Numerical Study on Seismic Isolation for Medium-rise Buildings Using Rubber-Sand Mixtures

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ABSTRACT: In recent years, Geotechnical Seismic Isolation (GSI) system as an alternative method for improving seismic performance of low- and mid-rise buildings has been proposed. One of GSI material is known as Rubber-Soil Mixtures (RSM). In this GSI concept, RSM is placed underneath the foundation and surrounds all the foundation of the building. This study proposes an alternative low-cost seismic isolation system involving the use of granulated rubber and sand mixtures as RSM material. The validity of the proposed method has been shown by a number of numerical simulations using PLAXIS Software. To demonstrate the feasibility of the GSI–RSM system, a number of important variables as a number of the storey and the thickness of RSM layer was studied. The results of the parametric study showed that the proposed method may be used to improve the seismic performance of the low-to-medium rise buildings. More importantly, the proposed method with low cost and easily accessible features can be of great benefit for developing countries.

1 INTRODUCTION

Recently, Geotechnical Seismic Isolation (GSI) system as an alternative method for improving seismic performance of low- and mid-rise buildings has been proposed. GSI system can be regarded as distributed seismic isolation system which involves isolating the entire contact surface of the foundation of the building (Tsang et al. 2007; 2008; 2012). The two types of geotechnical seismic isolation systems (smooth synthetic liners and rubber-soil mixtures) can be analogous to the conventional structural seismic isolation systems using spherical sliding bearings and laminated rubber bearings respectively (Figure 1). Soil and foundation isolation are the types of GSI with geosynthetics which can easily be applicable for low-to-midrise buildings. Experimental studies showed that using geosynthetics as foundation and soil isolation materials increased the seismic performance of the low-to-midrise buildings (Sekman, 2016; Edincliler and Sekman, 2016; Calikoglu, 2017; Edincliler and Calikoglu).

Both laminated rubber bearings and RSM layer decouple the building structure from ground motions by interposing elements or materials of low stiffness in between. The two geotechnical seismic isolation methods can be generalized as a distributed seismic isolation system, which involves isolating the entire contact surface of the foundation structure. This feature is clearly distinctive from conventional systems which are based on isolation at certain discrete supporting points (Tsang, 2008).

Tsang (2008) proposed an alternative seismic isolation scheme particularly suitable for developing countries, making use of rubber-soil mixtures. It is stated that the horizontal and vertical ground acceleration can be reduced by 60-70% and 80-90%, respectively. Tsang et al.

(2012) worked on a potential seismic isolation system by placing rubber-soil mixtures around foundations of low-to-medium rise buildings, which provides a function similar to that of a cushion. In general, they found that the structural responses, in terms of acceleration and inter-storey drift, can be reduced by 40–60%. The results were found to be the most sensitive to variations in the thickness of the RSM layer.

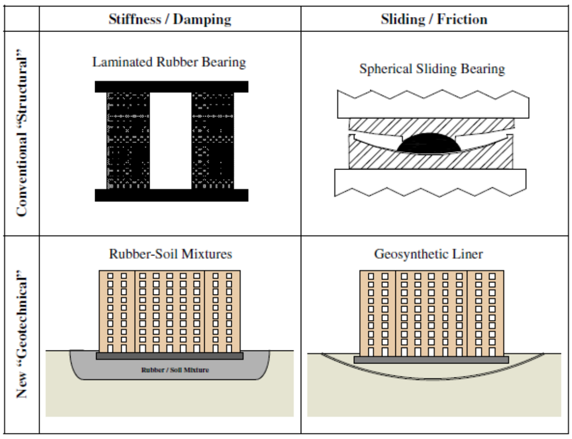

Figure 1. Proposed classification of seismic isolation systems (Tsang, 2009).

Adır (2013) investigated the applicability of GSI with numerical analysis. Tire Waste-Sand Mixtures (TWSM) as Tire Buffings and Tire Crumbs were revealed for different mixing proportions; are chosen as GSI material alternatives. TWSM use as GSI material is examined regarding the effect of number of storey, tire waste ratio, different earthquake records, TWSM layer thickness, and pile foundation. Numerical analyses of eight and 12 storey structures caused reduction in acceleration and drift by 40-60 per cent.

