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Evaluation of Rockfill Stabilized-Geosynthetics Reinforced Road Base with Repeated Plate Loading Tests

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Abstract: In this study, the performance of unpaved road sections over soft clay soil geosynthetic-reinforced and stabilized with rock fill layer was evaluated using repeated plate loading tests. A total of 10 field tests were carried out using a circular model rigid plate with a diameter of 0.30 m. The parameters investigated included the location and type of geosynthetics and loading conditions (number of loading cycle and traffic loading condition). Based on the test results, the least deformation was observed in the rockfill section. The geocell placed at a depth of one-third thickness of the granular fill layer from the top showed improved performance and was more effective as compared with other geosynthetic reinforcements. However, for granular fill geosynthetic-reinforced or stabilized with rock fill layer, the results demonstrate an improvement in the rutting performance of the pavement and the definite trend of increasing reloading elastic modulus, depending on the traffic loading situation. It has been also observed that the use of geocell or geogrid reinforcement in granular fill layer or more rigid rockfill layer provides an important increase in the modulus improvement ratio (MIR) by at least 36%, 45% and 60% compared to the granular fill section, respectively.

Keywords: field tests; soft clay soil; granular fill layer; rockfill layer; geosynthetics; repeated plate loading tests

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1. Introduction

A road pavement is a layered structure composed of several sections; the natural subgrade acts as the foundation above which unbound and bound courses are built. Unbounded (granular material) layers are an important component of high-traffic and low-volume roads, as their mechanical properties are essential for a well-performing road pavement. Most of the worldwide road network comprises the so-called low-volume roads (LVRs) [1]. Those roads are generally unpaved and characterized by low traffic, and their unbound layers are directly exposed to vehicle and weather actions without any reinforcement material [2,3]. On the other hand, whether it is a temporary access road, or a permanent road built over a weak subgrade, significant subgrade deformation can lead to the deterioration of the paved or unpaved surface. One solution to this problem is constructing a reinforced base or subbase layer to support the road system. This alternative method has considerable potential to be cost-effective compared to conventional support methods.

Problematic soil behavior can be improved by totally or partially replacing inadequate soils with granular fill compacted in layers in combination with geosynthetics. In this technique, one or more layers of geosynthetic reinforcement and controlled fill material are placed beneath the structures to create a composite material with improved performance characteristics. This technique is commonly used for unpaved roads, embankments, shallow foundations, and large stabilized areas such as car parks or working platforms for oil drilling [4–9]. Several studies have shown that geosynthetics can extend the service life of pavements [10–16], reduce base course thickness for a given service life [17] and delay rutting development [18,19]. The enhancement of road performance through the incorporation of geosynthetics in base layers depends on various factors, such as the subgrade's strength, the characteristics of the geosynthetic material, the positioning of geosynthetics within road structures, and the thickness of the base layer [20–22].

One of the primary considerations in road design is minimizing rutting failure and subgrade bearing capacity failure when subjected to traffic loads. Therefore, two approaches have typically been employed in the literature, including in laboratory or field tests, to evaluate the performance of unpaved and paved roadways: bearing capacity-based design methodology with static loading tests [23] and permanent deformation-based design methodology with cyclic loading tests [20]. Most studies in the literature use static loading experiments in laboratories, which only partially simulate traffic loads. Although studies in a controlled laboratory environment can be carried out more rapidly and typically incorporate more options, they can only simulate field situations to a limited extent (Hufenus et al. [14]). Hence, there remains a requirement for conducting field tests that ensure consistent conditions and integrate diverse geosynthetics to establish an adequate repository of performance outcomes. A comprehensive information database is necessary, given the ongoing requirement for a universally recognized and standardized design approach for paved or unpaved roads (or construction platforms), that integrates soil and geosynthetic material characteristics. On the other hand, a lack of understanding of the mechanisms of geosynthetic reinforcement or rockfill stabilization, especially regarding geosynthetics as an alternative to rockfill stabilization, has limited the effectiveness of the attempts to change the engineering design practice. These limitations motivate continual research on geosynthetic-reinforced pavements to better understand the geosynthetic-reinforcement benefits for future pavement design involving mechanistic empirical pavement design methods.

2. Objectives and Scope

This research primarily evaluates the benefits of using geosynthetics (geogrids, geotextiles and geocells) to stabilize the subsoil and/or strengthen the base layers in unpaved test sections. In addition, the cases of geosynthetic reinforcement and using a more rigid rock fill in the base/subbase course layer are compared by performing repeated plate loading tests in the field. The repeated plate loading test can be used to determine the elastic modulus of unpaved roads subjected to dynamic loading. Although this test uses the same equipment as the plate loading test, the method of performing this test is quite different [24].

The repeated plate loading test experiments were carried out separately before and after traffic loads ($N_{traffic}$ = 0, $N_{traffic}$ = 5000). These experiments were carried out to investigate the performance change of the filling layer (specifically, the modulus of elasticity and settlement behavior), depending on the traffic load. The studies in the literature are primarily on ruts. Although some studies have evaluated the results of plate loading experiments before traffic load, no significant study has been found that evaluates the performance of unpaved roads together before and after traffic load.

The literature indicates that the majority of experimental studies on reinforced soils were carried out using small-scale laboratory tests [25–27]. Modeling the full-scale behavior of reinforced soil using small-scale laboratory tests can be challenging due to the scale effect [22,28]. For this reason, full-scale field tests were conducted on soft clay deposits, compacted granular fill layers with and without geosynthetics, and rockfill overlying the natural clay deposit to evaluate the performance of geosynthetics on the roads.

3. Material Properties and Test Program

3.1. Subgrade and Fill Material Properties

In the experimental study, the silt–clay mixture soil used to create a problematic subgrade on the road section was obtained from a natural land (about 1.5–2.0 m deep) on which there was no construction in the Düziçi district of Osmaniye province. In addition, the filling material to be used as the base or subbase and rockfill layers in the road section were obtained from the Stone Quarry located in the Kadirli district of Osmaniye province.

