Proceedings of the XVII ECSMGE-2019
Geotechnical Engineering foundation of the future
ISBN 978-9935-9436-1-3
© The authors and IGS: All rights reserved, 2019
doi: 10.32075/17ECSMGE-2019-0383

XVII European Conference
ECSMGE 2019
Reykjavik
on Soil Mechanics
and Geotechnical Engineering

Effects of earthquake characteristics on soil isolation with geosynthetics

Effets des caractéristiques sismiques sur l'isolement du sol avec des géosynthétiques

Ayşe Edincliler
Bogazici University,İstanbul Turkey

Mustafa Sekman
Bogazici University,İstanbul Turkey

ABSTRACT: Geosynthetic liners can be placed within a soil profile as soil isolation materials. The proposed alternative isolation system is called as Geotechnical Seismic Isolation (GSI). GSI system is comprised of a geotextile laid over a geomembrane located within a soil profile beneath the structure with a cylindrical shape. Geosynthetics placed within a soil profile can absorb seismic energy and transmit smaller ground motions to an overlying structure by sliding. This paper presents the preliminary experimental study on a potential soil isolation method for medium-rise buildings by using geosynthetics under different earthquake motions. An experimental setup was developed to determine the effectiveness of the proposed GSI system under three different earthquake motions. The comparative study showed that the GSI system can affect the horizontal accelerations, horizontal drifts, Arias intensity, base shear, and base moment of the building. Noticeable reductions due to the proposed soil isolation system can improve the seismic performance of the structures under strong ground motions. It is revealed that earthquake characteristics (amplitude, time and frequency) affect the seismic performance of the medium rise building constructed on soil isolation with geosynthetics.

RÉSUMÉ: Les revêtements géosynthétiques peuvent être placés dans un profil de sol en tant que matériaux d'isolation de sol. Le système d'isolation alternatif proposé s'appelle l'isolation géotechnique sismique (GSI). Le système GSI comprend un géotextile posé sur une géomembrane située dans un profil de sol sous la structure de forme cylindrique. Les géosynthétiques placés dans un profil de sol peuvent absorber l'énergie sismique et transmettre de plus petits mouvements du sol à une structure sus-jacente par glissement. Cet article présente l'étude expérimentale préliminaire sur une méthode d'isolation potentielle du sol pour les bâtiments de hauteur moyenne en utilisant des géosynthétiques sous différents mouvements de tremblement de terre. Une configuration expérimentale a été développée pour déterminer l'efficacité du système GSI proposé sous trois mouvements de tremblement de terre différents. L'étude comparative a montré que le système GSI peut affecter les accélérations horizontales, les galeries horizontales, l'intensité de Arias, le cisaillement de la base et le moment de la base du bâtiment. Les réductions notables dues au système d'isolation du sol proposé peuvent améliorer la performance sismique des structures soumises à de forts mouvements du sol. Il est révélé que les caractéristiques sismiques (amplitude, durée et fréquence) affectent la performance sismique du bâtiment de hauteur moyenne construit sur une isolation du sol avec des géosynthétiques.

Keywords: Geotechnical seismic isolation, Geosynthetics, Soil isolation, Earthquake hazards, Shaking table tests.

