DOI: 10.5505/2023geoteknik.SS-35

DETERMINATION OF THE SEISMIC PERFORMANCE OF GEOGRID REINFORCED HIGHWAY EMBANKMENTS USING REDUCED SCALE SHAKE TABLE TESTS

DETERMINATION OF THE SEISMIC PERFORMANCE OF GEOGRID REINFORCED HIGHWAY EMBANKMENTS USING REDUCED SCALE SHAKE TABLE TESTS

Yasin S. Toksoy[1], Ayşe Edinçliler[2]

ABSTRACT

Roads and highway embankments are earth structures that are quite susceptible to earthquake hazards. In addition, they are considered to be main lifelines that should be in continuous operation during and after natural disasters like earthquakes. Geosynthetic reinforcement can successfully mitigate earthquake-induced damages on highway embankments. It is one of the smartest reinforcement techniques due to their unique characteristics. The inclusion of geosynthetics in highway embankments may provide additional tensile strength and durability to construct more stable and earthquake-resistant embankments. Reduced scale shake table laboratory testing is a very efficient way to determine the seismic performance of engineering structures. This study represents the experimental results of the reduced-scale shake table tests on the seismic behavior of the geogrid-reinforced embankment. Shake table tests of unreinforced and geogrid-reinforced highway embankment models, which had been modeled with respect to the prototype, have been subjected to harmonic dynamic excitation. Experimental results were compared due to the selected performance criteria. Presented results highlighted that using geogrid reinforcement in highway embankments is an efficient method to mitigate earthquake hazards.

Keywords: *Highway Embankments, Seismic Performance, Geosynthetics, Geogrid, Shake Table Tests*

1. INTRODUCTION

Major earthquakes cause significant damage to road and highway embankments. As a result of the recent destructive earthquakes of the 2023 Kahramanmaraş Earthquakes (M_w:7.7 and M_w:7.6), a significant number of highway embankments failed or were heavily damaged in the region which halted the transportation of the required safety and emergency needs (KRDAE, 2023). This situation clearly shows that highway embankments are seriously vulnerable to earthquake-induced damages. Renovation of earth structures is typically simpler than repairing concrete or other materials.

[1] Ph.D. Candidate, Boğaziçi University Kandilli Observatory and Earthquake Research Institute, Earthquake Engineering Department, yasin.toksoy@boun.edu.tr
[2] Prof. Dr., Boğaziçi University Kandilli Observatory and Earthquake Research Institute, Earthquake Engineering Department, aedinc@boun.edu.tr

Structural stability, integrity and durability of roads and highway embankments must be maintained during the early construction stages. Different methods can be implemented to achieve the required stability conditions. There are several techniques available in the literature to reinforce these structures and improve their static and dynamic performance (Edinçliler and Toksoy, 2017; Toksoy, 2014).

Geosynthetics are synthetic materials that are specifically designed to solve engineering problems of engineering structures. The use of geosynthetics has become a smart and cost-effective solution for achieving the required stability conditions in civil, geotechnical, and earthquake engineering applications. Geosynthetics can be used to solve and prevent a variety of problems under static loading conditions as well as under dynamic loading and seismic impact since geosynthetics have the ability to absorb dynamic forces and transmit reduced dynamic loads to engineering structures they are implemented to (Edinçliler and Toksoy, 2018).

Geogrids, which consist of synthetic material formed into a grid-like structure with openings, are one of the most popular and commonly used forms of geosynthetics. The effectiveness of geogrid reinforcement for increasing the performance of embankments, slopes, retaining walls, or any other engineering structures is based on the soil-geosynthetic interface properties such as interface friction and interlocking characteristics. (Koerner, 2005).