A group of conventional laboratory tests (sieve analysis, compaction, consistency limits, pycnometer, and CBR) were performed to determine the physical and engineering properties of the silty clay soil that would form the subgrade of the road and the filler material that would form the base/subbase course layer in the laboratory. The subgrade soil's clay content varied from 60 to 70%. Also, it was classified as high-plasticity clay (CI) according to the Unified Soil Classification System (USCS). Rock fill and granular fill materials have the same geological origin and consist of limestone. The granular fill material for this project consisted of crushed aggregates and was classified as GW (well-graded gravel with sand), according to the USCS classification system [29]. It contained 2–3 percent fines and more than 35 percent gravel (Figure 1a). In addition, large-sized rocks (average 30 cm in diameter) from the same quarry were used to create the rock-filling layer in the road section (Figure 1b).

(**a**) (**b**)

Figure 1. Filling materials: (**a**) the granular fill, (**b**) the rockfill.

The granular fill layer was prepared at an optimum moisture content of 4.80% and a maximum dry unit weight of 21.30 kN/m^3 obtained from the standard proctor test. The granulometer curves of the soils used in field tests are presented in Figure 2, and their physical properties are presented in Table 1.

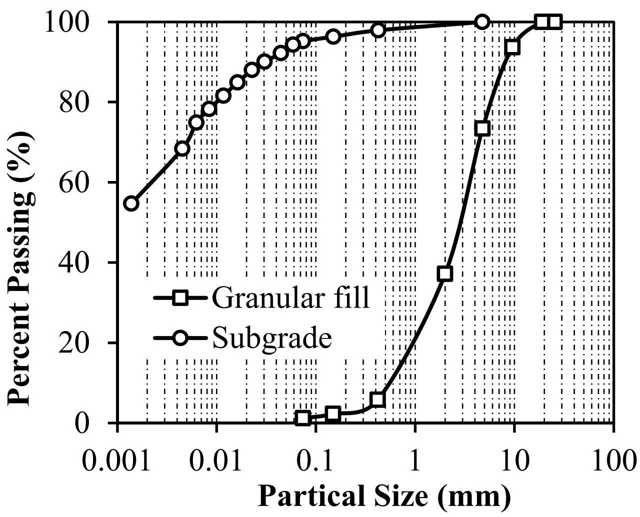


Figure 2. Particle size distribution of subgrade and subbase soil.

Table 1. The properties of subgrade and subbase/base course material.

Parameters	Subgrade Layer	Subbase/Base Course Layer
Max. dry unit weight γ_{kmax} (kN/m^3)	15.6	21.30
Opt. moisture content ω_{opt} (%)	21.0	4.80
Specific gravity Gs (-)	25.0	-
Liquid limit LL(%)	44.1	-
Plastic limit PL (%)	34.0	-
Plasticity index PI (%)	10.1	-
Classification (USCS)	CI	GW
Water absorption (%)	-	0.60

The CBR tests were carried out for the bearing capacity of the subgrade and subbase/base course material. The CBR values of the subbase/base course layer (fill material) were 32.74% and 56.71% for 2.5 and 5.0 mm displacement, respectively.

The CBR tests in the laboratory run on the base course material [30] resulted in a California Bearing Ratio (CBR) value of about 56; however, in-field CBR tests indicated that the average in-place CBR strength of the base layer was approximately 80–90 with dynamic cone penetrometer (DCP) tests [31]. This difference is due primarily to the conditions under which the base course was tested in the lab compared to how these values were obtained in the field. When performing laboratory CBR tests, limiting the material's grain size is necessary since standard cylindrical molds are used. Therefore, this limitation is thought to significantly affect the material's strength [32]. Moreover, the bearing capacity at higher penetration (5 mm) was greater than at 2.5 mm penetration, so the higher values are recommended to be reported by the standard. Considering that the aggregates are better interlocked with each other during compaction in the field, it can give higher CBR values. It is known that water content is a very important parameter in the subgrade layer to ensure weak soil conditions. For this reason, CBR experiments were carried out in the laboratory on subgrades prepared with different water contents. The results obtained are shown in Figure 3. As a result, it was concluded that the subsoil should be prepared with an average water content of 26% in order to ensure weak ground conditions (CBR 3–5). This water content was also checked by DCP experiments in the field and by water content tests in the laboratory.

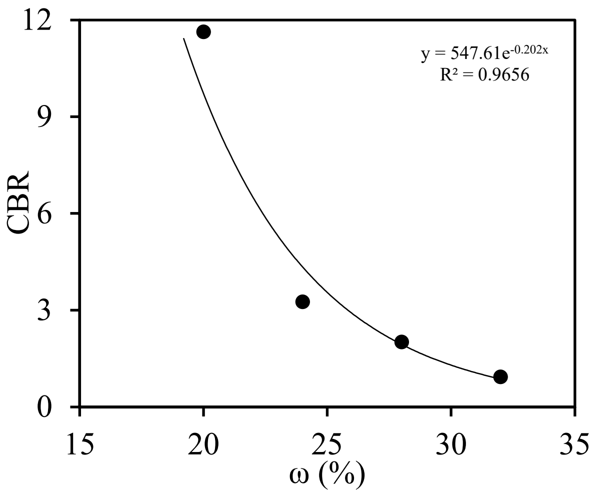


Figure 3. The variation of CBR with water content for subgrade soil.

