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CALCULATION OF SHEAR STRENGTH PROBABILITY OF GEOGRIDS USED IN HIGHWAY EMBANKMENTS

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ABSTRACT *In this study; experimental measurement data were performed for probability analysis. Geogrids are crucial reinforced material for civil engineering applications such as highway base/subbase reinforcement, railway ballast reinforcement and retaining walls. In this study, the cumulative distribution function was formed to estimate the probability of collapse risk of the highways. Probability density functions were calculated with the help of lognormal mean and lognormal standard deviation values of highway displacement points. The cumulative distribution functions were generalized and the probability of the damage was shown. With the results of this work; damage possibility can be estimated for any highway reinforced with geogrid which has same features such as 30x30mm, 40x40mm and 50x50mm etc.*

Keywords; highway reinforcement, damage estimation

1. INTRODUCTION In Turkey, slope and road embankment stability is very crucial problem. Especially Embankment settlement and deformations are difficulties frequently encountered on the highways. In recent years due to the increased amount of traffic, reinforcement of road layers has gain importance. Geogrids are crucial reinforced material for civil engineering applications such as highway base/subbase reinforcement, railway ballast reinforcement and retaining walls (Sert and Akpinar, 2010).

Figure 1. Highway settlements and shear deformations observed in Turkey (first one is from D-100 Highway İstanbul-Ankara Direction , near Abant Intersection)

Thus, there has been an increasing importance on the study of highway deformations and risk assessments have become one of the necessary issue for loss estimate.

The loss estimation is based on the damage states of the structures and there are several models which can be used to quantify the damages, characterization of damage state and estimation of losses after the earthquakes (FEMA 1997, Hamid and Mohamad 2013). Fragility analysis is one of the key component in seismic risk assessment and more specifically in regional seismic risk assessment (Abo-El-Ezz, Nollet et al. 2013).

In probability theory and statistics, the cumulative distribution function (CDF), describes the probability that a real-valued random variable "X" with a given probability distribution will be found to have a value less than or equal to x (Zwillinger and Kokoska 2010). In the case of a continuous distribution, it gives the area under the probability density function from minus infinity to "x". Cumulative distribution functions are also used to specify the distribution of multivariate random variables (Gentle 2009).

2. GEOGRID REINFORCEMENT Geogrids are usually evaluated in civil engineering applications such as roads, dams, landfills and others. Geogrids are geosynthetic products with apertures that are characterized by a coexist of transverse and longitudinal ribs. These transverse and longitudinal ribs enable interface shear contributions, passive, force and geogrid pullout resistance.

Figure 2. Geogrid types used in this study.

Four types of geogrids which are 50 mm x 50 mm, 40 mm x 40 mm, 30 mm x 30 mm square aperture size geogrids and crosswise aperture size geogrids as can be indicated in Figure 2 were investigated. Table 1 shows the dimension properties of these geosynthetic materials.

Table 1. Dimensions of geogrids

Geogrid Aperture Type	Aperture width (b) mm	Aperture length (h) mm	Rib width (w) mm
50 mm x 50 mm, Square	50	50	17
40 mm x 40 mm, Square	40	40	15
30 mm x 30 mm, Square	30	30	13
Crosswise	70	82	23

3. The Test Procedure And Device The pullout test mechanisms were used for determining geogrids' shear and tensile performance that are in compacted soil. The pullout interaction mechanisms between geogrid and soil are exclusively complex. Two cases come out of geogrid's pullout test procedure. The first one, interface shear resistance that takes place along the longitudinal ribs and the transverse ribs. The second one, the passive resistance that develops against the front of transverse ribs.

The pullout test apparatus is the first in Turkey with its dimensions. Figure 3 shows picture of pullout test apparatus that is built at Karadeniz Technical University. The dimensions of the box are 1 m length x 1 m width x 0.80 m height. The pullout test device is constituted of a rigid pullout box that have steel profiles, a vertical and horizontal pistons, a clamping system, and measurement sensors (pressure gages, strain gages, vertical and horizantal LVDTs) and data acquisation system.

Figure 3.1 The Pullout Test Device

In the pullout test, aggregate is spread to the geogrid level in the pullout box. The geogrid is placed in half of the pullout box. Up to the half of the box subgrade material is put; above the geogrid level, subbase material is spread. Placed aggregate material are considerably compacted. After compression is made at every level, the pullout force is applied to geogrid under vertical pressure. 35 kPa vertical pressure is applied in each test. The pullout force is applied to geogrid under constant test speed which is equal to 5 mm/min.