Goztepe (2016) determined the effectiveness of the proposed RSM method on the seismic performance of the low-to-medium rise buildings by shake table experiments. A designed 1/10 scaled three and five storey building models were used in order to represent low-to-medium rise buildings. From all comparative test results, reductions in top floor accelerations up to 75%, foundation accelerations up to 77%, first floor drifts up to 90%, top floor drifts up to 90%, base shear up to 71%, base moment up to 53%, top floor Arias intensities up to 93%, foundation Arias intensities up to 94% are obtained.

Feng and Sutter (2000) stated that the damping ratio in rubber-sand mixture is due to the friction particles and the deformation of particles. The sand particles are very stiff and thus dissipate very little energy in particle deformation. Edincliler et al. (2004) conducted a set of cyclic triaxial tests with tire buffings, sand and tire buffing mixtures. Test results demonstrate that tire buffings added to the medium dense sand changed the deformation behavior and the dynamic behavior of sand–tire buffings mixture. The damping ratio of sand was increased more than threefold by the addition of tire buffings due to the fiber shape of tire buffings. Yildiz (2012) conducted a series of cyclic triaxial tests to determine the effects of type of scrap rubber, rubber content and confining pressure on dynamic behaviour of rubber-soil mixtures. It is found that the dynamic properties of the RSM depend on the type and content of rubber added to the sand. The aim of this study is to determine the effects of thickness of RSM layer around the foundation on the seismic performance of low- to medium rise buildings. RSM layer was used as a promising earthquake protection system for absorbing vibration energy and exerting a function similar to that of a cushion. The validity of the proposed method has been shown by a number of numerical simulations using PLAXIS Software.

2 NUMERICAL STUDY

This paper presents a new method of utilizing scrap tires for earthquake hazard mitigation. The method involves mixing scrap tires with sand and placing the mixtures beneath building structures by which cushioning effect can be provided for earthquake protection. A numerical study has been carried out to evaluate its effectiveness and robustness.

2.1 Materials and methods

Previous studies showed that rubber content and processing type of the rubber are important factors on the dynamic properties of RSM. Evaluation of the previous studies on dynamic properties of tire waste-sand mixtures at various contents showed that RSM having 70% sand and 30% granulated rubber by weight (TC30) has the highest damping property (Yildiz, 2012). By these reasons, the TC30 was selected as RSM material.

2.2 Geometry of model

For finite element analysis of the low- to medium rise buildings with a raft foundation with and without the RSM layer, PLAXIS 2D software program was used. The dimensions of the building, b = 8 m; storey height, h=3 m; and the width of footing, B=10 m. The thickness of the RSM layers were designed as d= 5 and d=10 m. The dimension of mesh is taken as 50m x 100 m (Figure 2). The effect of the number of storeys and thickness of the RSM layer are determined.

Numerical simulations consist of six different cases subjected to real earthquake excitations are performed. The first three models represent the low-rise buildings. The other models are for medium-rise models. Model 1 and Model 4 simulate the fixed based mıdels while Model 2, 3, 5 and Model 6 simulate the base isolated building models, For the low- to medium rise buildings, Model 2 and Model 5 represent the RSM layer with the thickness of 5m whereas Model 3 and Model 6 represent the RSM layer with the thickness of 10m. The cases considered in this study was summarized in Table 1.

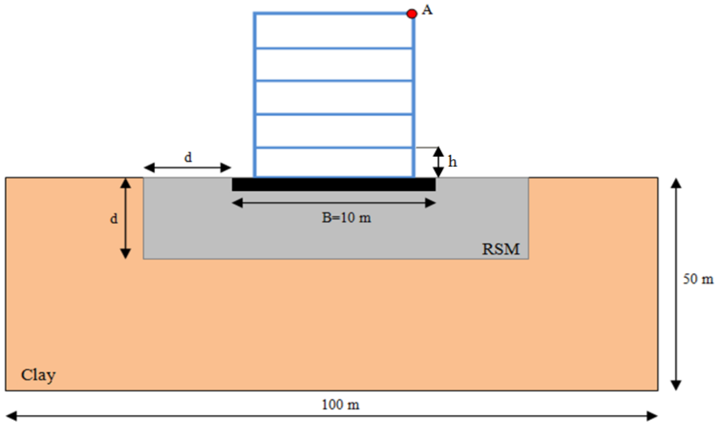

Figure 2. Numerical model of building on RSM layer.