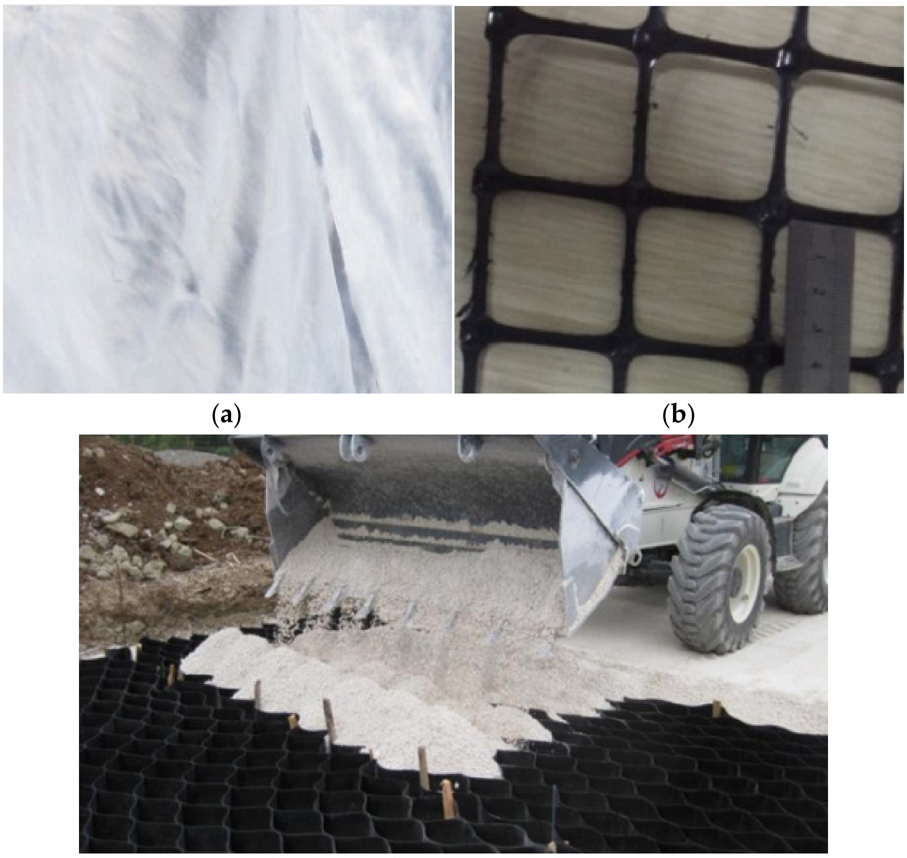
3.2. Geosynthetics

Three geosynthetic products (geotextile, geogrid, and geocell) were used in this research project to evaluate their relative performance under the conditions presented herein. The geosynthetics used were obtained from Geoplas and their technical properties are given in Table 2. Corresponding photos are provided in Figure 4. Geosynthetic tensile strength is a prevalent method employed to evaluate the load-bearing capacity of geosynthetics, particularly their strengths, which typically align with the material's machine and cross-machine directions.

Table 2. Mechanical properties of geosynthetics.

Parameter	Geotextile	Geogrid	Geocell
Raw Material	Polypropylene + UV	Polypropylene	Polyethylene (HDPE)
Unit weight (min. kN/m^3)	0.002	-	0.094
Thickness (mm)	1.50	3.10	1.50
Aperture size (MD/CMD) (mm)	0.13 (equiv.)	35 × 35	-
Tensile strength (MD/CD) kN/m	11–13	325	-
Elongation at break strength (MD/CD)	50–80%	90%	-
Puncture Resistance (CBR Test, N)	2500	-	-
Permeability (m/s)	0.070	-	-
Dynamic drilling (mm)	24	-	-
Cell length (mm)	-	-	300
Cell depth (mm)	-	-	150
Cell width (mm)	-	-	250

MD, Machine direction. CMD, Cross machine direction.



(**a**) (**b**) (**c**)

Figure 4. The types of geosynthetics: (**a**) geotextile, (**b**) geogrid, (**c**) geocell.

4. Experimental Setup and Test Program

A total of 10 full-scale tests were conducted at the construction site of the Osmaniye Governorship, the Special Provincial Administration (SPA) that is located in the north part of Osmaniye, Turkey. The primary objective of this research was to quantitatively assess the performance disparities among geosynthetic products, namely geogrid and geocell, within identical conditions at the experimental test site (SPA). These conditions encompassed identical subgrade strength and base course thickness. Furthermore, an additional experimental section was developed to investigate the impact of the rock fill layer employed as the subbase course layer on the overall performance. The control section, which did not contain geosynthetic materials, was constructed with identical thicknesses of base course aggregate and subgrade strengths. Figure 5 displays the ultimate configuration of the test sections, encompassing the mean subgrade strengths and base thicknesses.

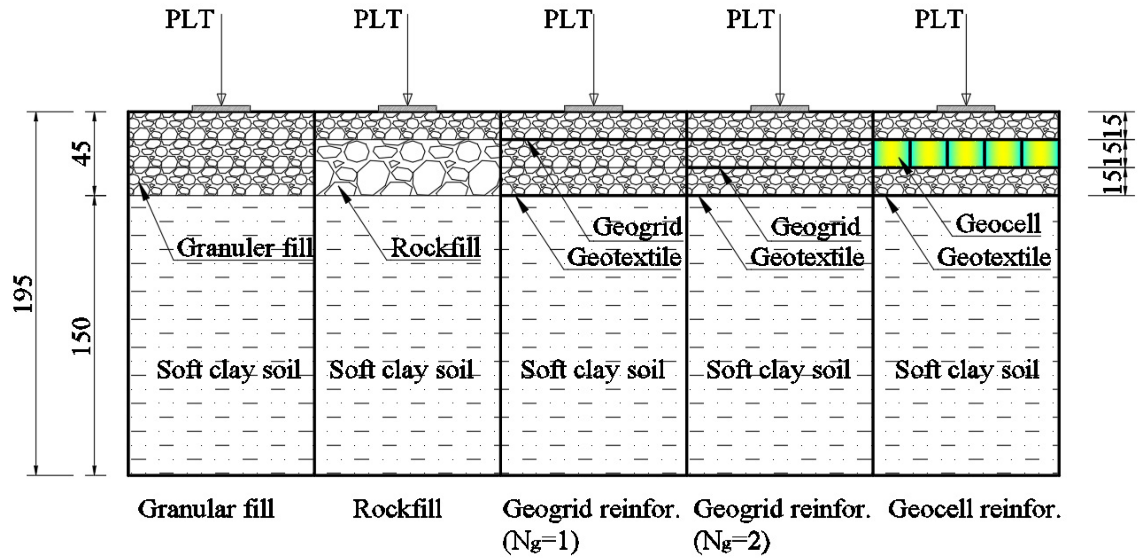


Figure 5. The summary of test sections.