4. Description Of The Proposed Methodology: It is possible to use linear or nonlinear methods in seismic analyses of structures. Linear analysis uses the methods of the elastic solution. Inelastic behavior includes to solution by specific coefficients. Results obtained from elastic analyses are lower realistic than inelastic analyses (Tekin, Gürbüz et al. 2013). It is need to include inelastic behavior of structural elements for more realistic results. Nonlinear time history (TH) analysis is the represents the most actual behavior of the structure. However, developing computer technologies provide easy to carry out it. TH analyses need to long time period bacause of multi-parameter solution way. Seismic loads are applied to the building directly in TH method. Earthquake data should be selected carefully. Past studies shows that nonlinear pushover (NSP) analysis is suitable alternative to TH by correct selection of parameters and assumptions (Saidi and Sozen 1981).

Fragility curve is a useful tool for predicting damage risk of structures with similar characteristics such as material, height and design code level(Abo-El-Ezz, Nollet et al. 2013). The curves can be formed empirical, heuristic or analytical based methods(Singhal and Kiremidjian 1996, Porter, Kiremidjian et al. 2001, Rossetto and Elnashai 2003, Wu, Tesfamariam et al. 2012, Zhang and Hu 2005). The principle of the analytical method which is preferred in this study is to analyze the damage state of highways.

In addition, fragility curves are cumulative distribution functions that probability of reaching or exceeding a damage state as demand parameters such as story drift ratio(SDR), peak ground acceleration (PGA), spectral acceleration (Sa) or spectral displacement (Sd) (Serdar Kirçil and Polat 2006, Lignos and Karamanci 2013, Su and Lee 2013), (Hsieh, Lee et al. 2013, Suppasri, Charvet et al. 2013). It has been widely accepted that spectral displacement can be closely correlated with seismic damage of structures(Serdar Kirçil and Polat 2006) (Su and Lee 2013).

Probability density function of a random variable with lognormal distribution is as follows equation-1:

$$f(x) = \frac{1}{x\sigma_Y\sqrt{2\pi}} \exp - \left[-\frac{(\ln x - \mu_Y)^2}{2\sigma_Y^2} \right], (0 < x < +\infty) \quad \text{(Eq.1)}$$

In this distribution; μ_Y is lognormal mean of variable Y and σ_Y is lognormal standard deviation of variable Y. μ_X ve σ_X are associated with μ_Y ve σ_Y by equation-2 and equation-3.

$$\mu_Y = \ln \left[\mu_X / \sqrt{\left(\frac{\sigma_X^2}{\mu_X^2} + 1 \right)} \right] \text{(Eq.2)}$$

$$\sigma_Y = \sqrt{\ln \left(\frac{\sigma_X^2}{\mu_X^2} + 1 \right)} \text{(Eq.3)}$$

Probability of having a specific range of a continuous random variable can be written as equation-4:

$$P(a < X \leq b) = \frac{1}{\sqrt{2\pi}} \int_{x=a}^{x=b} f(x)dx = \int_{x=a}^{x=b} \frac{1}{x\sigma_Y\sqrt{2\pi}} \exp - \left[-\frac{(\ln x - \mu_Y)^2}{2\sigma_Y^2} \right] dx \quad \text{(Eq.4)}$$

Probability distribution of earthquake damage is assumed to be lognormal distribution. Thus, the analytical expression of fragility curve for a damage level is written as the follows equation-5

$$P_d \geq \left(d_{s_i} | S_d \right) = \varphi \left(\frac{\ln (S_d) - \overline{S_{d_{s_i}}}}{\beta_{d_{s_i}}} \right) \text{(Eq.5)}$$

P_d is probability of damage. S_d is modal displacement. d_{s_i} is modal displacement for damage level “i”. $\overline{S_{d_{s_i}}}$ is mean modal displacement for damage level “i”. $\beta_{d_{s_i}}$ is lognormal standard deviation of modal displacement values for damage level “i”. φ is cumulative distribution function.