Table 1. Properties of numerical Models.

Model No.	Thickness of RSM Layer, d (m)	Number of Storeys
Model 1	0	3
Model 2	5	3
Model 3	10	3
Model 4	0	5
Model 5	5	5
Model 6	10	5

2.3 Material properties

The foundation soil was selected as clay material and represented as hardening soil model. The material properties of clay is given in Table 2. The structural elements were categorized in two groups as footing and building materials. The material of the foundation were assumed to be concrete and the frame of the buildings were simulated with the plate elements. The material properties are shown in Table 2 and Table 3.

Table 2. Parameters of foundation soil.

Soil Type/ Behaviour Model	Clay/ HS Small
γ_{unsat}	16 kN/m^3
γ_{sat}	20 kN/m^3
c'_{ref}	10 kN/m^2
Ø	18°
ψ	0
E	20.000 kN/m^2

Table 3. Material properties of building elements.

Parameter	Footing	Plate Elements
Material Type	Isotropic-Elastic	Isotropic-Elastic
EA_1	7,6E6 kN/m	9E6 kN/m
EA_2	7,6E6 kN/m	9E6 kN/m
EI	24E3 kN/m	67,50E^3

Granulated rubber -sand mixture having 30% granulated rubber by weight was used as RSM layer with the thickness of 5 to 10 m around the foundation. The material properties of the RSM layer is given in Table 4.

Table 4. Material properties of the RSM layer.

Parameter	RSM Layer
γ_{unsat}	10,3 kN/m^3
γ_{sat}	15,0 kN/m^3
c'_{ref}	4 kN/m^2
Ø	29,5°
ψ	0
E	20.000 kN/m^2

2.4 *Dynamic loading*

The 1999 Kocaeli earthquake motion (PGA=0.22g) which is known as one of the destructive earthqukae in the world was taken as an input motion (Figure 3). Earthquake record was obtained from BU-KOERI-BDTIM and used after baseline corrected and filtered.

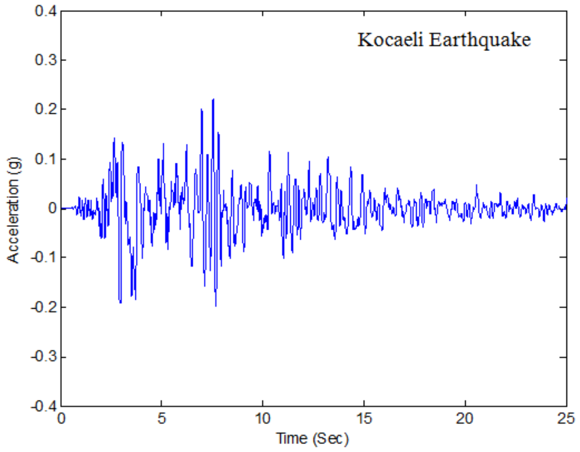

Figure 3.Acceleration-time history of the 1999 Kocaeli Earthquake Motion (E-W).

3 RESULTS

Numerical results of each model under the 1999 Kocaeli earthquake excitations are represented in terms of acceleration responses and total displacements

3.1 *Acceleration Response*

The acceleration time histories of three storey building models are given in Figure 4. The PGA values of the fixed base building model is found as 0,22g. The PGA value at the top of the building on RSM layer with a thickness of 5m is calculated as 0,16g. When the thickness of the RSM layer is increased to d= 10 m, the PGA value is reduced to 0.15g.