1 INTRODUCTION

Nowadays, seismic isolation is a technique developed to prevent or minimize damage to buildings during an earthquake The seismic isolation is able to filter out high frequencies from the ground motion and prevent the structures from being damaged or collapsed, also protect the occupants and in-house sensitive instruments with shifting the natural period of the structure and/or increasing the damping ratio of the structure. However, these systems are expensive and difficult to implement, especially in developing countries. Thereby, alternative low-cost isolation systems have been investigated. One of the alternative isolation systems is stated as Geotechnical Seismic Isolation (GSI) by Tsang et al. 2008. Furthermore, Yegian and Catan (2004) mentioned that a smooth synthetic liner placed within a soil deposit can dissipate earthquake energy through slip deformations along the liner interface, thus reducing the intensity of the propagating shear waves. Such a system is referred to as soil isolation with geosynthetics because the soil layer above the liner is isolated from the underlying soil deposit that is experiencing the excitation. The system is the placement of geosynthetics within the soil profile at some depth below the foundation of a structure. Yegian and Catan (2004), Georgarakos et al. (2005) and Tsatsis et al. (2013) have studied the soil isolation approach with different geometries and depths. It was known that cylindrically shaped geosynthetics geometry generates the restoring gravitational force that would bring the isolated sand deposit back to its horizontal position like a re-centering capability. Thus, cylindrical shaped GSI is going to decrease the expected permanent slip displacements of both structure and isolated soil region after excitation ceased. Considering gravity restoring effect and the results of the mentioned studies, it can be deduced that cylindrically shaped geosynthetics geometry is the most efficient one among the others. Edincliler and Sekman (2016) studied on the soil isolation with geosynthetics by considering soil-structure interaction effects. The effects of geosynthetic linear beneath the mid-rise building model are investigated by shake table tests. They mentioned that using soil isolation with geosynthetics had beneficial effects on the seismic performance of the mid-rise building model.

The aim of this study is to determine the effectiveness of soil isolation with geosynthetics on seismic behavior of mid-rise buildings through shaking table experiments under three different earthquake motions. This study is the first experimental study in the literature that makes possible to evaluate the validity of the proposed GSI system together with the soil-structure interaction by considering fundamental seismic isolation principles. It can be important to observe the seismic behavior of the foundation soil and structure altogether while determining the effectiveness of the GSI system for the structures, Previous experimental researches on the similar subject did not cover the effects of GSI system on the foundation soil and superstructure in the same experimental model. The study aims to obtain preliminary results by considering the needs in the literature. By using the experiences from both experimental and numerical studies done in the literature, a new shaking table test setup was developed to check the validity of proposed GSI system by taking into account the seismic behavior of soil and structure. It is aimed to be a guide for further detailed investigations.

2 MATERIAL AND METHODS

For this study, the laminar box was designed and constructed to simulate the field conditions in the laboratory environment by the help of experiences, guidance, and knowledge taken from the literature. After constructing, the reliability of the laminar box was confirmed by the performance criteria specified in the literature. These performance tests investigate the effect of inertia, friction, membrane, and boundary on laminar box performance (Prasad et al. 2004, Jafarzadeh 2004).

The soil material used in the experiments is named as “Silivri Sand" which is locally found around Istanbul region. The grain-size distribution of the sand was determined according to the ASTM D422 as shown in Figure 1. According to the Unified Soil Classification System, the sand material is classified as poorly graded sand (SP) with the coefficient of curvature as Cu = 2.29 and the coefficient of uniformity as Cc = 1.1. The triaxial test conducted by Cagatay (2008) gives the internal friction angle as ϕ = 41.5°. The specific gravity of sand was obtained as Gs = 2.67 and unit weight of sand is 16.5 kN/m^3. The maximum and minimum void ratios of the sand were obtained as 0.73 and 0.37, respectively.

The simple idea of the proposed GSI system is transforming ground motion to slip displacement via creating an additional geosynthetics layer beneath the structure. This geosynthetics layer consists of two geosynthetics in the way that one on the top of the other. Moreover, Yegian and Kadakal (2004) summarized the requirements to select geosynthetics for an alternative SI. Considering all given requirements and reviewing the literature, commercially available 1.0 mm thick PTFE sheet and 150 gr/m2 nonwoven geotextile (Typar DuPont SF 44) were utilized as GSI material. The proper geosynthetic couple as GSI material was selected and evaluated regarding the series of block test results (Sekman 2016).

The 5-story building model was selected as a prototype. The dimensions of the laminar box do not allow the full-scale buildings thereby, considering maximum allowable dimensions for the building model 1:10 scale factor was determined. Similitude requirements of the building model were taken from Harris and Sabnis (1999). The most important issue during the design and scaling of the building was soil structure behavior that occurs during the experiments because; this research directly interests the GSI and its effectiveness. By taking into consideration this, the prototype was scaled oriented with base pressure and soil structure behavior. The scale factors for the required parameter are given in Table 1. Some physical quantities, such as acceleration and strain, remain the same even after scaling.