Fragility curves can be formed empirical, analytical or heuristic based methods (Singhal and Kiremidjian 1996, Porter, Kiremidjian et al. 2001, Rossetto and Elnashai 2003, Wu, Tesfamariam et al. 2012, Zhang and Hu 2005). In this study, analytical fragility curves were obtained by experimental shear strain analysis.

Besides analytical fragility curves were obtained by shear strenght values of highways with variable square aperture size geogrid.

5. Analytical Results: The principle of the analytical method is based on the pullout test analyze. In the pullout test, aggregate is spread to the geogrid level in the pullout box. The geogrid is placed in half of the pullout box. Up to the half of the box subgrade material is put; above the geogrid level, subbase material is spread. Placed aggregate material are considerably compacted. After compression is made at every level, the pullout force is applied to geogrid under vertical pressure. 35 kPa vertical pressure is applied in each test.

Each procedure was applied for all geogrid types. Totally, 4 shear strength versus displacement graphics were obtained. Figure 5.1 shows that shear strength versus displacement graphics of 4 geogrid types.

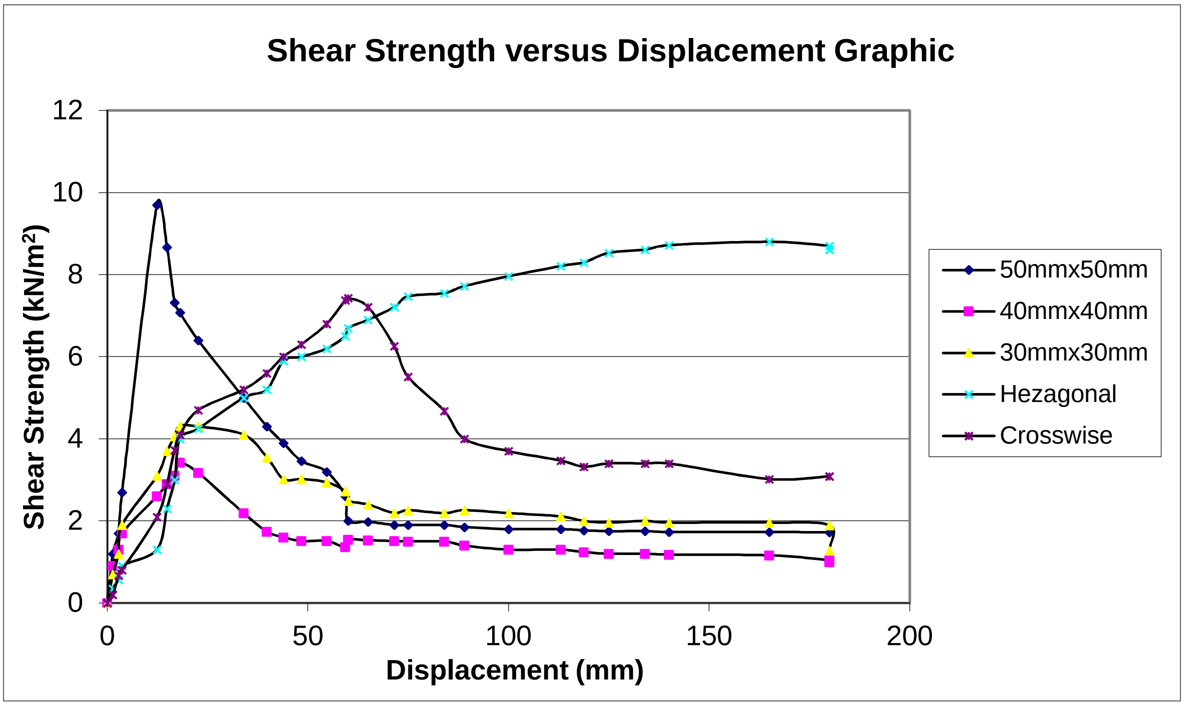

Figure 5.1. Shear strength versus displacement graphics of variable square aperture size geogrid

After the obtaining capacity curves of materials; critical shear strenght values were calculated for related geogrids. Table 5.1 shows the obtained test data inventory for fragility analyze.

