Evaluation of geogrid reinforced unpaved roads using large scale tests

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ABSTRACT: The technique of ground improvement using geogrid reinforcement in roadway applications started in the 1970s. Geogrid reinforcement has been increasingly used in the construction of roadways, nowadays. It is clear from the literature that geogrids can reduce permanent displacement (rutting) and base course thickness and extend the service life of a pavement. In this study, the effects of geogrid reinforced unpaved roads on weak subgrade was investigated by conducting large scale laboratory tests under cyclic loading. Large scale cyclic plate load test equipment was developed for this purpose. Using this test setup, performance of base and subgrade soil under cyclic loading test conditions were evaluated. In large scale tests, cyclic loading at a fixed frequency was applied with 300 mm diameters of circular plate. The results of this paper showed the benefits of the geogrid reinforcement and effect of the base layer thickness. It was observed that, geogrid reinforcement improve the performance of the base course layer and protecting/stabilizing the subgrade layer, thus reducing the pavement's permanent displacement (rutting) under cyclic loading. In summary, permanent settlement decreased with both of increasing the base course thickness and using the geogrid reinforced in base course layer.

Keywords: Base Course, Geogrid, Cyclic Load, Rutting, Weak Subgrade

1 INTRODUCTION

Unpaved roads are generally used for low-volume traffic such as the access and temporary roads. If unpaved roads are built on soils which has a very low bearing capacity, extremely large permanent displacement (rutting) occurs. Also, unpaved roads are subjected to many repeated traffic loads, bearing capacity failure occurs and it lead to progressive rutting. In the case of these problems, the design base/subbase layers have become thicker. Thicker base/subbase layers led to consuming more material, so spent more cost. Geogrid which is one of the geosynthetic products can be used as an alternate to reduce the thickness of base/subbase layers and cost. Geosynthetic materials have been used to improve performance of flexible pavements and its use has been increasing significantly in the past three decades. Among the various geosynthetic available in the market, geogrid has been commonly used for base/subbase reinforcement by interlocking with granular soils. The growth of the use of geogrid has been supported by considerable research (Hass et al., 1988; Barksdale et al., 1989; Al-Qadi et al., 1994; Berg et al., 2000; Perkins, 2002; Hufenus et al., 2006; Giroud and Han, 2004a; Giroud and Han, 2004b). According to the studies in literature, geogrid use to help in reducing the material needed (Montanelli et al., 1997), extend the service life of the pavement (Al-Qadi et al., 1997), improve the bearing capacity (Huntington and Ksaibati, 2000), reinforce unpaved roads on the weaker subgrade areas (Bloise and Ucciardo, 2000) and delay rutting (Mekkawy et al., 2011). There are generally three types of geogrid. These are uniaxial, biaxial and triaxial geogrids. Uniaxial geogrid has a tensile strength in one direction while biaxial geogrid has tensile strengths in two directions. But, it is expected that, triaxial geogrids provide tensile strengths in all directions as compared with uniaxial and biaxial geogrids (Qian, 2009). The most basic mode of geogrid works is that the soil aggregates penetrate through those apertures and eventually interlock in them. Geogrids can provide basic reinforcement mechanisms such as a lateral confinement, improved bearing capacity and tensioned membrane effect. Lateral confinement refers to the interlocking and confinement of aggregate (Hufenus et al., 2006). Increase in performance with the inclusion of geogrid in the base layer depends on many factors such as physical properties of geogrid, mechanical properties of geogrid, location of geogrid in pavement, thickness of base layer and aggregate base residual stresses (Abu-Farsakh and Chen, 2011). In addition, Cancelli and Montanelli (1999) emphasize that in case of using geogrid reinforcement, the weaker the subgrade, the higher the reduction of rutting value.

