

Interface behavior of sand/copper slag- biaxial geo-grid.

The values of shear stress and horizontal displacement obtained from tests were plotted in the graph for three different normal stress are shown in Figures 3.20 and 3.21. The peak shear stress values of sand were found to be in the range of 4 - 6 mm horizontal displacement, while residual shear stress values were found to be in the range of 6 - 9 mm. The peak shear stress values of copper slag were found to be in the range of 2 – 3 mm horizontal displacement, while residual shear stress values are found at a horizontal displacement from 5 mm to 7 mm.

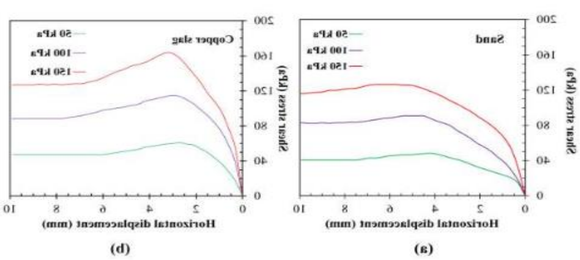


Figure 3.30 Response of shear stress horizontal displacement for (a) sand (b) copper slag

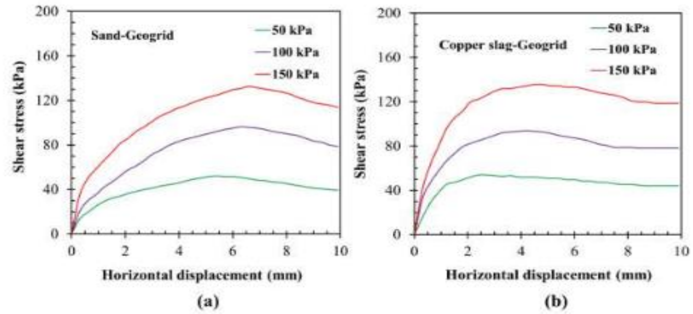


Figure 3.31 Response of shear stress and horizontal displacement for (a) sand-geo-grid (b) copper slag-geo-grid.

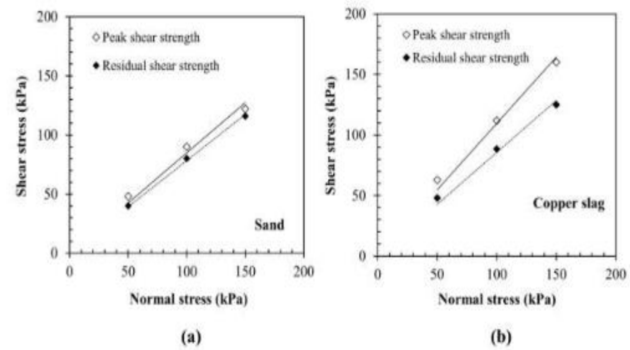


Figure 3.32 Shear strength envelopes for (a) sand (b) slag at peak and residual states.

Interface behavior of sand/copper slag- bamboo grid.

In the present set of large direct shear tests, bamboo grids were used to obtain the coefficient of interfacial friction between copper slag/sand and the bamboo grid and examine the influence of aperture shape and size on interface shear strength parameters. The picture of bamboo grids in three different sizes are shown in Figure 3.34

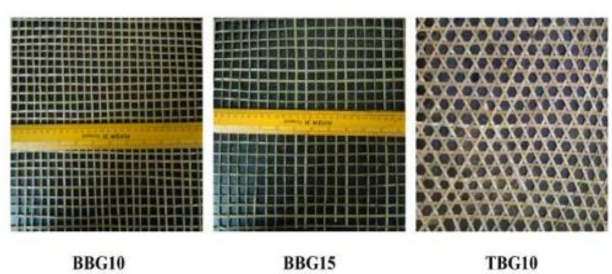


Figure 3.34 bamboo grids in different aperture sizes and shape.