Table 5.1. Obtained test data inventory

Model Code	Aperture size (mm)	Shear Strength (kN/m^2)
B_01	30x30	4,06
B_02	30x30	4,32
B_03	30x30	4,3
B_04	30x30	4,1
B_05	30x30	3,55
B_06	40x40	3,42
B_07	40x40	3,17
B_08	40x40	3,1
B_09	40x40	2,9
B_10	40x40	2,6
B_11	50x50	9,7
B_12	50x50	8,67
B_13	50x50	7,32
B_14	50x50	7,08
B_15	50x50	6,4
B_16	Crosswise	8,61

B_17	Crosswise	8,72
B_18	Crosswise	8,8
B_19	Crosswise	8,7
B_20	Crosswise	8,61

Mean shear strenght value and lognormal standard deviation of values for each material type was utilized for fragility analyze. Fragility curves are assumed cumulative distribution functions that probability of reaching or exceeding a damage state as demand parameters of shear strenght.

Thus, probability density functions were calculated for four material types. Figure 5.2 shows probability density function graphics for four materials.

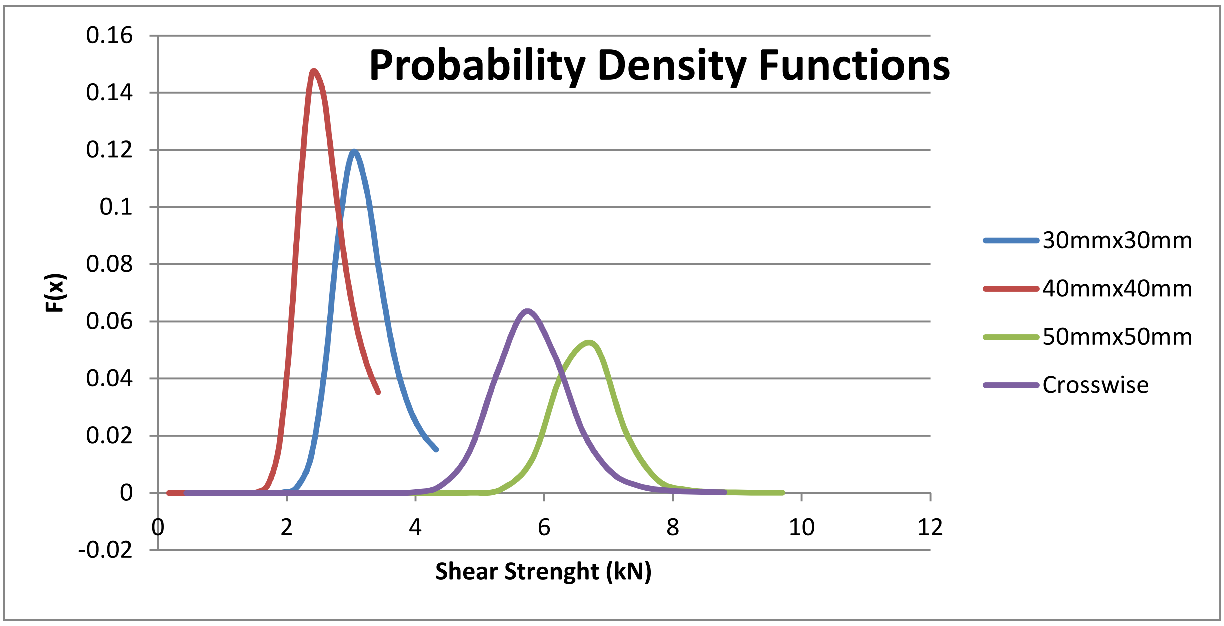

Figure 5.2. Probability density function graphics

The area under the line shows that probability of damage in probability density functions. Figure 5.3 shows the transformation of probability density function to cumulative distribution function.