Bloise and Ucciardo (2000) conducted field investigation for practical use of the geosynthetics in road construction as reinforcement. They reported that the use of a geogrid with high modulus allows the reduction of sub-base thickness. So, use of energy and required natural resources decreases when using geogrid. Qian et al. (2011) conducted an experimental study on the unreinforced and triangular-aperture geogrid-reinforced bases over a weak subgrade were constructed in a large testing box. Unreinforced and reinforced tests were done under cyclic loading. Their paper showed that triangular aperture geogrids reduced the permanent displacement and vertical stress at the interface as compared with the unreinforced base and the benefit became more pronounced when a heavier-duty geogrid was used. Al-Qadi et al. (2008) carried out full-scale accelerated pavement testing to quantify the geogrid effectiveness in a low-volume flexible pavement. They proposed that for a thin base course layer, placing a geogrid at the subgrade/base course interface gives better performance. Also, for a thicker base layer, they suggested that it is optimal to place a single geogrid at the upper third of the layer. Furthermore, in case of placing a single geogrid at the upper third of the layer, the addition of another geogrid at the subgrade–base layer interface may be needed for stability. Moghaddas-Nejad and Small (1996) carried out an experimental test to investigate the influence of geogrid reinforcement for the granular base layer of a flexible pavement constructed on sand. Their tests were performed using a model testing facility with repeated passes. Surface deformations and internal movements in the pavement and subgrade were measurement by them therefore improvement in pavement performance due to the inclusion of the geogrid were determined. They pointed out that two different mechanisms that reduced the permanent displacement (rutting) which are confinement and interlocking of the base material. They suggested that geogrid inclusion improved the performance of the base courses.

This paper investigated the performance of unreinforced and geogrid-reinforced bases over weak subgrade under cyclic loading. Laboratory large scale cyclic plate load tests were conducted on unreinforced and reinforced bases in a large test box to investigate the influence of geogrids on the reduction in the permanent displacement (rutting). In addition, this study investigated the influence of the base thickness on the permanent displacement (rutting).

2 MATERIALS USED

2.1 *Weak soil*

A weak soil was used to create the subgrade. The maximum dry unit weight of the subgrade is 17.94 kN/m^3, which corresponds to the optimum moisture content of 17%, based on the Standard Proctor Tests. Grading curve of weak soil based on sieve analysis and hydrometer test is shown in the Figure 1. Also, other properties of weak soil are presented in Table 1.

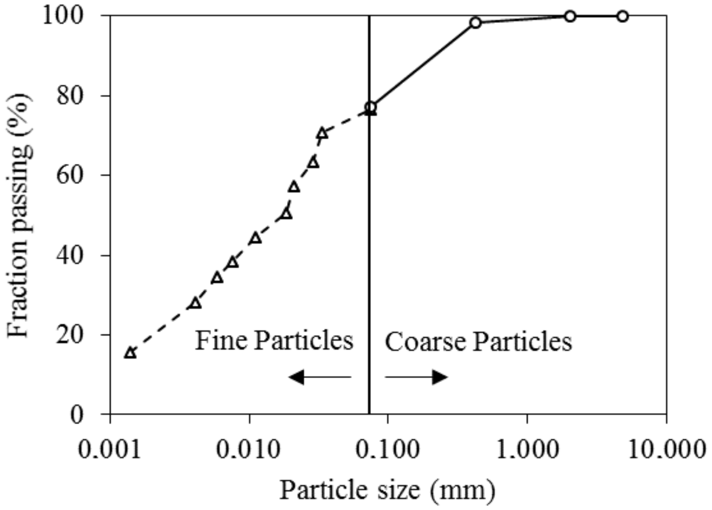

Figure 1. Grading curve of weak soil

Table 1. Properties of weak soil

Property	Unit	Value
Liquid Limit (LL)	%	24
Plastic Limit (PL)	%	17
Plasticity Index (PL)	%	7
Optimum Moisture Content (ω_{opt})	%	17
Maximum Dry Unit Weight (γ_{kmax})	kN/m^3	17.94
Soil Particle Unit Weight (γ_s)	kN/m^3	26.70
CBR (at 19% water content)	%	4

2.2 *Granular material*

A granular material was used to make up the base course. Particle size distribution of granular material is shown in Figure 2 with upper and lower bound from the Road Technical Specification of Republic of Turkey General Directorate of Highways. Maximum dry density obtained was 22.48 kN/m^3 at a water content of 4.6% based on the Modified Proctor Tests while maximum dry density obtained was 23.45 kN/m^3 at a water content of 4.0% based on the Vibratory Proctor Tests Large scale direct shear tests were performed at normal stress levels which are 25, 50 and 75 kPa and friction angle of 62.07° was found. Other properties of granular base course material are shown in Table 2.