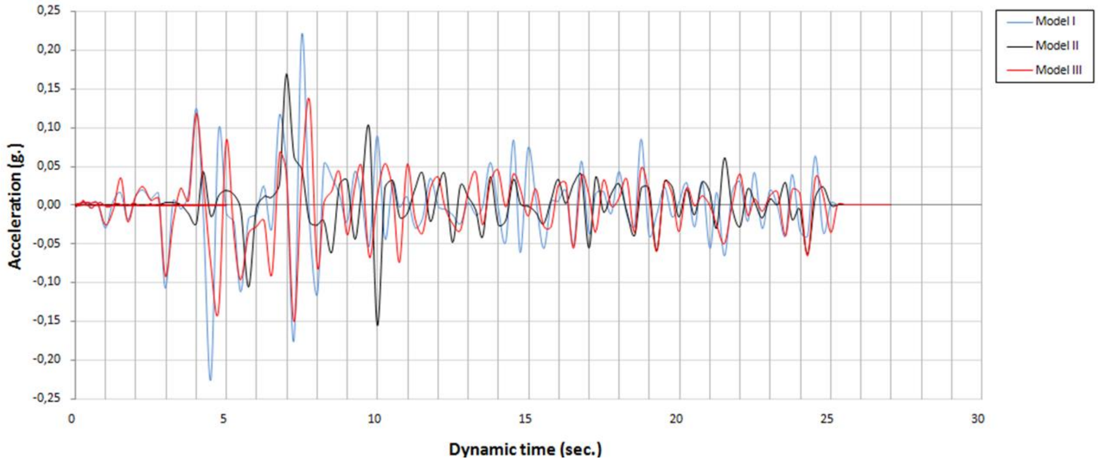

Figure 4. Acceleration time history for Model 1, Model 2 and Model 3.

The acceleration time histories of five storey building models are given in Figure 5. The PGA value of the fixed based models is calculated as 0,22g. The PGA value at the top of the isolated building model with a thickness of 5m is calculated as 0,165g. As the thickness of RSM layer increased to 10 m, the PGA value is reduced to 0.135g.

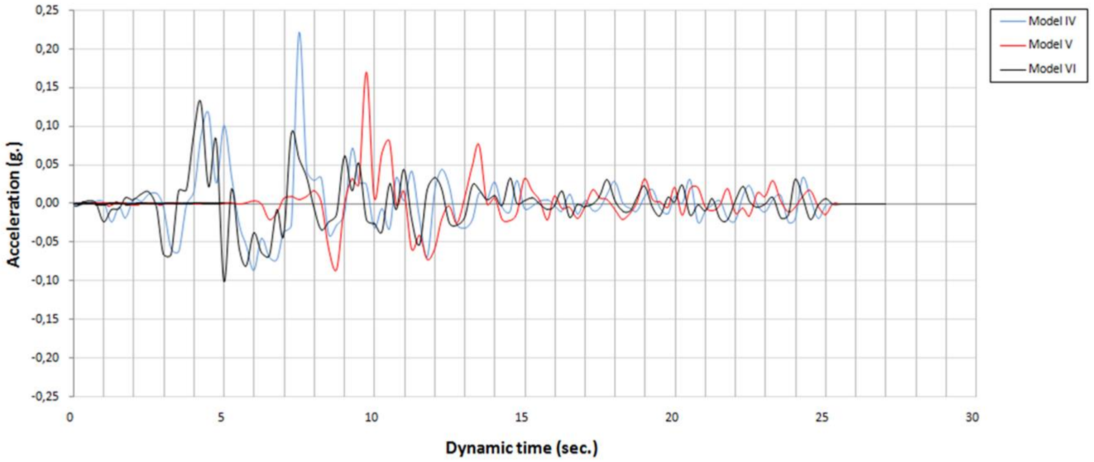

Figure 5. Acceleration time history for Model 4, Model 5 and Model 6.

3.2 Displacement response

The displacement time histories of three storey building models for non-isolated and isolated cases are given in Figure 7. The maximum vertical settlements for the foundations covered by the RSM layer with the thickness of 10 m (d=10m) and 5m (d=5m) are found as 43 cm. and 38 cm, respectively. The maximum settlement of the fixed base model is 34 cm.