The shear stress and horizontal displacement curves were plotted for the bamboo grid with sand and copper slag are shown in Figures 3.35, 3.36 and 3.37. From Figure 3.35, it is observed that the interfacial shear stress increases rapidly at the 3 mm to 5 mm horizontal displacement and reaches a peak value, after which a slight decrease in the shear stress for the bamboo grid-BBG10 combination. In the case of BBG 15, where the aperture size is increased by 5 mm, the magnitude of shear stress is decreased. The less interaction between the surface of the bamboo grid and granular fill is offered because fewer bamboo strips

required for preparing big aperture size may be the reason for low shear stress. In the case of a tri-directional bamboo grid, the interfacial shear stress increases with normal stress and horizontal displacement. The geometry of the tri-directional bamboo grid provides a higher surface area for the frictional interaction may be the reason for the higher peak stress value.

3.8 Coefficient of Interface shear strength

The interface shear strength coefficient is defined as a ratio of the shear strength in a soil geosynthetics direct shear test, τsoil/geo, to the shear strength in a direct shear test on soil τsoil, under same normal stress. The coefficient of interaction or interface shear strength coefficient of sand-geogrid and copper slag-geogrid were determined from the equation. Table 3.6 summarizes the values of the interface shear strength coefficient of the interfaces for normal stresses of 50, 100 and 150 kPa. The test results show that the coefficient of interaction ranges from 0.79 to 0.98 for the sand geogrid interface and 0.67 to 0.85 for the copper slag-geogrid interface. (Cazzuffi et al., 1993) Presented coefficients of interaction values in the range of 0.83-1.04 for soil-geogrid interfaces, and (Liu et al., 2009 and Umashankar et al., 2015) reported interfaces shear strength coefficient values from 0.89-1.01 for different soil-geogrid interfaces. The coefficient of interaction for geogrid with copper slag and sand were obtained from this study have good agreement with the values available in the literature.

Table 3.3 Shear strength parameters for sand and copper slag with different reinforcements.

Interface material	Peak shear strength		Residual shear strength	
	C, Ca (kPa)	Φ ,ρ (°)	C, Ca (kPa)	Φ ,ρ (°)
Sand	8.67	39	0.41	36
Copper slag	14.67	44	10.13	38
Sand-geogrid	12.33	38	3.67	35
Copper slag-geogrid	14.33	39	5.33	37
Sand-BBG10	8.67	33	9.67	26
Copper slag-BBG10	16.67	37	11.0	32
Sand-BBG15	11.33	28	8.0	26
Copper slag-BBG15	17.0	34	11.33	30
Sand-TBG10	8.33	36	5.67	33
Copper slag-TBGI0	16.33	39	12.67	36

Table 3.4 Coefficients of interaction for sand and copper slag with different-reinforcements.

INTERFACE MATERIAL	COEFFICIENTS OF INTERACTION
Sand-geo-grid	0.90
Copper slag-geo-grid	0.85
Sand-BBG10	0.67
Copper slag-BBG10	0.72
Sand-BBG15	0.65
Copper slag-BBG15	0.68
Sand-TBG10	0.71
Copper slag-TBG10	0.81

V. CONCLUSION

Stabilizing subgrade with geo-synthetics effectively enhances soil properties, providing increased strength, reduced settlement, and improved load distribution. This approach is cost-efficient, durable, and environmentally sustainable, leading to more reliable and long-lasting infrastructure. Geo-synthetics offer versatility in various applications, making them a key component in modern civil engineering projects.

VI. FUTURESCOPE

The future scope of subgrade stabilization using geo-synthetics is promising, with several key areas of advancement:

1. **Innovative Materials**: Research is on-going to develop new geo-synthetic materials with enhanced properties, such as greater durability, flexibility, and environmental compatibility.
2. **Smart Geo-synthetics**: The integration of sensors and smart technologies into geo-synthetics could allow for real-time monitoring of subgrade performance, enabling proactive maintenance and extending the lifespan of infrastructure.
3. **Sustainable Solutions**: The development of biodegradable and recycled geo-synthetics will further reduce the environmental impact, aligning with global sustainability goals.
4. **Wider Application**: As understanding and technology improve, geo-synthetics could be more widely adopted in areas like disaster-prone regions, remote locations, and in green infrastructure projects.
5. **Enhanced Design Tools**: Advanced modelling and simulation tools will improve the design and implementation of geo-synthetics in subgrade

stabilization, making the process more efficient and effective.

Overall, the continued evolution of geo-synthetics holds great potential to revolutionize subgrade stabilization, leading to safer, more sustainable, and cost-effective infrastructure solutions.

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