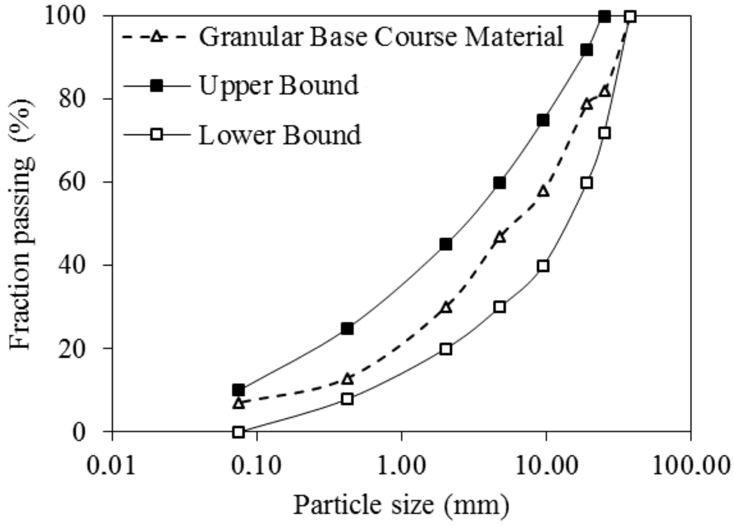

Figure 2. Grading curve of granular base course material

Table 2. Properties of granular base course material

Property	Unit	Value	
		Modified Compaction	Vibratory Compaction
Maximum Dry Density (γ_{kmax})	kN/m^3	22.48	23.45
Optimum Moisture Content (ω_{opt})	%	4.6	4.0
Liquid Limit (LL)	%	N.P. (Non-Plastic)	
California bearing ratio (CBR)	%	252-246	
Los Angeles Abrasion loss	%	30	
Water Absorption	%	0.82	
Methylene Blue Test	%	1.25	
Friction Angle	Degree	62.07	

2.3 *Geogrid*

Triaxial geogrid were used to reinforce the base layer in the large scale cyclic plate load test sections. It is made from polypropylene. The physical and mechanical properties of geogrids, as provided by the manufacturers, are listed in Table 3 and Figure 3 shows photographs of the geogrid.

Table 3. Properties of the geogrid.

Property	Value
Raw Material	Polypropylene
Aperture Type	Triangle
Aperture Dimensions (mm)	40x40x40
Tensile Strength at 5% strain, md/cmd* (kN/m)	300