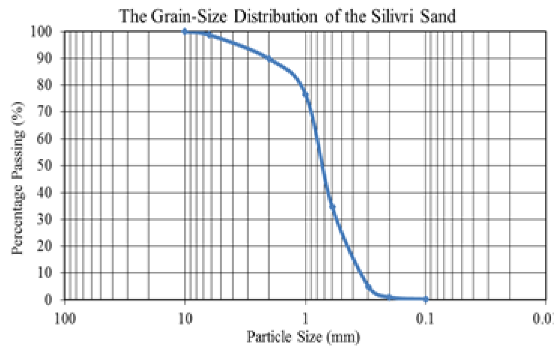

Figure 1. Grain-size distribution of the Silivri Sand.

Table 1. Scaling Parameter of the Building Model (Iai 1989).

Parameter	1:10 Scale Model/ Prototype	
Length	L	1/10
Time	$\sqrt{L}$	$1/\sqrt{10}$
Mass	L^2	1/100
Displacement	L	1/10
Acceleration	1	1/1
Stress	1	1/1
Strain	1	1/1
Force	L^2	1/100

Yegian and Catan (2004) plotted the graph displaying the transmitted acceleration versus H/D ratio. This chart helped to decide ideal GSI depth (H/D ratio) according to the width of the covered geosynthetics as seen in Figure 2. In the current research, GSI width toward the shaking direction was established as constant one meter due to the dimensions of the laminar box. Thereby, the depth of the GSI became directly proportional to transmitted acceleration. This means that if the GSI depth is increased, transmitted acceleration to the building increases for this condition. Transmitted acceleration becomes quite stable after H/D ratio exceeds 6.0. Therefore, the depth of the GSI was distinguished as 10 cm (H/D = 10).

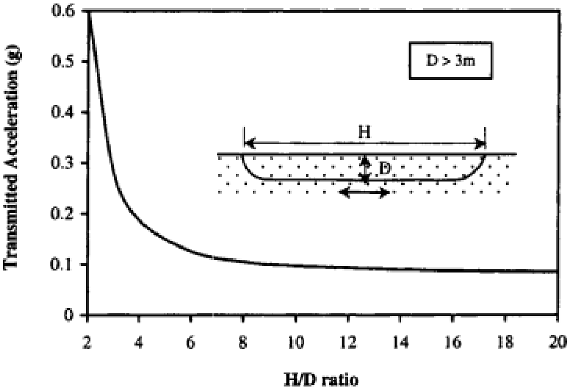

Figure 2. Transmitted Acceleration as a Function of H/D Ratio (Yegian and Catan 2004).

Four accelerometers with ±3g capacity were placed in soil and accelerometers with ±20g capacity were mounted on the building to measure acceleration. Six ODS were utilized for measuring story displacements. Sketch of the experimental setup is shown in Figure 3. ODSs were placed on frame toward each floor of the building model. Likewise, ±20g capacity accelerometers were mounted on the midpoint of every floor and ±3g accelerometers were placed in soil. Locations of the in-soil accelerometers were determined carefully in order to understand the influence of the GSI. First in soil accelerometer was located midpoint of the laminar box under the GSI. The second one was positioned between the foundation and GSI. The third accelerometer was placed outside of the GSI system near the surface.

The 1940 El Centro (Array #9 station), 1995 Kobe (KJMA station), and 1999 Kocaeli (Izmit station) earthquakes. Because of having the uniaxial shaking table in the laboratory, one of the horizontal components of the earthquakes were selected. The basic specifications of the earthquakes were tabulated in Table 2. The earthquake data were obtained from the PEER Ground Motion Database - PEER Center. To apply the earthquake records to proposed GSI system and building models, duration of the earthquake input data were scaled 1:10 by multiplying duration with a scaling factor of in the light of similitude rules taken from Iai (1989). In other words, to maintain dynamic similitude, each record was compressed in time by a factor of $\sqrt{10}$.