The study investigated the effect of reinforcement and rockfill on load-deformation behavior by the repeated plate loading tests in geosynthetic-reinforced and rockfill-stabilized subbase/base layers built on soft clay soil in actual field conditions. For this purpose, excavation was performed approximately 2 m deep, 5.6 m wide, and 25 m long in the previously determined land (SPA). Approximately 1.5 m of clay soil was placed under control, and a plate loading test was carried out on the clay ground. Then, approximately 0.45 m of foundation or sub-base fill layer was built on the clay soil, and repeated plate loading tests were carried out on these sections. In the rockfill test section, approximately 30 cm of rockfill material was placed on soft clay soil. Subsequently, 15 cm of granular filler was placed on it and compacted in a controlled manner (Figure 6).

In terms of reflecting soft soil conditions, all test conditions in the field were prepared to be uniform, considering that if the water content of the clay soil placed on the excavation floor is 26 $\pm$ 1 percent, the CBR value would be between 3–5 percent. A vibratory roller was used to compact the subgrade by making three passes (enough) of the roller for the longitudinal path of the newly placed subgrade. The homogeneity of the soft soil condition was ensured by the water content samples taken from the field and the DCP tests [33]. The test area's upper surface was leveled, and a rigid plate was positioned on a predetermined line to ensure that the loads exerted by the hydraulic jack and loading mechanism, consisting of a vibratory roller with a capacity of 20 tons, would be evenly distributed onto the rigid plate. A hydraulic jack applied a downward force to the vibratory roller. The reaction loading system was subjected to a series of static loads that increased monotonically in each test. The load was applied using a hydraulic jack and maintained manually with a hand pump until the ultimate vertical deformation was obtained. The load and the corresponding plate settlement were measured by a calibrated pressure gauge and two LVDTs, respectively. The repeated plate loading test procedure was performed according to ASTM [34], where the load increments were applied and maintained until the settlement rate was less than 0.03 mm/min over three consecutive minutes. To accurately determine the deflection for each load increment, the load on the plate must be maintained until all observed settlements have decreased. The duration of the settlement process is ascertained by graphing a time-deformation curve during the test and determining where this curve essentially becomes horizontal.

(**a**)

(**b**)

(**c**)

Figure 6. Preparation of test sections in the field: (**a**) filling trench with prepared subgrade; (**b**) base/subbase course layer reinforced with geosynthetics; (**c**) the construction of base/subbase course rockfill layer.

For each test section, the granular fill material for the base course layer was placed and compacted in layers. The base material was laid and compacted at optimum water content in 3 layers, each 0.15 m thick, on weak ground. The compacted granular fill layer had a moisture content of 4.80% and a unit weight of 21.0 kN/m^3. The initial step in constructing the test sections involved determining the required granular fill material (crushed aggregates) and water for each layer. Subsequently, the granular fill material underwent compaction up to a predetermined height using a vibratory roller to attain the desired density. A compaction effort was implemented for each layer to ensure consistent density within the granular fill layer. In the field tests, sand cone tests were carried out to control the base layers' compaction. During the placement of geosynthetics in the tests' sections, significant attention was devoted to ensuring the optimal flatness of the geosynthetics. The geosynthetic materials were laid down once the desired reinforcement depths were achieved. The compaction process was subsequently carried out until the desired height of the granular fill was attained. The tests were conducted briefly until the initial settlements were assessed under soil conditions without drainage. So, the testing program did not measure the long-term settlement (consolidation) of clay.

The research was conducted in two series. In the first series of experiments, that is, before the field trial road was opened to traffic, plate loading tests were carried out in different repetitions (N_{PLT} = 1–2–5) on all research sections (unreinforced, geosynthetic reinforced and rock-filled) created on the road. In the second series of experiments, plate loading experiments were performed on the same sections and repetitions after traffic on the test road (5000 cycles). Table 3 summarizes the testing program and variables such as $N_{traffic}$ = 0 and 5000 cycles.

Table 3. Details of the PLT test program.

Test Series	Traffic Loading Condition	Test Number	Test Condition
I	$N_{traffic}$ = 0	1	Granular Fill
		2	Rockfill
		3	Geogrid Reinforced (N_g = 1)
		4	Geogrid Reinforced (N_g = 2)
		5	Geocell Reinforced
II	$N_{traffic}$ = 5000	1	Granular Fill
		2	Rockfill
		3	Geogrid Reinforced (N_g = 1)
		4	Geogrid Reinforced (N_g = 2)
		5	Geocell Reinforced

N_g: the number of the geogrid; $N_{traffic}$: the number of traffic cycles.

5. Test Results and Discussion

5.1. The Effect of Traffic Loading on the Unpaved Road

The repeated plate loading test results in the sections in test series I and II ($N_{traffic}$ = 0, 5000) are given for the percentage deformation ratio (s/D) versus plate loading pressure in Figure 7. Figure 7 shows that deformation values are quite limited (decreased by 60% to 70%) in all sections for Test Series II ($N_{traffic}$ = 5000). The least deformation was observed in the rockfill section in the plate loading tests performed under both test series I and II traffic loading conditions. It shows that the rock fill section has a rigid base effect due to the high interlocking of the grains (rocks) and, thus, can spread the load to the weak ground more than the granular fill. In sections reinforced with geosynthetics, the best performance was obtained in the geocell-filled section, followed by the double and single geogrid sections. Geocells have been employed in road engineering to enhance the stability of base course aggregates and subgrade soils, thereby enhancing the overall performance of both unpaved and paved roads. Geocells have the potential to effectively enhance the bearing capacity and trafficability of a base layer while simultaneously reducing the rut depth within the aggregate layer located above the geocell [35]. Although rock fill is seen to be better in terms of settlement behavior, depending on the number of traffic cycles, it has been observed that geosynthetic sections show a performance close to the rock-filled section. It proves that geosynthetics can be an alternative to rock fill.