Physical modeling represents the behavior of a model structure, which is considered a representative of a prototype. Full-scale modeling is used when all the properties of the prototype structure are replicated with a 1:1 scale in the laboratory. In the small-scale models, a reduced-scale model of a full-size structure, a prototype, is created. The scaled model is instrumented and tested to investigate the behavior of the prototype structure. Various studies in the literature focus on mitigating earthquake hazards in engineering structures. Highway embankments are one of the least studied structures, even though highway embankments and roads are clearly vulnerable to earthquake-induced damage. It is crucial to improve the seismic performance of highways as well as to mitigate earthquake-related hazards to provide continuous operation of such lifeline structures (Toksoy, 2014**;** Edinçliler and Toksoy, 2017). In the literature, a few shake table experiments related to the seismic behavior of reinforced slopes and embankments were performed by Wartman et al. (2005), Lin and Wang (2006), Srilatha et al. (2013), Lin et. al. (2015).

Seismic performance of highway embankments, especially in earthquake-prone areas should attract more attention due to the necessity that highways should be in continuous operation. This experimental study consists of shake table tests performed on a 1/10 scaled unreinforced highway embankment model and a geogrid reinforced highway embankment model. In this study, the similitude requirements for 1g tests (Iai, 1989; Iai, 1997; Iai and Sugano, 1999) were adopted for the embankment models. The obtained results were evaluated and compared with respect to the defined performance indicators of transmitted accelerations and displacements.

2. EXPERIMENTAL STUDY

1g shake table tests were performed on reduced scale models. Highway embankment models for shake table experiments were designed using a rigid soil box with dimensions of 90×40×50 cm. The rigid soil box is made of plexiglas with 15mm thickness.

During the study, two different embankment models were studied. These are dimensionally identical unreinforced and geogrid-reinforced embankment models. Preliminary seismic performance tests showed that two layers of geogrid reinforcement is enough to provide the required stability conditions under static and dynamic conditions. Geogrid reinforcement layers are placed at the bottom and precisely in the middle height of the embankment model. The geogrid layers have an ultimate tensile strength of T_{ult}:40 kN/m.

Embankment models are designed with respect to the regulations and the recommendations of FHWA-NHI-09-083 and KGM 2013. The prototype highway embankment is considered as a 10mx10m dimensions with 2m height, and the model embankment is designed as a 1:10 scale of the prototype. Embankments were placed over the same foundation soil, which is Silivri Sand with a density of 16.5 kN/m^3 and the relative density of Dr: 60%.

Embankment models are dimensionally identical with H:20cm, L:25cm with slope inclination of 45° shake table tests are performed at BU-KOERI laboratory. A total of nine accelerometers and three displacement sensors were used for the experiments. The test set-up is represented in Figure 1 and the instrumentation plan is given in Figure 2. Time-scaled incremental harmonic excitation (1-50Hz;38sn) used for the shake table experiments is shown in Figure 3.

Figure 1. Test set-up of the embankment models.

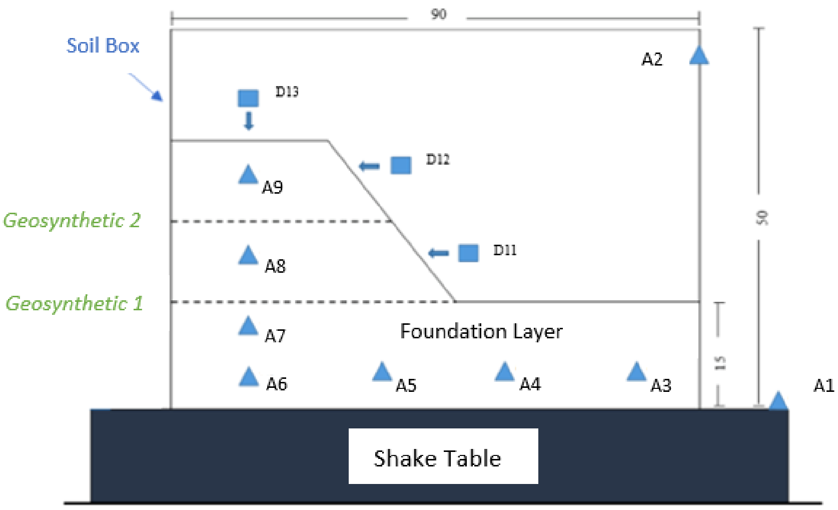

Figure 2. Instrumentation plan.