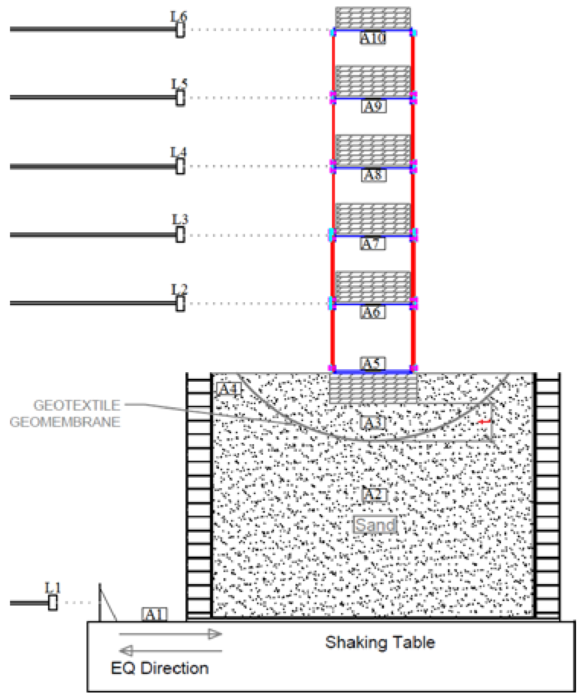

Figure 2. Sketch of Proposed GSI System Experiment Setup with Five-Story Building Model.

Table 2. Information about the Earthquakes (PEER Ground Motion Database).

Earthquake Name	Date	Station Name	Earthquake Magnitude	Component	High Pass Filter (Hz)	Low Pass Filter (Hz)	PGA (g)	PGV (cm/sec)	PGD (cm)
Imperial Valley-02	19.08.1940 04:37:00	El Centro Array #9	6.95	N-S	0.20	15	0.32	31.74	18.01
Kobe, Japan	16.01.1995 20:46:00	KJMA	6.90	N-S	0.05		0.82	77.83	18.87
Kocaeli, Turkey	17.08.1999	Izmit	7.51	E-W	0.10	30	0.22	27.02	14.61

3 SHAKE TABLE TESTS

In order to investigate the effectiveness and robustness of the proposed GSI system, Control model (CM) was created to observe the behavior of the unisolated system including the 5-story building model under the same input motions.

The results of the experiments would be presented as comparisons that were made based on the control model. Three main performance indicators that were foundation horizontal acceleration response, top floor horizontal acceleration response and first-floor drift and their peak and root-mean-square (RMS) parameters were selected. Furthermore, the "percentage (%) reduction" parameter was computed to exemplify better the effectiveness of the proposed GSI system regarding its ability to reduce the acceleration and drift demand in a structure. This parameter was computed as 100% minus the response quantity gathered from the proposed GSI system expressed as a percentage (%) of the respective response quantity as obtained from the control model. Beside of these performance indicator parameters used in the literature, additional performance indicator parameters were chosen. Arias intensity parameter was selected to observe the earthquake energy dissipation and strength of an earthquake as a comparison between isolated and unisolated systems. Both Arias intensity and % reduction of Arias intensity values were computed for each floor. Base shear and base moment were chosen as performance indicator parameters to see the effects of the proposed GSI system on total lateral seismic forces and its relevance to building height. In this study, the effects of the soil isolation with geosynthetics are given for H/D=10 under the three selected earthquake ground motion.

3.1 Seismic Performance of 5-Story Building Model Constructed on Unisolated Soil

CM was established to observe the behavior of the unisolated system including 5-story building model under chosen earthquake motions. In order to clarify the effectiveness of the proposed GSI system. The experiment results are presented as the comparison forme that was made based on the control model.

3.2 Seismic Performance of 5-Story Building Model Constructed on Isolated Soil

For the isolated situation, PTFE 1 mm geomembrane over Typar DuPont SF56 nonwoven geotextile, which were tagged together as GSI, were placed with cylindrical shaped 10 cm (H/D =10) under the foundation. 5-story building model excited with the selected earthquake motions. Besides, the results of isolated model comparing with an unisolated case are given in Table .3.