*md/cmd: machine direction/cross machine direction

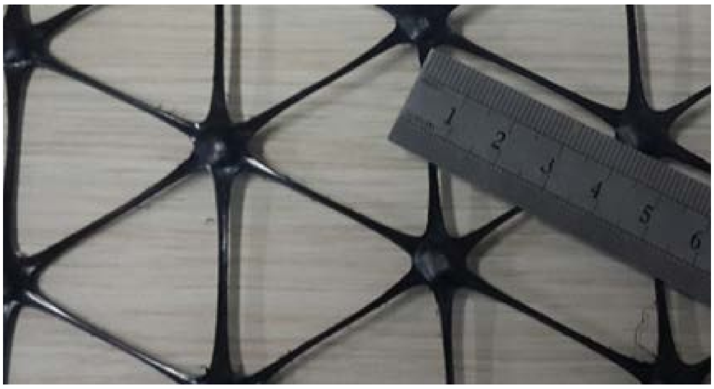

Figure 3. Photograph of geogrid used for the study

3 EQUIPMENT

A steel test box with inside dimensions of 2.0m length, 2.0m width and 2.0m height was constructed to host the test sections. The vertical stress on the granular base course layer surface was applied by a 300 mm diameter steel plate underneath a jack connected to a hydraulic system. During the cyclic loading, maximum applied load in tests was 40 kN, which resulted in a loading pressure of 550 kPa. It is simulated typical truck axle load with contact pressure of 550 kPa (Qian et al. 2012). The load pulse values measured during cyclic loading are presented in Figure 4. The frequency of this load pulse was 0.77 Hz.

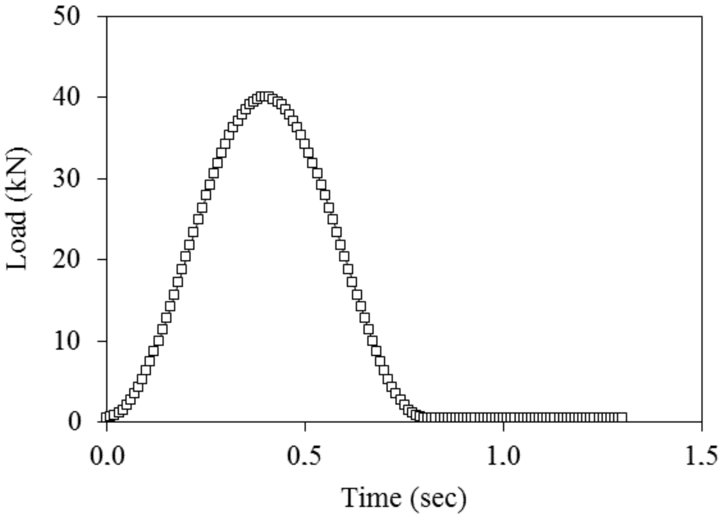

Figure 4. Load pulse values measured during cyclic loading

The test setup consisted of displacement transducers (LVDTs) to measure vertical displacements of the 300 mm diameter steel plate and a load cell to measure the loads during cyclic loadings. Figure 5 presents the schematic sketch and photograph of the large scale cyclic plate loading test setup. In this schematic sketch, H is the thickness of base course and u is the placed depth of geogrid. As can be seen from the Figure 5, thickness of weak subgrade was 1.40 m in all tests.

