SCIENNOVATION
A Journal of Structural Science and Innovation

RESEARCH ARTICLE

Date Received: 30. January.2020
Date Accepted: 03. March.2020

A Study on the Effects of Highway Reinforcement on Load Distribution

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Keywords:
Base-subbase reinforcement,
Geogrid,
Base-Subbase Layers

Abstract

Highways, one of the most fundamental elements of civil engineering, are constantly exposed to dynamic loads. Undesirable damage due to these loads can be occurred. This study discusses the geogrids used to strengthen highway layers. Using the probability density functions obtained from the experimental results, damage probability tables were created for highway layers reinforced with geogrids. Vertical pressure distribution according to traffic loads, tire configuration and layer thickness were examined by field and laboratory tests. Within the scope of the study, five types of geogrids were used for experimental and analytical studies. “As a result, damage for any road reinforced with different geogrid types can be estimated using the damage probability table obtained in this study.

Otoyol Güçlendirmenin Yük Dağılımına Etkileri Üzerine bir Çalışma

Anahtar Kelimeler;
Temel-alttemel güçlendirmesi,
Geogrid,
Temel alttemel tabakaları

Özet

İnşaat mühendisliğinin en temel unsurlarından biri olan otoyollar sürekli olarak dinamik yüklemelere maruz kalmaktadır. Bu yüklerin sebep olduğu istenmeyen hasarlar ortaya çıkabilmektedir. Bu çalışma otoyol tabakalarının güçlendirilmesinde kullanılan geogridleri ele almaktadır. Deneysel sonuçlardan elde edilen olasılık yoğunluk fonksiyonları kullanılarak geogridler ile güçlendirilmiş otoyol tabakaları için hasar olasılık cetvelleri oluşturulmuştur. Trafik yüklerine, lastik konfigürasyonuna ve tabaka kalınlığına göre dikey basınç dağılımı saha ve laboratuvar testleri ile incelenmiştir. Deneysel ve analitik çalışmalar için beş tür geogrid kullanılmıştır. Bu çalışma sonucunda elde edilen hasar olasılık cetveli ile; farklı geogrid tipleriyle güçlendirilmiş herhangi bir yol için hasar tahmini yapılabilir.

1. INTRODUCTION

According to the developing infrastructure, in addition to the rapid increase in urbanization and more carrying capacity of transportation trucks, the importance of road and highway transportation technology has also grown worldwide. Also, high traffic characteristics bring out higher traffic volumes and tire pressures; consequently, development in vehicle axles, tyres and technologies causes road damages (Cebon D., 2000; Sebaaly P. E., 1992). Excessive axle load increases road damaging potential, exponentially. Therefore, transport planning for future and improving economic life standards are very crucial. Recent research indicates truck weights over 113.4 ton and tire pressures of 150 psi (Emery J., 2007). Due to the increased traffic capacity and heavier vehicle loads, the roads are exposed to more stress and strain factors, permanent deformations, rutting and fatigue damages than ever before (Mulungye et al., 1987). If these stresses measured on the road surface (definite point on the pavement) or interface of sub-layers have too high values, they may induce a permanent road surface or sub-layer damage. These permanent deformations reduce the road economic life, increase the maintenance costs and may give rise to failure of the asphalt pavements, rutting and fatigue failure, particularly or completely.

A flexible pavement consists of asphalt surfacing layer and combined unbound aggregate road base, on a subgrade of natural soil. The stress distribution can be seen in Figure 1. (Mulungye et al., 1987). Truck loads bring out the top and bottom of the pavement to shift rapidly from compression to tension, and fatigue cracks result from the repeated tensile strains. According to the elastic layer theory, the maximum strain is located at the bottom of the asphalt surfacing layer (Ullidtz P., 1987). In order to predict the formation of fatigue cracking, a lot of pavement design models are based on straining at the bottom of the asphalt layer (European Commission, 1997). The vertical strain on the road layers and the subgrade causes deformation as a result of rutting.

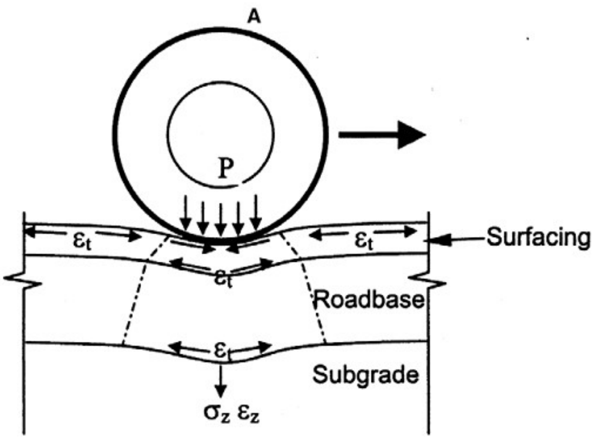

Figure 1. Strain distribution in road layers (Mulungye et al., 1987).