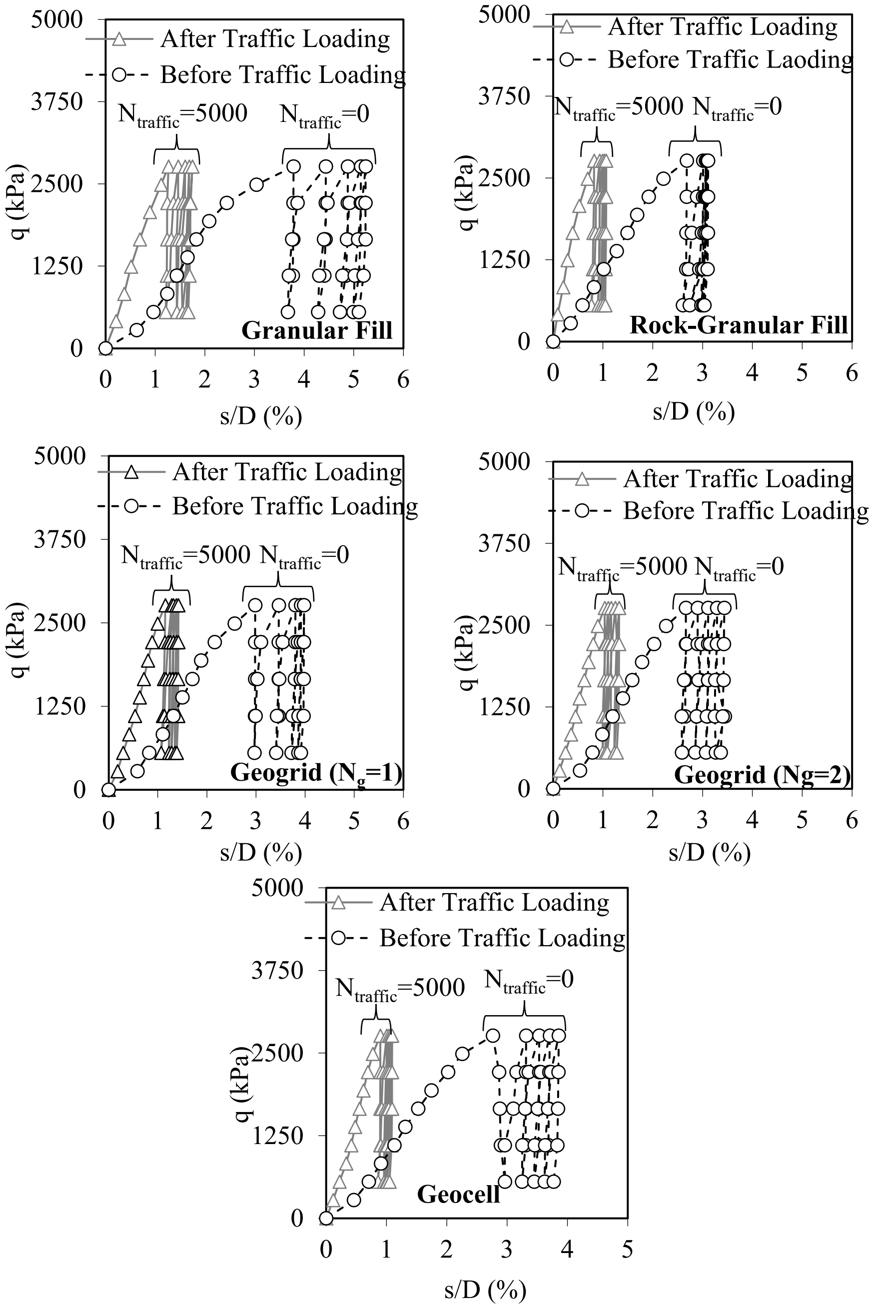


Figure 7. The deformation change depending on the number of traffic passes in the test series.

5.2. The Behavior of Total and Permanent Displacements after Traffic Loading

It is known that the total deformation occurring under repeated traffic loads for the road fill layer is equal to the sum of permanent deformation and elastic deformation. In road design, permanent deformation is considered one of the most important parameters for the stability of the road over long periods of time. Figure 8a shows the elastic, permanent and total displacements that occurred after repeated traffic loads as a representation [36]. In Figure 8b, the percentage deformation ratio (s/D) change is given for the number of plate loading cycles from 1 to 5 (N_{PLT} = 1–5) in the granular filled section in test series II ($N_{traffic}$ = 5000). The percentage deformation ratio (s/D) is determined as the displacement (s) obtained after each load stage to the loading plate diameter (D). It is seen that the increase in the percentage deformation rate gradually decreases for the number of plate loading cycles from 1 to 5 (N_{PLT}). This percentage deformation change is expected to asymptote in progressive cyclic loads.