The reduction in the foundation acceleration, top floor acceleration, and first-floor drift with comparing CM are shown in Figure 4, Figure 5 and Figure 6 under Kocaeli, El Centro, and Kobe Earthquake, respectively. The foundation acceleration is reduced up to 23% in both RMS and peak. The acceleration values are taken from the accelerometer that was placed midpoint of the isolated soil region is decreased up to 19% in RMS and 13% in peak value. Nonetheless, acceleration reduction becomes up to 24% in RMS and 34% in peak at the upper stories.

Even though the first-floor drift is decreased up to 35% in RMS, the top floor drift is magnified. Figure 4e, 5e, and 6e show the percentage reduction of base shear and the base moment that are diminished up to 23% and 15% in RMS respectively. As can be observed in Figure 4f, 5f and 6f, Arias intensity values calculated for the floors are reduced up to 43%. In brief, almost all indicator parameters indicate that the proposed GSI system decreases the seismic effects.

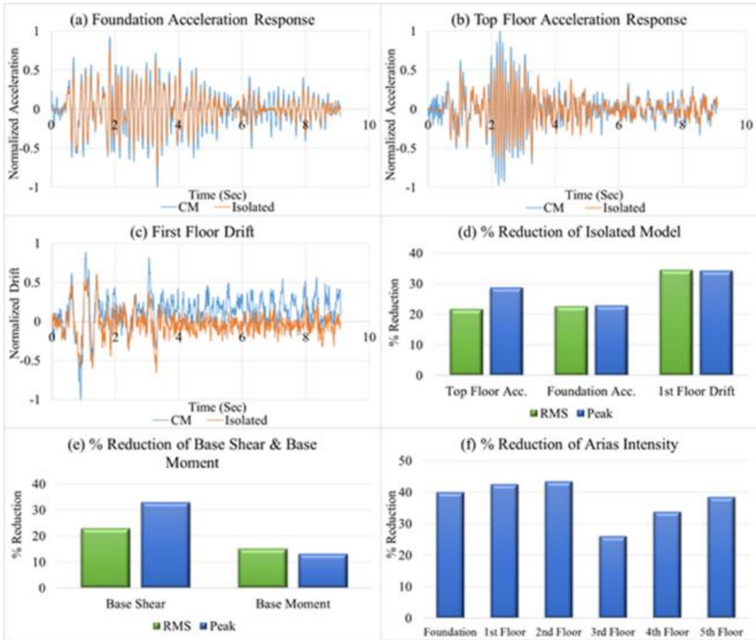

Figure 4. (a) Foundation, (b) Top Floor Horizontal Acceleration Response, (c) First Floor Drift, (d) % Reduction of Isolated Model, (e) % Reduction of Base Shear & Base Moment and (f) % Reduction of Arias Intensity of Isolated Model Comparing CM under Kocaeli Earthquake.