Since the first pneumatic tire was made in 1888 by J.B. Dunlop, many researches have fulfilled the related truck loads effecting on road layers (surface layer, base, subbase and subgrade) and the interaction between vehicle tires and pavement (Behiry, 2013). Some studies related to the tire science. A tire is the connection between truck and road surface and it is made through the tire contact area, which occurs due to all forces included in the vehicle and its movement.

The tire contact area is related to the rough surface, aggregate and cements characteristics. For the hot-mix asphalt concrete, these aggregates are of varies sizes, ranging from very fine particle size to 20 mm dimensions and road surfacing seals have approximately 13 mm dimensions (Beer and Fisher, 2013).

2. RESEARCH APPROACH

2.1. Loading Unit and Experiments

The tests were performed using a loading unit and a test box of pull-out device illustrated in Figure 2. The pull-out test device was constituted of a rigid pull-out box which had steel profiles, a loading and clamping system, measurement sensors (pressure gages, strain gages, LVDT) and a data acquisition system.

Figure 2. The loading unit and test.

In the test unit, the subgrade material was put into the half of the box then geogrid was laid and, subbase material was spread above the geogrid. Optimum water contents of the subgrade material and the subbase material were 18% and 4.7%, respectively. The loose granular subgrade fill material was placed in the 100 mm lifts. The total fill thickness of 800 mm was maintained prior to pull-out testing.

2.2. Soil Properties

The aggregates used in this study were chosen as mainly existed in the Black Sea Region in Turkey. Subbase materials were provided by the Highway Regional Officials. After subbase material was subject to the drying process in oven, sieve analysis was performed with ASTM sieves in KTU Department of Civil Engineering Structures and Materials Laboratory. Subbase and subgrade materials contained 20 % filler, 60 % fine aggregate, 20 % coarse aggregate and 3 % filler, 45 % fine aggregate, and 52 % coarse aggregate, respectively. Gradation curves are shown in Figure 3.

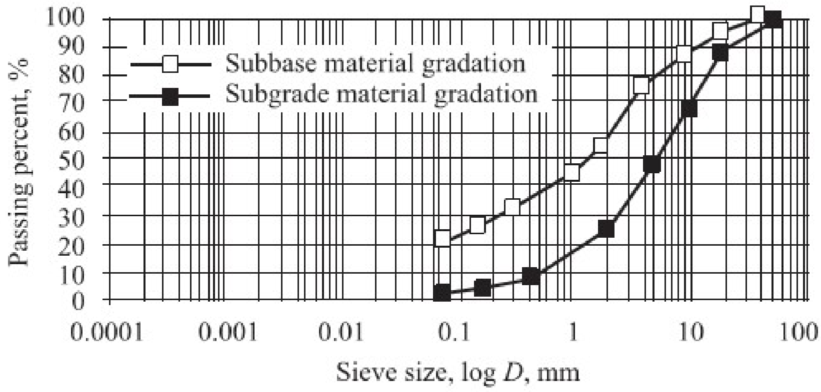

Figure 3. Gradation distribution of soils.

2.3. Geogrid Materials

The test specimen was cut from the sample rolls of the geogrid material. Five types of geogrid samples were used in this loading unit. These geogrids which were 50×50 mm, 40×40 mm, 30×30 mm square aperture size, hexagonal and crosswise aperture shape geogrids are shown in Figure 4.