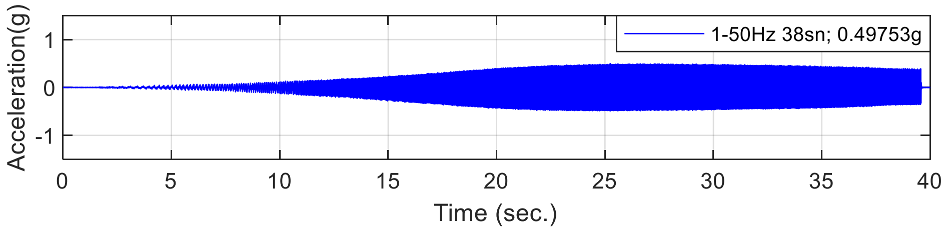

Figure 3. Input dynamic motion.

3. RESULTS

When the input dynamic motion is subjected to the unreinforced embankment model, the accelerometers located at the same height in the foundation layer (A3-A6) measure around 0.75g. Transmitted accelerations increase within the embankment body with respect to the increased height and reach to 1.23g on A8 and 1.43g on A9 at crest level (Figure 4).

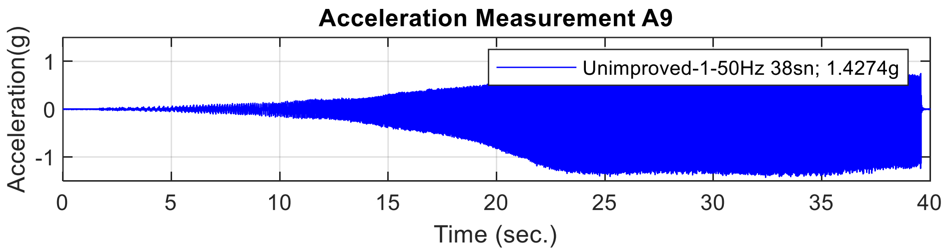

Figure 4. Acceleration-Time History of A9 in unreinforced model.

Due to the applied dynamic motion, the crest of the embankment model displaces 1.40cm horizontally (D12) and 12mm vertically (D13) for the given dynamic excitation, as given in Figure 5 and Figure 6.

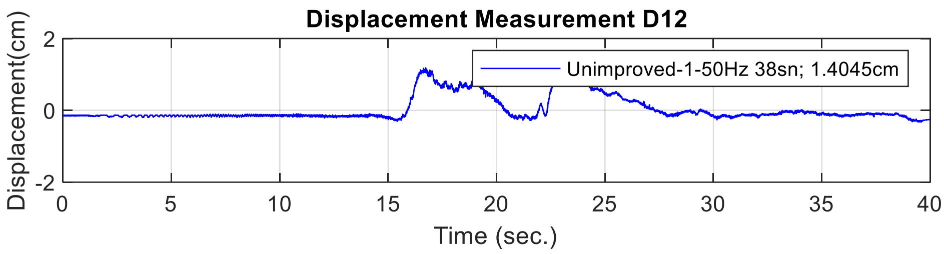

Figure 5. Displacement-Time History of D12 in unreinforced model.

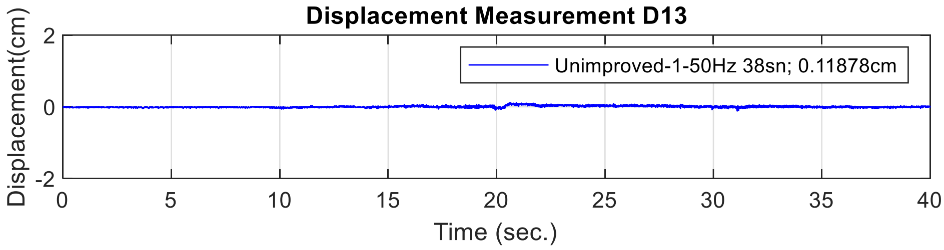

Figure 6. Displacement-Time History of D13 in unreinforced model.