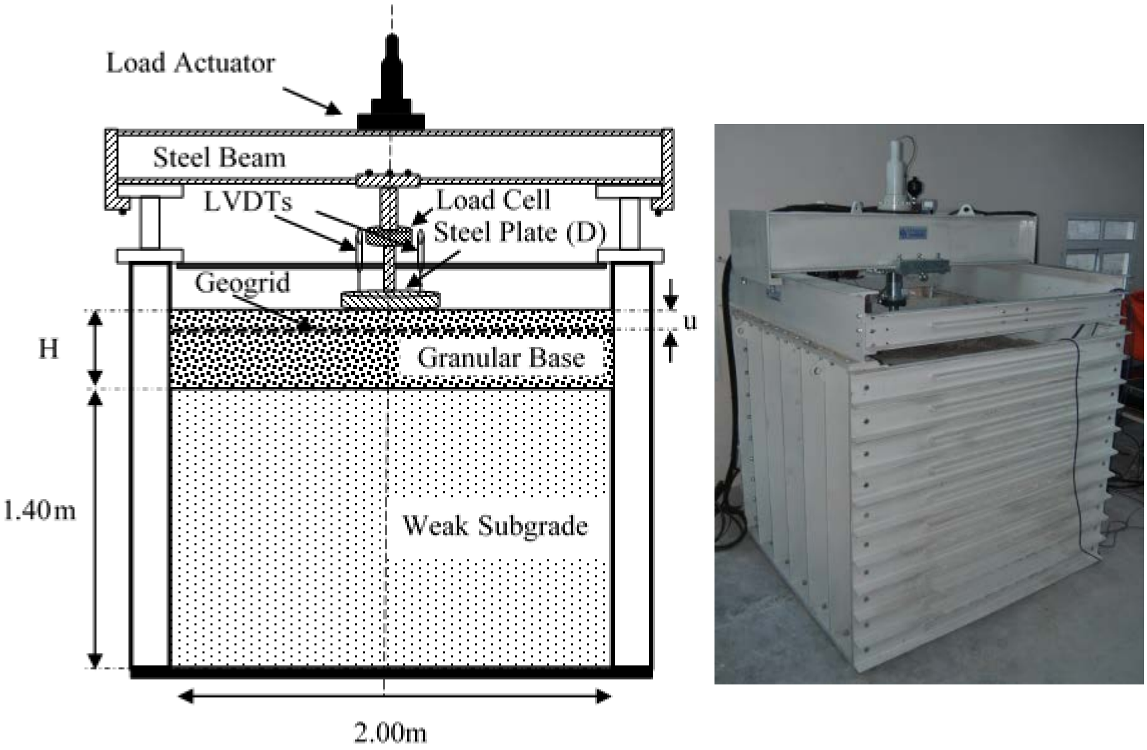

Figure 5. Schematic sketch and photograph of the large scale cyclic plate loading test setup

4 TESTING METHODOLOGY

Firstly, the weak soil was placed in the steel test box to create weak subgrade. And then, weak soil was compacted in layers. The target density and water content of weak soil for each layers were adjusted to achieve a weak subgrade. The weak soil was compacted at a water content of 19% for the large scale cyclic plate loading tests to achieve its CBR value at approximately 4%. This CBR value was estimated by the dynamic cone penetration (DCP) test after the preparation of the subgrade layer. Uniformity of water content and density were checked by taking undisturbed sample of weak soil at different locations. After preparing the 1.40m height of subgrade, and then granular material was placed in the steel test box to build the base course and then, granular material was compacted in layers. The granular material was compacted to about 98% of maximum dry density at an optimum moisture content of 4% to make the base course in all tests. The granular material was compacted using a vibratory hammer. The nuclear density gauge apparatus was deployed to measure the properties of base granular base to ensure required quality. The target thickness of the granular base layer was variable in study. To prepare reinforced sections geogrid was placed within the base at the desired location.

A total of six tests were performed in this study. In Series I tests, large scale cyclic plate load tests were conducted on unreinforced granular base for different granular base thicknesses (H= 30, 40, and 45 cm; H is the thickness of granular base). In Series II tests, large scale cyclic plate load tests on the geogrid reinforced granular base were carried out for different placed depth of geogrid (u=0.33D, 0.67D and 1.00D; u is the placed depth of geogrid and D is the diameter of steel plate). Test program are shown in Table 4.

Table 4. Test Program

Test No	Test Series	Placed Depth of Geogrid (u)	Thickness of Granular Base (H) (cm)
1	Series I	-	30
2			40
3			45
4	Series II	0.33D (10 cm)	45
5		0.67D (20 cm)	
6		1.00D (30 cm)	

5 RESULTS and DISCUSSION

Investigate the potential benefits of using geogrid for base reinforcement and thickness of the unreinforced granular base under cyclic loading are the main objective of this paper. For this purpose, large scale cyclic plate loading tests were conducted. . In Series I tests were conducted on unreinforced granular base for different granular base thicknesses while in Series II tests were carried out for different placed depth of geogrid.

Figure 6 presents the curves of the permanent displacement versus the number of cycles for the Series I tests. It is clear from the Figure 6 that permanent displacement increases as the number of cycle increases in all granular base thickness. The permanent displacement increase was fast at the early stage of the loading cycles. But, the rate of increase in permanent displacement decreased as long as the increase of the number of load cycles. In addition, as can be seen in the Figure 6, with increase in the thickness of granular base, the permanent displacement decreases.