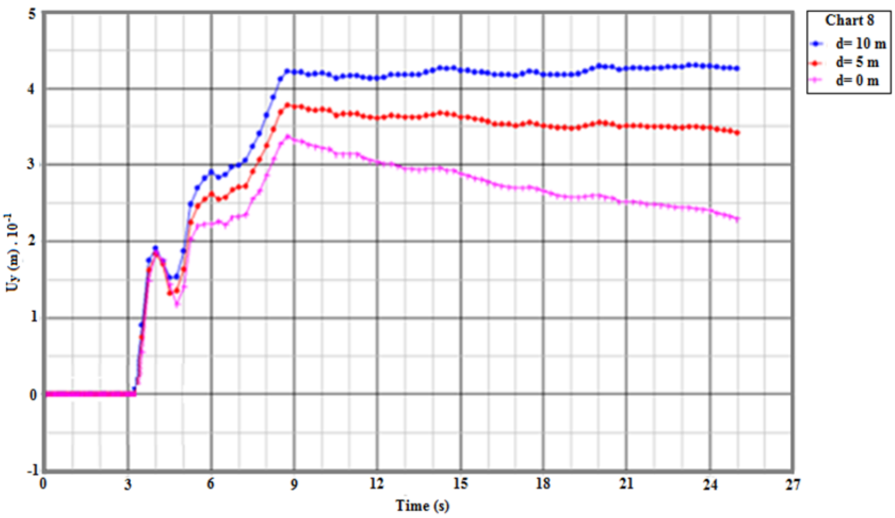

Figure 7. Displacement time history for Model 1, Model 2 and Model 3

The displacement time histories of 5 storey non-isolated and base-isolated Models are given in Figure 7. The maximum vertical settlements for Model 5 and 6 are 36 cm. and 39 cm, respectively. The maximum settlement of the fixed based model is found as 31 cm.

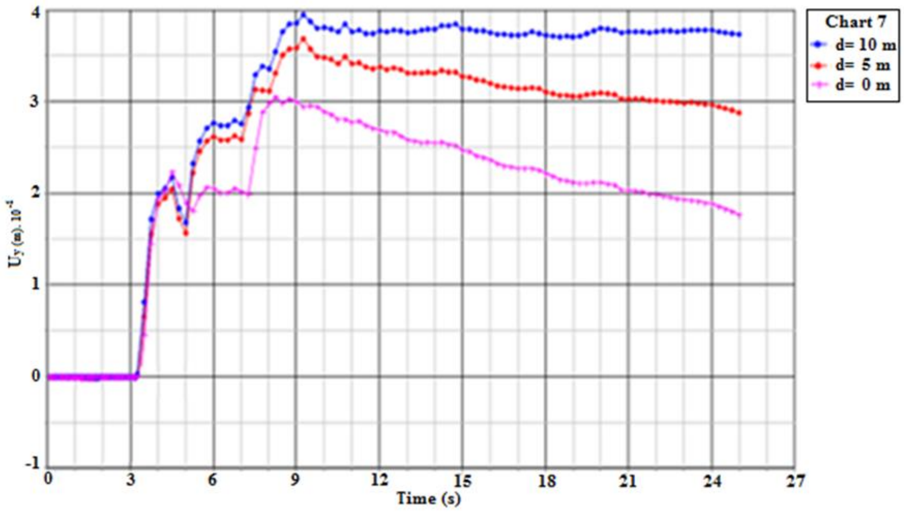

Figure 8. Displacement time history for Model 4, Model5 and Model 6.

4 DISCUSSION OF THE RESULTS

The seismic performance of the Models were evaluated with comparing the transmitted acceleration values and the amount of vertical displacements. In addition, Amplification Factor(s) (A.F.) are calculated as the ratio of transmitted maximum acceleration to the peak input acceleration value (PGA). The changes in accelerations and displacements by inclusion of the RSM layer are summarized in Table 5. As the thickness of the RSM increased from 5 m to 10 m for low and medium rise building models, the percentage reductions in the horizontal accelerations of the roof increased from 27% to 32%, and from 25% to 39%, respectively (6).

It is obviously seen that the AF of the low and medium-rise building models are always lower than the fixed based models. When the RSM layer added around the foundation, a reduction of AF values up to 39 % is obtained. With increasing of the RSM layer from 5m to 10m for the low- and medium rise buildings, AF values are decreased from 0.73 to 0.69 and 0.78 to 0.64 respectively. It makes a decrease of 5.5% for the low-rise building and 17.97% for the medium-rise buildings. For all cases with the RSM layer, deamplification is obtained.