Obtained results from the geogrid reinforced highway embankment model show that, the amplitude of transmitted accelerations increase within the embankment is measured as 0.74g on A8 and 0.95g on A9 (Figure 7).

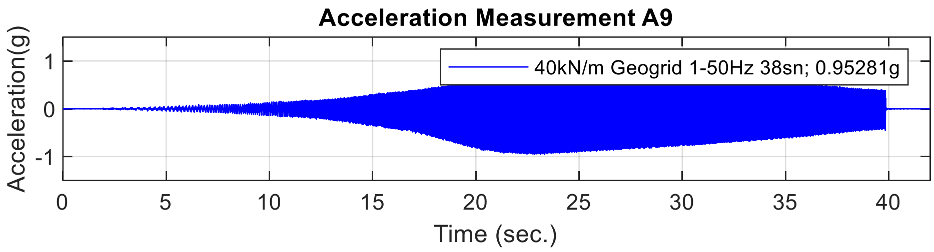

Figure 7. Acceleration-Time History of A9 in geogrid reinforced model.

Under the given motion, the geogrid reinforced embankment model displaces 45mm horizontally (D12) and 32mm vertically (D13), as represented in Displacement-Time histories (Figure 8 and Figure 9).

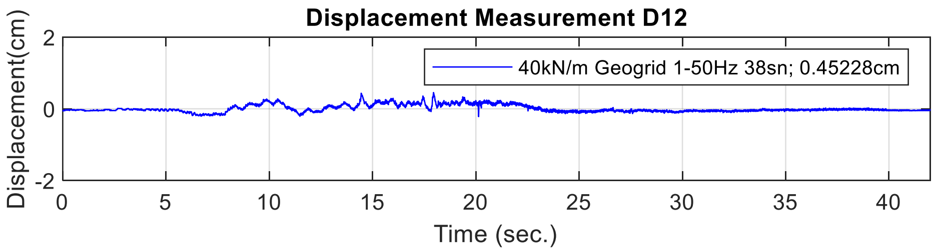

Figure 8. Displacement-Time History of D12 in geogrid reinforced model.

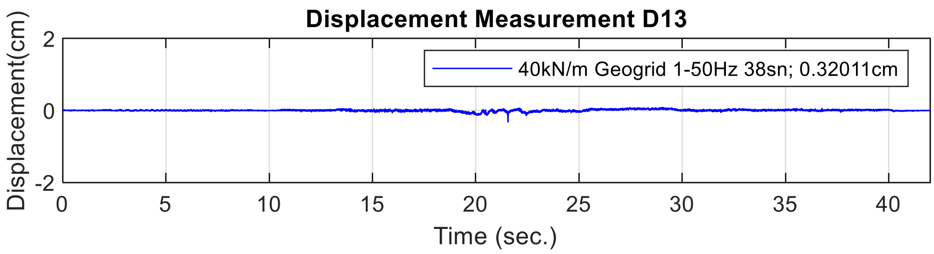

Figure 9. Displacement-Time History of D13 in geogrid reinforced model.

4. DISCUSSIONS AND CONCLUSIONS

The objective of this study is to investigate the seismic performance of reduced scale unreinforced and geogrid reinforced highway embankments in a comparative manner performing shake table tests. Evaluation of the seismic performances of unreinforced and geogrid-reinforced embankment models in terms of transmitted accelerations show that the geogrid-reinforced embankment model performs much better Transmitted accelerations measured on A8 and A9 are 39.8% and 33.6% less in geogrid reinforced embankment model under 1-50Hz sine sweep excitations in comparison with the unreinforced case.