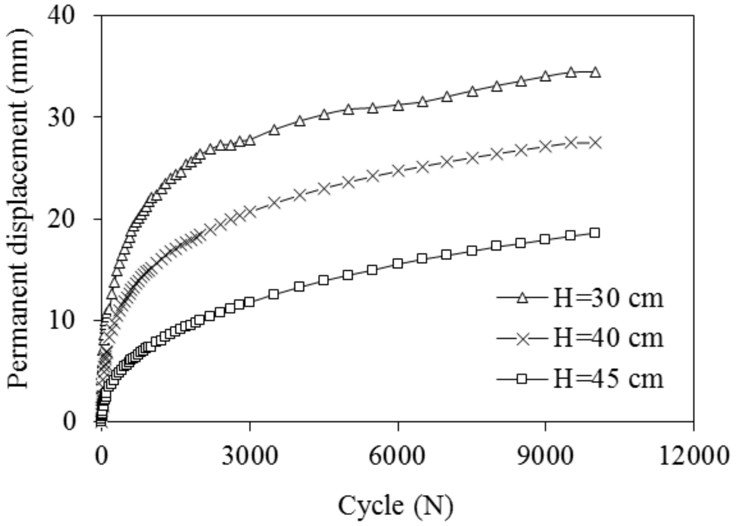

Figure 6. Thickness effect on the permanent displacement for unreinforced granular base

Figure 7 shows the curves of the permanent displacement versus the number of cycles for the unreinforced 45 cm granular base and Series II tests. It is clear from the Figure 7 that the reinforced granular bases developed less permanent displacement than the unreinforced granular base at the same number of load cycles. In addition, as can be seen in the Figure 7, with decrease in the geogrid location depth, the permanent displacement decreases.

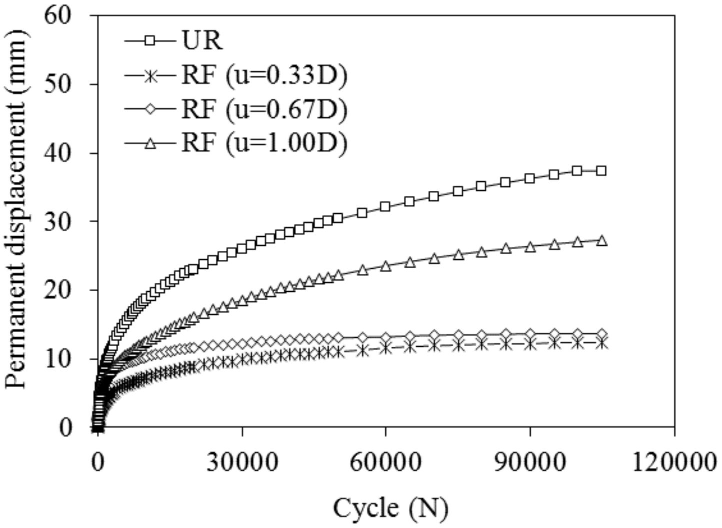

Figure 7. Effect of geogrid and its location on the permanent displacement for reinforced (RF) and unreinforced (UR) 45 cm granular base

6 CONCLUSIONS

This paper presented results of large scale cyclic plate loading tests on unreinforced and geogrid reinforced unpaved roads. The main conclusions obtained are presented as follows:

- A large scale cyclic plate loading test equipment was developed for the purpose of evaluating the performance of base/subbase and subgrade soil in pavement sections under cyclic loading conditions. This has been a very valuable achievement and using this test system, studies which are contributors to the application in the field and literature can be conducted.
- In all test series, the permanent displacement increase was fast at the early stage of the loading cycles. But, the rate of increase in permanent displacement decreased as long as the increase of the number of load cycles.
- Increase in thickness of granular base over the weak subgrade improved the performance. The thicker granular base helped in reducing the permanent displacement of granular base.
- The permanent displacement of unpaved road section over the weak subgrade can be decreased by the inclusion of geogrid.
- To get best performance of geogrid reinforced granular base, geogrid may be placed at the upper one-third of granular base.

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