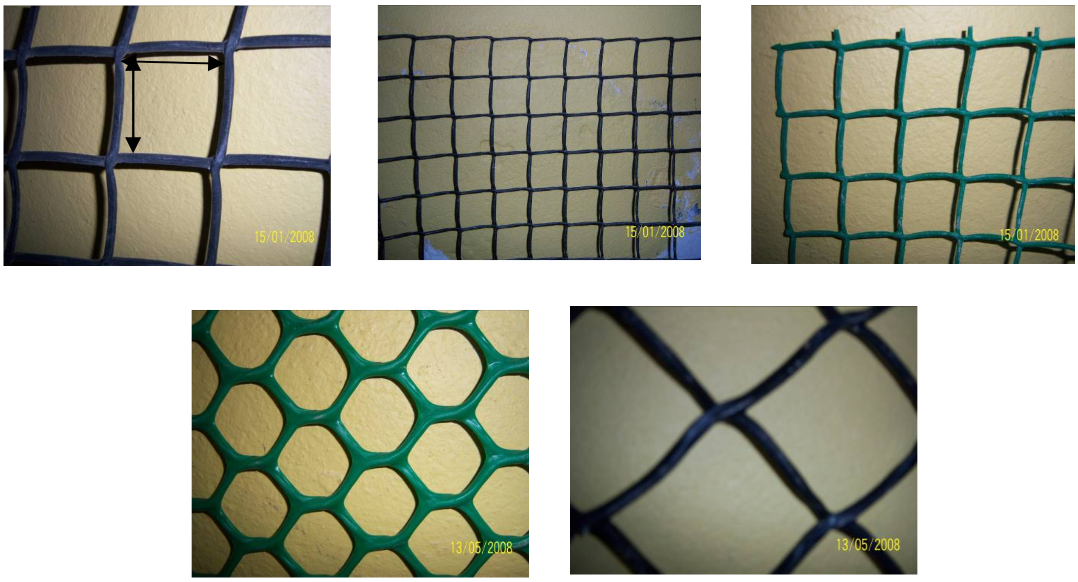

Figure 4. Geogrid Examples.

2.4. Field Analyses

In literature, an 80 kN single axle load (Mulungye et al., 1987), (Sert and Akpinar, 2012), (Fange et al., 2007) and 700 kPa pressure are considered (Wu, 2007). The most commonly used equivalent load in the U.S. is the 18,000 lb (80 kN) equivalent single axle load (generally designated as ESAL) (2002 Guide for the Design of New and Rehabilitated Pavement Structures). Park (2008) determined that tire pressures on the pavements ranged from 550 kPa to 890 kPa. (Priest and Tim, 2005) showed the vertical pressure on the subbase layer as 35 kPa. In this study, vertical pressure and tire load were measured on the field by using the 200 mm diameter pressure gauges installed on the top of the asphalt pavement layer and subbase layer. The pressure values ranging from 550 kPa to 790 kPa on the top of the pavement surface and from 31 to 33 kPa on the top of the subbase layer were obtained. In each test, in accordance to the field, 35 kPa vertical pressure and ESAL's of 80 kN were applied by the vertical piston.

4. RESULTS AND DISCUSSIONS

The data obtained from pressure cells settled in sublayers are seen in Table 1. Two different levels existed. One of them was upper level and the other one was lower level of geogrid. For each level, four pressure sensors were used and every test was repeated three times.

Table. 1. Pressure Distributions According to Geogrid Samples.

Geogrid Aperture Shapes	Test No	Pressures from lower level of geogrid (kPa)				Pressures from upper level of geogrid (kPa)			
		Sensor No				Sensor No			
		1	2	3	4	5	6	7	8
50×50 mm	1	91	14	27	64	113	18	13	39
	2	54	39	17	56	63	73	4	29
	3	14	5	17	34	22	31	14	75
40×40 mm	1	5	17	21	40	1	2	3	53
	2	31	13	16	18	25	16	17	9
	3	26	19	32	13	40	41	16	66
30×30 mm	1	5	6	19	_	5	7	11	_
	2	17	3	65	26	2	11	109	101
	3	7	16	36	17	155	11	20	31
Hexagonal	1	29	24	34	19	51	23	21	6
	2	15	58	50	28	27	66	43	72
	3	18	2	19	1	24	25	14	15
Crosswise	1	31	38	45	34	19	51	37	_
	2	44	37	163	82	56	34	95	186
	3	29	44	65	70	25	40	46	102

After obtaining vertical pressure measurements of sublayers; lognormal mean vertical pressure value and lognormal standard deviation of values for each material type were utilized. The probability of reaching or exceeding a "damage state" as demand parameters of vertical pressure was calculated. The obtained distribution graphic of sublayers reinforced with geogrids are shown in Figure 5.

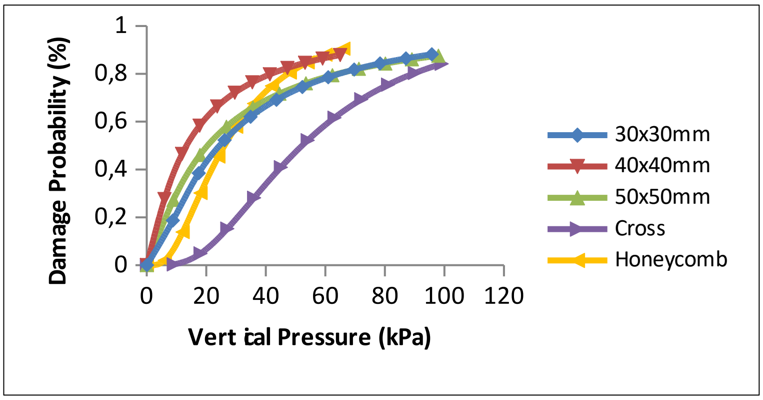

Figure 5. Cumulative distribution functions on the top of the geogrids.