The provided additional tensile strength by the geogrid reinforcement successfully reduces the measured displacements on the embankment model. Experimental results show that horizontal displacements measured from the toe (D11) and the crest (D12) of the geogrid reinforced embankment model are 74.6% and 67.9% less, respectively, when compared to the unreinforced model.

The presented results highlighted that using geogrid reinforcement in highway embankments is an efficient method to mitigate the earthquake hazards of such engineering structures. The effectiveness of geogrid reinforcement for increasing the dynamic performance of structures is based on the soil-geosynthetic interface properties such as interface friction and interlocking characteristics.

It should be highlighted that the obtained results are only valid for the given dimensions, specified embankment, and geosynthetic material properties and applied dynamic excitation.

ACKNOWLEDGEMENT

This research has been supported by Boğaziçi University Research Fund Grant Number BAP 15901 and Türkiye Cumhuriyeti Cumhurbaşkanlığı Strateji ve Bütçe Başkanlığı Geoteknik Deprem Mühendisliği Araştırma Merkezi Projesi Fund Grant Number 2012K120500.

REFERENCES

2023 KRDAE Deprem Öndeğerlendirme Raporu v.2 (2023).

Edinçliler, A., Toksoy, Y.S. (2017), “Physical model study of the seismic performance of highway embankments with and without geotextile”, Journal of Earthquakes and Tsunami, Vol 11, No 2.

Edinçliler, A., Toksoy, Y.S. (2017), “Shake table tests to measure the dynamic performance of geotextile-reinforced embankment”, Periodica Polytech Civil Engineering, Vol 61, No 4, 803–814.

Edinçliler, A., Toksoy, Y.S. (2018), “Effects of improvement techniques on seismic performance of highway embankments”, In: 16th European conference on earthquake engineering (16ECEE) proceedings, 18–21 June, Thessaloniki, Greece.

FHWA NHI-07-092. (2008), “Geosynthetic Design & Construction Guidelines”, U.S. Department of Transportation Federal Highway Administration, Washington, USA.

Iai, S., Sugano, T. (1999), “Soil-structure interaction studies through shaking table tests”, Earthquake Geotechnical Engineering, Vol. 3, 927–940.

Iai, S. (1989), “Similitude for shaking table tests on soil-structure fluid models in 1-g gravitational field”, Soils and Foundations, Vol. 29, No 1, 105–111.

Iai, S. (1997), “Discussions: One gravity model testing”, Soils and Foundations, Vol. 37, No 1, 137.

Karayolları Teknik Şartnamesi. (2013). Karayolları Genel Müdürlüğü, Ankara, Türkiye.

Koerner, R.M. (2005), "Designing with Geosynthetics", Pearson Education, Inc, Upper Saddle River, NJ, USA.

Lin, M. L., Wang, K. L. (2006), "Seismic behavior in a large-scale shaking table test", Engineering Geology, Vol 86, 118–133.

Lin, Y. L., Leng, W. M., Yang, G. L., Li, L., Yang, J. S. (2015), "Seismic response of embankment slopes with different reinforcing measures in shaking table tests," Nat. Hazards, Vol 76, 791–810, doi:10.1007/s11069-014-1517-5.

Srilatha, N., Latha, G. M., Puttappa, C. G. (2013), "Effect of frequency on seismic response of reinforced soil slopes in shaking table tests", Geotextiles and Geomembranes, Vol 36, 27–32.

Toksoy, Y.S. (2014), "Investigation of the seismic performance of reinforced highway embankments", MSc Thesis, Boğaziçi University, Istanbul, Turkey.

Wartman, J., Seed, R. B., Bray, J. D. (2005), "Shaking table modeling of seismically induced deformations in slopes", Journal of Geotechnical and Geoenvironmental Engineering, Vol 131, No 5, 610–622.