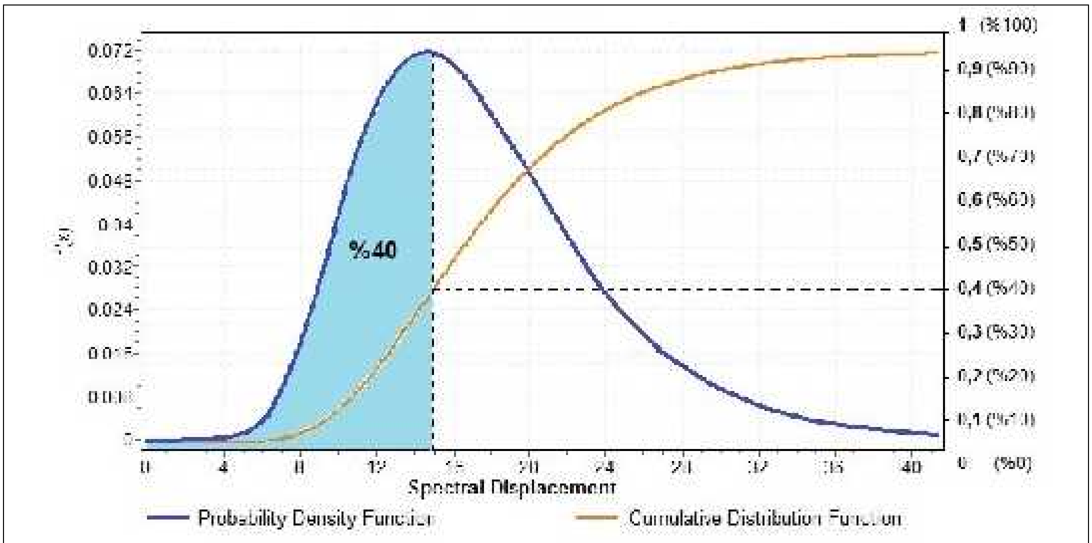

Figure 5.3; Transformation of probability density function to cumulative distribution function.

Fragility curves of slight, moderate, external and complete damage level for all buildings are shown in Figure 4.5.

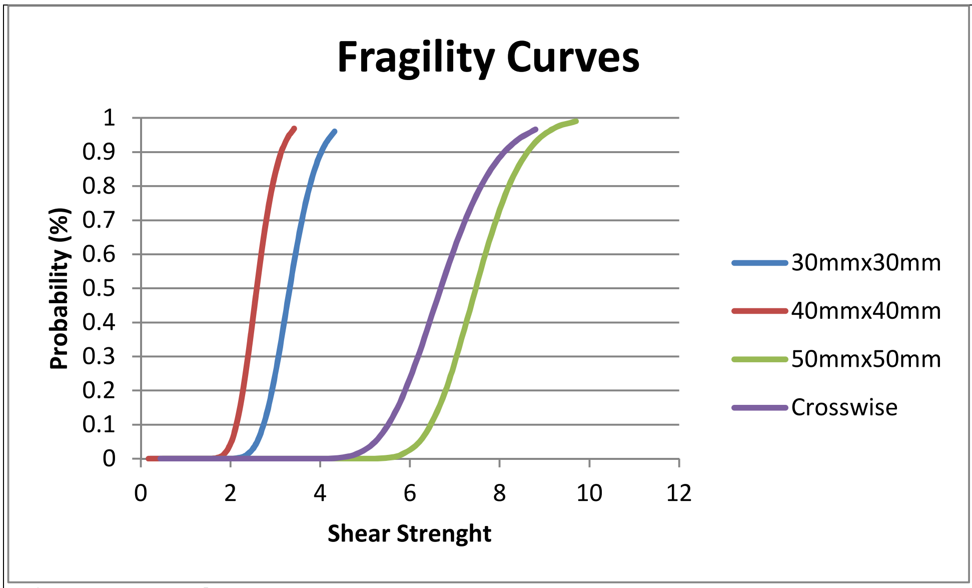

Figure 5.4. Fragility curves

Conclusions : In this study, cumulative distribution functions were formed for 4 different type geogrid materials. Probability density functions were calculated with the help of lognormal mean and lognormal standard deviation values of limit states. Then, fragility curves that show probability of the damages according to shear strength limits.

According to experimental results; 40x40mm square aperture size geogrid has lower shear strenght capacity compared to other types. However capacity curves give information about the current status of the materials, there are lots of different measuring point and material types located in highways. Therefore, probability studies and rapid risk assessment methods are required. Therewith, a general assessment can be made by the results of the fragility curves.

By the result of this study, cumulative distribution functions were applied as an shear strenght estimation graphics. The rupture on the geogrid samples were observed just outside the pullout test box. Some reasons that is occurred this situation may be vertical pressure effect, max. soil compaction, pullout rate, soil gradation type and geogrid’s horizontal- longitudinal rib effect.

Among geogrids with square aperture dimensions, as aperture dimensions get larger, aggregate penetrate capacity become higher and this type of geogrid (50x50mm square aperture size geogrid) has higher strength value. So, this geogrid type can be used as a prime reinforcement for subbase structures.

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