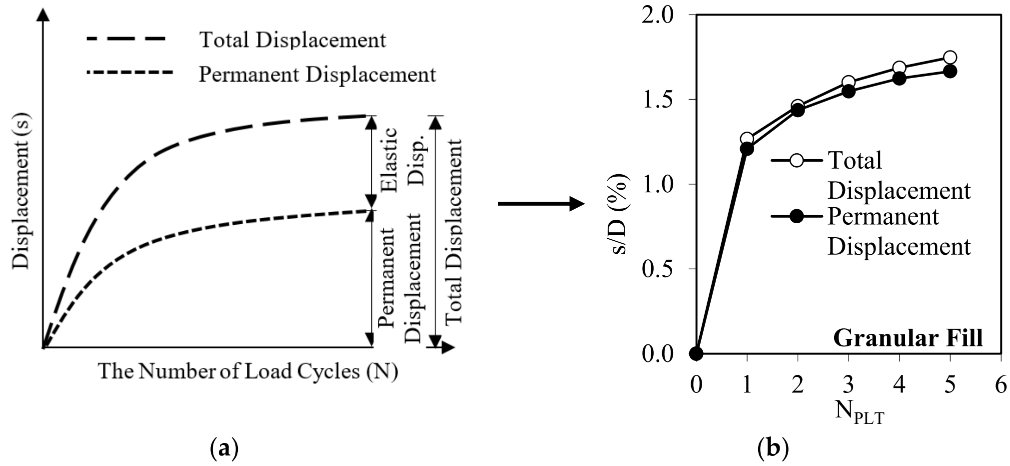


Figure 8. The change of displacements for granular fill section.

The total and permanent displacement changes that occurred due to repeated plate loading tests for sections reinforced with geosynthetics and stabilized with rock fill in test series II are compared in Figure 9. The best performance for total and permanent displacements was obtained in sections stabilized with rock fill and reinforced with geocell. It is considered that the section reinforced with geocell performs better than the section reinforced with geogrid because geocell provides better lateral confinement of granular material, especially after traffic loads [37].

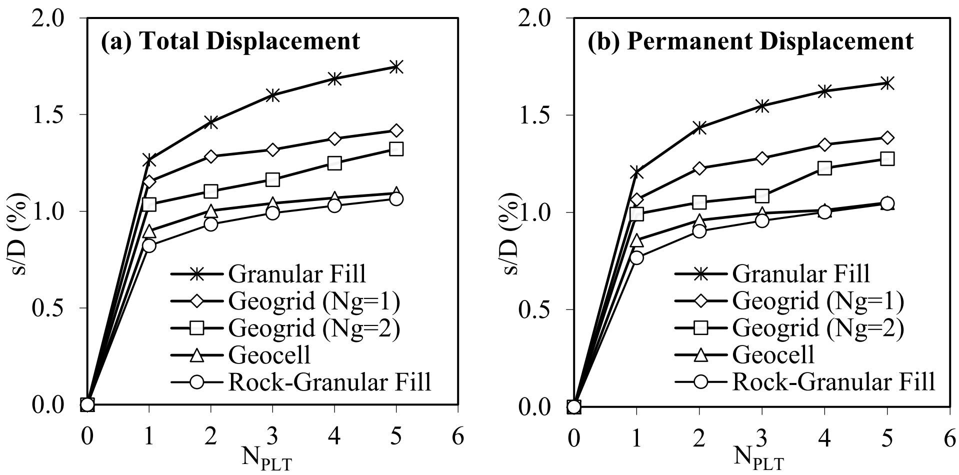


Figure 9. Comparison of displacements for test sections: (**a**) total displacement, (**b**) permanent displacement.

5.3. The Variation of Elasticity Modules after Traffic Loading

The PLT can be carried out using different methods, depending on the required information. These methods include: (1) determining the initial tangent modulus; (2) assessing the tangent modulus at a specific stress level; (3) determining the reloading and unloading modulus; and (4) determining the secant modulus at a specific stress level. In all cases (test series I–II), a load–displacement curve following the general relationship shown in Figure 10 will be obtained. It is known that the influence depth of the PLT is about two times its diameter. Given that the thickness of the base/subbase layer is 450 mm, it can be observed that the influence zone of the PLT (with a diameter of 300 mm) extends to the underlying layer. Hence, the modulus derived from PLT represents the combined modulus rather than the actual modulus of the tested layer. In this research study, the initial tangent modulus (the composite modulus) ($E_{PLT}(1)$) and the reloading elastic modulus for the second and fifth load cycles (E_{PLT}(i)) were determined from the PLTs using the following equation [38]:

$$E_{PLT}(n) = \frac{2P(1-\nu^2)}{\pi R \delta} \quad (1)$$

where P is the applied load; R it the radius of plate; δ is the deflection of plate at load, P; and ν is the Poisson ratio, 0.3, in this study.

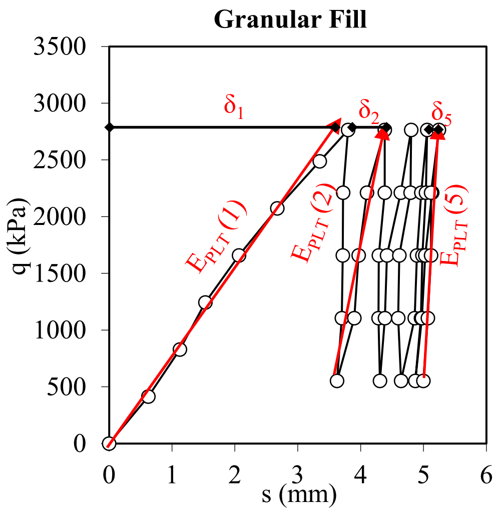


Figure 10. Definition of modulus from the repeated PLT.