Load distributions for the different types of geogrid at upper level are shown on the same graph. The horizontal axis of the graph shows the vertical pressure values acting on the soil layer, while the vertical axis of the graph shows the potential for these pressures.

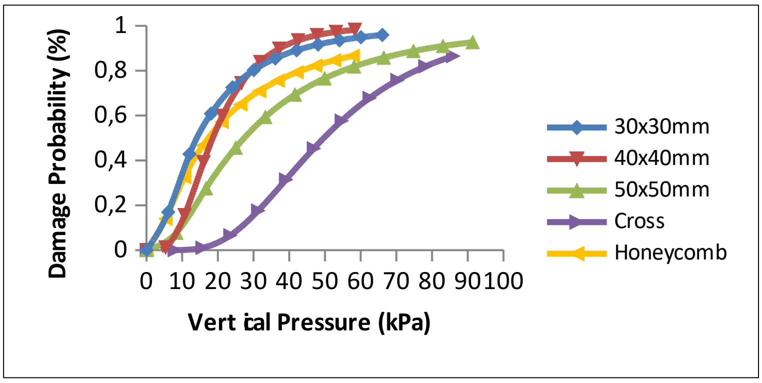

Figure 6. Cumulative distribution functions at the bottom of the geogrids.

Figure 6 shows the load distributions in the lower layers. When Figure 5 and Figure 6 are analysed together, vertical pressure distributions obtained from different shaped would significantly change between top and bottom layers.

Pressure gauges installed on upper and lower levels of the geogrid indicated that the geogrids reduce the vertical stress significantly by distributing the vertical load to a wide range over the subgrade soil. The vertical pressures were obtained from tests. The graphics indicated that the 40×40 mm aperture size geogrid and the hexagonal aperture size geogrid showed close performances. The 30×30 mm aperture size geogrid showed some more resistance to vertical pressure. But when it started to lose its strength, it showed less resistance to vertical pressure distribution than the 40×40 mm aperture size geogrid. The reduction in the vertical stress on upper level of the geogrid was 12%, 14%, 52%, 10% and 25% for 50×50 mm, 40×40 mm, 30×30 mm square aperture size, crosswise and hexagonal aperture shape geogrids, respectively. This crucial result shows that smaller aperture size geogrids can improve the subgrade bearing capacity in terms of vertical stresses.

When it is thought that tensile stress behaviour has a different tendency than vertical stress distribution, the 50×50 mm aperture size geogrid gives a better performance with the respect to tensile stress behavior than the other geogrid types. As long as high strength junctions and square aperture shape advantage are provided with the effective mechanical interlock of aggregate particles into the aperture, the permanent deformation of subbase layer is expected to result in a high resistance. Because of its larger aperture size, 50x50mm aperture size geogrid effects more than the other square size aperture geogrids, and so it can penetrate more aggregate inside aperture. According to this feature, 50x50mm aperture size geogrid indicates a perfect interlock effect. However, in terms of vertical stress distribution in sub-soils of highway, an opposite behaviour is observed for the tensile stress distribution. In this case, smaller aperture size geogrids can improve the sub-soil bearing capacity

5. CONCLUSIONS

In this study, vertical pressure distributions in the loading unit were analysed and the cumulative distribution of damage was formed for five different type geogrids. According to experimental and analytical results; the basic conclusions obtained from the study are as follows:

1. The geogrids reduce the vertical stress significantly by distributing the vertical load to a wide range over the subgrade soil. It can be said that using geogrid for road embankments is so efficient.
2. The square aperture size geogrids are more efficient than other type geogrids (hexagonal and crosswise) in terms of load transfer.
3. The reduction in the vertical stress on upper level of the geogrid was 12%, 14%, 52%, 10% and 25% for 50×50 mm, 40×40 mm, 30×30 mm square aperture size, crosswise and hexagonal aperture shape geogrids, respectively.
4. The 30×30 mm aperture size geogrid has shown some more resistance to vertical pressure.
5. Smaller aperture size geogrids can improve the subgrade bearing capacity in terms of vertical stresses.

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