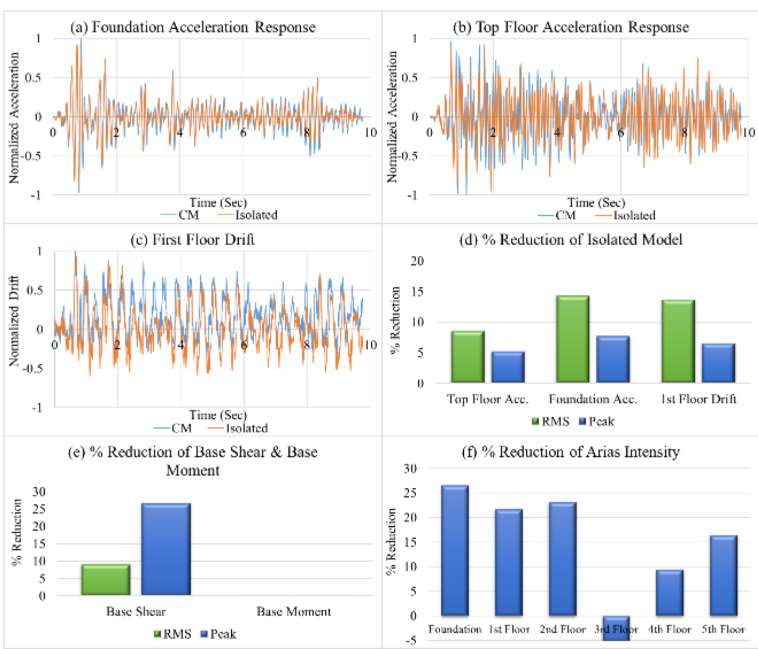

Figure 5. (a) Foundation, (b) Top Floor Horizontal Acceleration Response, (c) First Floor Drift, (d) % Reduction of Isolated Model, (e) % Reduction of Base Shear & Base Moment and (f) % Reduction of Arias Intensity of Isolated Model Comparing CM under El Centro Earthquake.

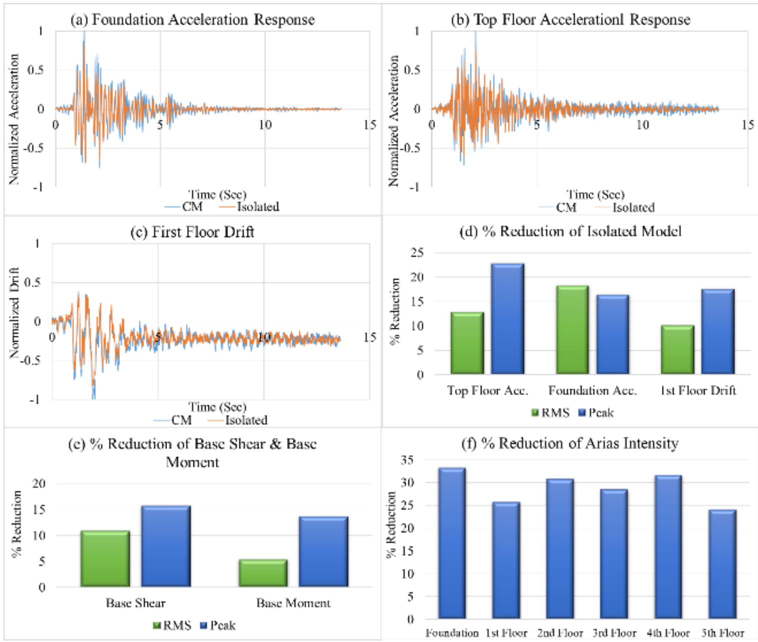

Figure 6. (a) Foundation, (b) Top Floor Horizontal Acceleration Response, (c) First Floor Drift, (d) % Reduction of Isolated Model, (e) % Reduction of Base Shear & Base Moment and (f) % Reduction of Arias Intensity of Isolated Model Comparing CM under Kobe Earthquake.

4 DISCUSSION OF THE TEST RESULTS

The duration, intensity, and magnitude of the earthquake motions affect the efficiency of the aforementioned GSI system. For instance, among the 3 different earthquakes were applied, the system behaved less beneficial under the El Centro earthquake. The high amplitude content and having longer duration may not let the slip of the GSI system as expected. On the other hand, the top story drift magnified under all applied excitations. Considering the working mechanism of the system which is based on slip displacement between GSI couple, building displacements increase as the distance extends from the GSI due to the cylindrical shape of the GSI. However, according to height and weight of the isolated building, the amount of the soil deposit on the GSI system can be regulated based on H/D relationship to minimize the expected slip displacements by counterbalancing the building weight.