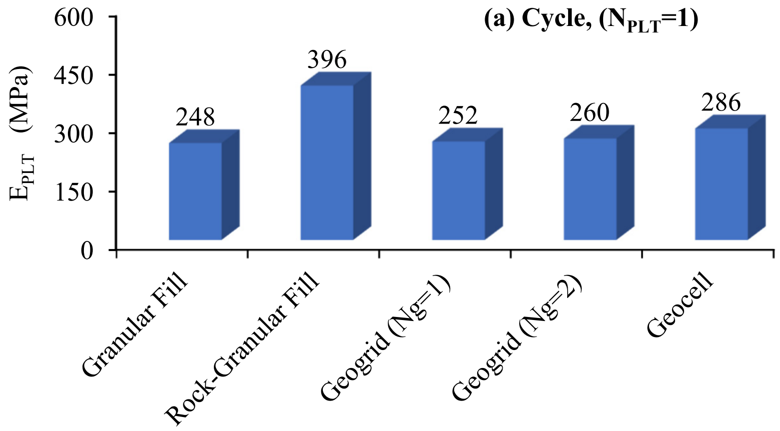
The comparison of E_{PLT} values obtained from the plate loading test for the N_{PLT} = 1 cycle case for sections stabilized with rock fill and reinforced with geosynthetics compared to the unreinforced section is presented in Figure 11a. Additionally, a comparison of the same test sections for N_{PLT} = 1–2 and 5 cyclic plate loading tests–repetition situations is given in Figure 11b.

The findings showed a clear difference between the section stabilized with rock fill and other test sections for the N_{PLT} = 1 cycle case. Nevertheless, as the plate loading number increased (N_{PLT} = 1–2–5), there was also a significant increase in the elasticity modulus in the sections reinforced with geosynthetics. The unreinforced section (granular fill layer) did not show an increase similar to reinforced sections. The best performance was obtained from the section stabilized with rock fill. The dimensions of the rock particles were specially selected with an average size of 30 cm. In addition, in order to minimize the voids between the rocks, the voids were filled with granular material. In this way, a uniform, rigid rock fill layer was obtained. It enabled the rock fill layer to spread the applied load over a larger area, reducing displacements and, therefore, having a higher modulus of elasticity.

The relationship between the modulus of elasticity of the sections stabilized with rock fill and reinforced with geosynthetics by the modulus of that same granular fill is called the modulus improvement ratio (MIR), determined from the E_{PLT} values using the following equation [39]:

$$MIR = \frac{E_{PLT}(\text{section stabilized or reinforced})}{E_{PLT}(\text{granular fill})} \quad (2)$$

The MIR values calculated for N_{PLT} = 1 are shown comparatively in Figure 12a. Additionally, the MIR values obtained in the N_{PLT} = 1–2–5 case are presented in Figure 12b. For the first plate loading test (N_{PLT} = 1), in the case stabilized with rock fill, the MIR value was approximately 59% higher than in the granular fill section, while this rate was 15% in the section reinforced with geocell. It can also be seen that the elasticity modulus improvement ratio (MIR) is approximately 2% greater for single geogrid and 5% greater for double geogrid compared to the granular fill section. On the other hand, as the number of repetitions increased in the repeated plate loading tests, the increase in the elasticity modulus improvement ratio (MIR) was even greater. As a result of the fifth repeated plate loading test ($N_{PLT} = 5$), the MIR value was approximately 85% for the section improved with rock filling, while this rate was 48% for the section reinforced with geocell. Additionally, in the test sections reinforced with geogrid, the MIR value was obtained at approximately 12% for single geogrid and 28% for double geogrid.



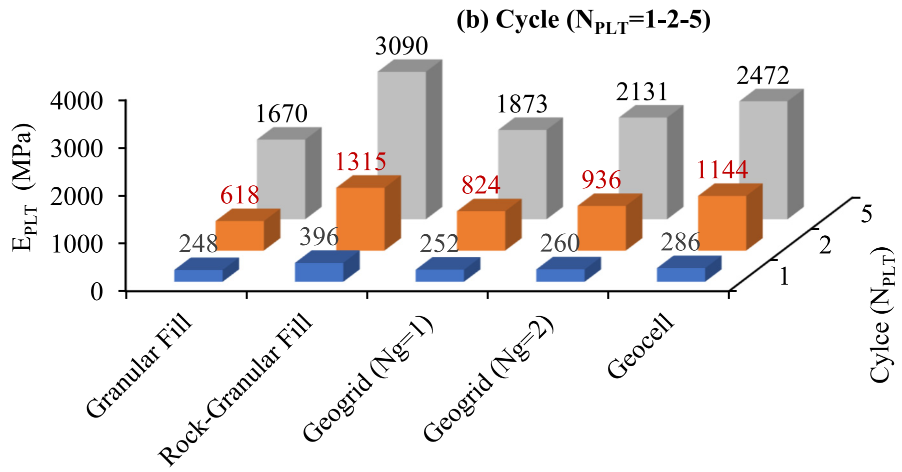


Figure 11. The variation of elasticity modules for different repeated plate loading (**a**) $N_{PLT} = 1$ (**b**) $N_{PLT} = 1–2–5$.