Table 5. Summary of numerical results.

Model No.	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
Acceleration	0,22	0,16	0,15	0,22	0,17	0,14
% Change		-27	-32		-25	-39
AF	-	0.73	0.69	-	0.78	0.64
Displacement	34	38	43	31	36	39
% Change		12	27	-	16	26

At the same time, the vertical displacements of the foundation increased from 12% to 27%, and from 16% to 26% respectively. Depending on the thickness of RSM layer, the displacement values increased due to high compressibility of rubber material.

According to the numerical simulations, the most effective seismic improvement was occurred for the inclusion of a 10m thick RSM layer around the foundation of the medium rise building.

Overall results showed that the seismic response of the model building with the RSM layer under earthquake motion is improved. With the inclusion of the rubber to the sand, the transmitted accelerations decreased due to the damping capacity of the rubber.

5 CONCLUSIONS

This paper presents a promising earthquake protection method by placing rubber-soil mixtures (RSM) around foundations of low-to-medium-rise buildings for absorbing vibration energy and exerting a function similar to that of a cushion. The validity of the proposed method has been shown by a number of numerical simulations using real earthquake motion. Parametric studies have been conducted to examine a number of important variables, namely the number of stories and thickness of the RSM. It is revealed that the utilization of RSM can effectively reduce the acceleration response at the top of the building models at all levels. On average, the horizontal accelerations of the roof can be reduced by 25-39%. .In regard to horizontal accelerations of the roof, it is revealed that the results were most sensitive to variations in the thickness of the RSM layer. It is stated that the seismic isolation performance of the GSI system with RSM can be dependent on the percentage of rubber in RSM, thickness of RSM layer, and the level of input ground shakings. It is emphasized that there is no intention to claim that the proposed method can replace the well-established and commonly-adopted isolation system.

6 REFERENCES

Adir, K., 2013, Mitigation of earthquake induced geotechnical hazards using tire waste-sand mixtures, MSc Thesis, Bogazici University.

Edinçliler A., G. Baykal, and K. Dengili, 2004, Determination of static and dynamic behavior of recycled materials for highways. *Resources, Conservation and Recycling*, 42(3):223-237.

Calıkoglu, M., 2017. Experimental Study on Foundation Isolation Using Geosynthetics. MSc. Thesis. Bogazici University, Turkey.

Edinçliler, A., and Çalıkoğlu, M., 2017. Improvement of Seismic Performanc of Low-rise Buildings with Geosynthetics: Experimental Study. Seventh National Geosynthetics Conference (G7). Istanbul (in Turkish).

Edinçliler, A., and 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.

Feng ZY. and Sutter KG. 2000, Dynamic properties of granulated rubber/sand mixtures. *Geotechnical Testing Journal*, 23(3):338–344.

Goztepe, B. (2016). Experiemental study on mitigation of earthquake hazards using rubber-soil mixtures, MSc Thesis, Boğaziçi University.

Sekman, M. 2016. Experimental Study on Mitigation of Earthquake Hazards Using Geosynthetics, MSc. Thesis, Bogazici University.

Tsang HH., M. Sheikh, M. Neaz, and TK. Lam Nelson, 2007, *Rubber-soil CUSHION for earthquake protection*, Uni. of Wollongong, Sch. of Civil, Mining and Env. Eng.Research.

Tsang HH., 2008, Seismic isolation by rubber-soil mixtures for developing countries, *Earthquake Engineering Structural Dynamics*, 37:283 – 303.

Tsang H.H., S.H. Lo, X. Xu, and M.N. Sheikh, 2012, Seismic isolation for low-to-medium rise buildings using granulated rubber-soil mixtures: Numerical study, *Earthquake Engineering and Structural Dynamics*. DOI: 10.1002/eqe.2171.

Yıldız, O. 2012, Investigation on the mitigation of earthquake hazards with inclusion of tire wastes into the sand, MSc Thesis, Boğaziçi University.