Table 3. % Reduction of Selected Performance Indicator Parameters

Performance Indicator Parameters (% Reduction)	Kocaeli Earthquake		El Centro Earthquake		Kobe Earthquake	
	RMS	Peak	RMS	Peak	RMS	Peak
Top Floor Acceleration	21.7	28.7	8.6	5.3	12.9	22.8
Foundation Acceleration	22.7	22.9	14.3	7.7	18.3	16.4
Top Floor Drift	-8.5	-21.0	-17.7	-48.9	-36.1	-24.5
First Floor Drift	34.6	34.3	13.7	6.5	10.1	17.6
Base Shear	22.9	32.9	9.1	26.7	10.9	15.7
Base Moment	15.1	13.1	-1.8	-1.1	5.4	13.6
Top Floor Arias Intensity	38.5	-	16.3	-	24.1	-
Foundation Arias Intensity	40.0	-	26.5	-	33.2	-

5 CONCLUSIONS

A preliminary shake table experimental setup has been developed for modeling seismic responses of soil–foundation–structure system by which the effectiveness and robustness of the proposed method have been evaluated. Comparison of the soil isolated model with the unisolated model revealed the following results.

- An isolation liner can significantly reduce the accelerations at the surface of the isolated soil mass.
- The transmitted top and foundation accelerations of the building model and first-floor story drifts can be substantially decreased due to the inclusion of GSI material within the soil profile. Except for the top floor drifts as discussed in the previous part, the rest of the performance indicator parameters that are base shear, base moment, top floor Arias intensity, and foundation Arias intensity were also reduced.

As a conclusion, the proposed GSI system works efficiently under the considered seismic motions. As further studies, detailed experimental study with changing the type of foundation soil and size of structures should be performed. The seismic performance of the scaled model should be validated with the prototype models in the field.

6 ACKNOWLEDGMENTS

This study was supported by the Boğaziçi University Research Fund (Project No. BAP8084). The authors are grateful for funding by Boğaziçi University.

7 REFERENCES

Cagatay, A. 2008. Investigation of the Effect of Tire Waste Inclusions on the Shear Strength Parameters of Sand. Ms. Thesis, Bogazici University, Civil Engineering, Istanbul.

Edinçliler, A., Sekman, M. 2016. Investigation on Improvement of Seismic Performance of the Mid-Rise Buildings with Geosynthetics. The Sixth International Conference on Structural Engineering, Mechanics and Computation (SEMC 2016). Cape Town.

Iai, S. 1989. Similitude for Shaking Table Tests on Soil-Structure-Fluid Model in 1g Gravitational Field. Soils and Foundations, Vol. 29, p.105-118.

Georgarakos, P., Yegian, M. K., Gazetas, G. 2005. In-Ground Isolation Using Geosynthetic Liners. 9th World Seminar on Seismic Isolation, Energy Dissipation and Active Vibration Control of Structures. Kobe.

Harris, H. G. & Sabnis, G. M. 1999. Structural Modeling and Experimental Techniques. CRC Press.

Jafarzadeh, F. 2004. Design and Evaluation Concepts of Laminar Shear Box for 1g Shaking Table Tests. 13th World Conference on Earthquake Engineering, (p. 1391). Vancouver.

Prasad, S. K., Towhata, I., Chandradhara, G. P. & Nanjundaswamy, P. 2004. Shaking Table Tests in Earthquake Geotechnical Engineering. Current Science, pp..1398-1404.

Sekman, M., (2016). "Experimental study on mitigation of earthquake hazards using geosynthetics", Ms. Thesis, Bogazici University, Civil Engineering. Turkey.

Tsang, H., Lo, S. H., Xu, X., Sheikh, M. Neaz. 2012. Seismic isolation for low-to-medium-rise buildings using granulated rubber-soil mixtures: Numerical study. Earthquake Engineering and Structural Dynamics, 41 (14), pp.2009-2024.

Tsatsis, A. K., Anastasopoulos, I. C., Gelagoti, F. L., Kourkoulis, R. S. 2013. Effectiveness of In-soil Seismic Isolation Taking into Account of Soil-Structure Interaction. 18th International Conference on Soil Mechanics and Geotechnical Engineering, (p. 1635-1638.

Yegian, M. K., Catan, M. 2004. Soil Isolation for Seismic Protection Using a Smooth Synthetic Liner. Journal of Geotechnical and Geoenvironmental Engineering, pp. 1131-1139.