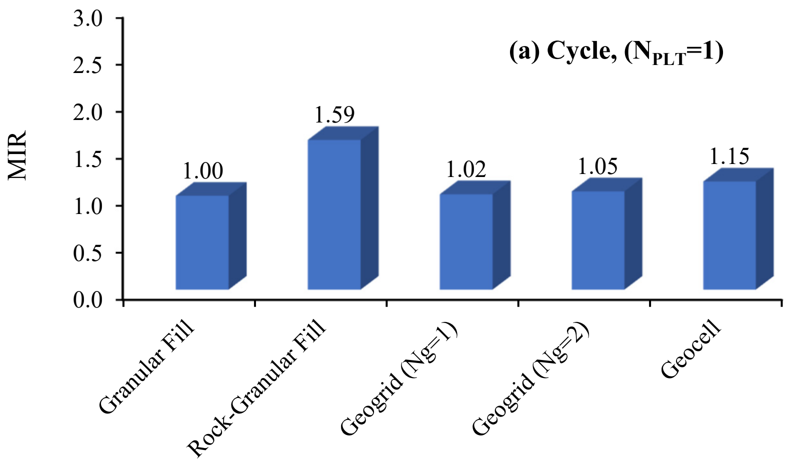


Figure 12. *Cont.*

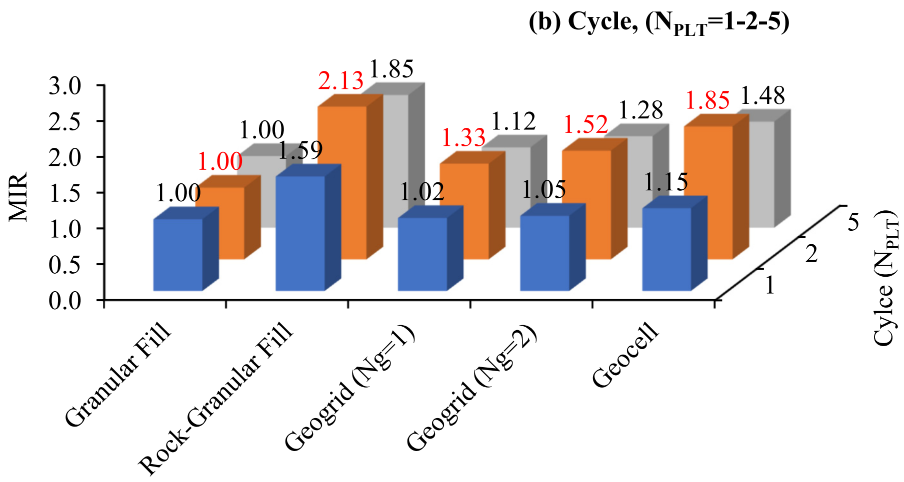


Figure 12. The effect of NPLT on the modulus improvement ratio (MIR): (**a**) N_{PLT} = 1, (**b**) N_{PLT} = 1,2,5.

In this study, the reinforcement of the base course with different geosynthetics was investigated in order to evaluate it as an alternative to quality rock fill. The test results obtained showed that rock fill showed the best performance. However, quality materials, such as those used for rock filling, are rapidly depleting around the world. In addition, the cost of this material is constantly increasing. Although geocells were initially designed to support base layers in flexible pavements, their use was limited to unpaved low-volume roads due to concerns about stiffness, durability, and a lack of design methodologies [40]. With the confinement of the materials, the geocells significantly increased the filler materials' strength and the pavement layer's elastic modules. Reduced layer thickness for the asphalt, base, and subbase layers might also be possible thanks to geocells' increased strength and bearing capacity. This circumstance creates a sustainable construction method with clear environmental and economic benefits suitable for all types of transportation infrastructure. Also, the results of the tests showed that geocell reinforcement performs better than geogrid reinforcement, followed by cases with double- and single-row geogrid reinforcement. Especially in cases with geogrid reinforcement, although the degree of improvement remained low after the first plate loading, the degree of improvement increased rapidly as the number of plate loadings increased. This situation is thought to be due to the membrane and interlocking effects that occur after the increasing displacement of the geogrid. The mobilization of rock fill into a very soft subgrade has been shown to be effective in improving the weak subgrade and preparing a fairly stable working platform for the construction of the layers being placed above [41].

6. Conclusions

To assess the potential advantages of utilizing geosynthetic-reinforced or rock-stabilized granular fill layers constructed above natural clay deposits for unpaved roads, a series of 10 full-scale model repeated plate loading tests was carried out. The findings of this investigation led to the following primary conclusions.

For all sections, after traffic passage ($N_{traffic}$ = 5000), repeated plate loading test results showed that deformation values decreased by 60–70% compared to before traffic passage. The best performance was obtained in the rock fill section. Furthermore, it has been observed that geosynthetic sections show a performance close to the rock-filled section. Among the sections reinforced with geosynthetics, the best performance was obtained using geocell.

Repeated plate loading experiments performed after traffic loading were used to determine the total and permanent displacements of the sections. The best performance in total and permanent displacements was obtained in sections stabilized with rock fill and reinforced with geocell. It is considered that the section reinforced with geocell performs better than those of geogrid because of the better lateral confinement of geocell granular material, especially after traffic loads. The findings showed that there was also a significant increase in the elasticity modulus in the sections reinforced with geosynthetics as the plate loading number increased (N_{PLT} = 1–2–5). It was observed that as the number of repetitions increased in the repeated plate loading tests, the increase in the elasticity modulus improvement ratio (MIR) was even greater. As a result of the fifth repeated plate loading test (N_{PLT} = 5), the MIR value was approximately 85% for the section improved with rock filling, while this rate was 48% for the section reinforced with geocell. Additionally, in the test sections reinforced with geogrid, the MIR value was obtained as approximately 12% for single geogrid and 28% for double geogrid.

While the best performance in elastic modulus was seen in rock fill, the same increase was not observed in the unreinforced (granular fill) section. In fact, the results indicated that the rock fill layer spreads the applied load over a larger area, reducing displacements and, therefore, having a higher modulus of elasticity.

The results of the repeated PLT on the unpaved test sections demonstrate the benefits of using geosynthetics in reducing the permanent deformation in the road structure. This evaluation proves that geosynthetics can be an alternative to rock fill, as quality materials such as those used for rock filling are rapidly depleting worldwide, and the cost of this material constantly increases. The investigation is considered to have provided a valuable basis for further research, leading to a better understanding of the benefits of using geosynthetics in reducing permanent deformation on unpaved roads. On the other hand, the findings offer valuable insights for road construction on soft subgrades. The results on the geosynthetics reinforcement and rock fill stabilization provide alternative application methods for engineering practice, considering the cost and environmental impact.

7. Limitations of Research Program

It is important to note that there are some limitations. Initially, just one subgrade soil type was used in the experiments. For various soils, this test program might produce different results. Since some geosynthetics were considered, the findings alone were limited to the geosynthetic types used. The performance of other geosynthetics might vary considerably. It is essential to verify the trends observed for these conditions across different traffic situations. To further understand the behavior of the permanent settlement–elastic modulus comprehensively and potentially develop a design method, additional research should be conducted using different granular fill thicknesses and reinforcement configurations.

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