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Investigation of Sand and Shredded Rubber Tyre Mixture as a Natural Base Isolator for Earthquake Protection

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Abstract. The proper disposal of used tyres is a serious and genuine ecological problem. The level of reuse is significantly less when compared with the accumulating consistently. It is well known that rubber serves as an excellent damping material. Therefore, there is a huge possibility for the utilization of these rubber pieces for earthquake-resistant design purposes. This study suggests developing an economic seismic isolation system utilising soil and waste tyre scrap. The inclusion of tyre chips modifies the damping properties of the soil by expanding energy dispersion. A FEM investigation of the isolated framework is analyzed by PLAXIS 2D. The time history of acceleration of some well-known seismic tremors is utilised as an input motion in the study. Due to the damping effect produced by soil-rubber tyre isolators, peak ground acceleration response is observed to decrease considerably. The de-amplification values found for the acceleration at the model's peak of the isolated building are promising.

Keywords: Base Isolator, Finite Element Method, Seismic, Soil-rubber, Damping.

1 Introduction

Seismic isolation is a strategy for safeguarding structures from tremor-prompted distortions by utilising isolators under the foundation. By installing energy-retaining components, the seismic isolation technique seeks to reduce the effects of earthquakes transmitted from the soil to the building. Housing structures in highly populated regions are seismically susceptible to the activity of major seismic actions. The significant expense and technical challenges connected with using existing seismic isolation frameworks rule out its establishment in low to mid-rise structures in the modern world.

The ecological issues related to the stockpiling of scrap tyres have led the researcher to investigate reasonable re-utilizing solutions in civil works. A few researchers have proposed a seismic detachment framework by reusing rubber tyres with sand particles. The idea of seismically protective design has been essential for civilization because regular innovation is insufficient to predict the location, size, and timing of seismic disturbances. The main variable factors for designing the structural frameworks to prevent the construction from the earthquake are the materials used in construction, the region's seismic activity, and local soil characteristics. In standard methodology, earthquake mitigation is achieved by planning construction with sufficient strength and capacity to deform in a ductile way. Seismic isolation is broadly utilised as a viable response alteration scheme, resulting in decreased seismic harm to various structures in technologically advanced nations. In this respect, fundamental flexibility can be accomplished by using the rubber base isolation strategy. The idea is that one can obtain fine sand from nearby sites, and it is reasonable to source the rubber from reused automobile tyres. The construction of this economical seismic isolation technique comprising these locally accessible materials is vital for seismic destruction mitigation in emerging nations. There is a rising interest in emerging countries to apply economic seismic isolation to public structures like places of business, schools, etc. The importance is that the expense of the isolation framework utilised ought to be low cost contrasted with the expense of substitution because of tremor harms.

2 Statement of the Problem

A parametric analysis has been performed on key factors, including side width and thickness beneath the foundation and input ground motions caused by earthquakes. Data on the acceleration time history of different tremors is utilised for investigation. It ought to be noticed that only one input variable has differed while holding every leftover input variable constant in every execution.

2.1 Characteristics of the Structural System

The structure model has a fixed story level of 3 m. The material characteristics of each beam and column are made up of M20 concrete and have a density of 2400 kg/m^3. The geometry of the beam and column are 0.45 x 0.45 m and 0.4 x 0.4 m individually. The live load on the structure is 5 kN/m^2. The magnitude of EA and EI are taken for footing as 7600000 kN/m and 24000 kNm^2/m, respectively, while other structural components are considered as 9000000 KN/m and 67500 kNm^2/m, respectively.

Ground and Isolating Layer. The technique includes blending scrap tyres with sand and setting the combinations underneath building structures by which cushioning effect can be provided for seismic disaster mitigation. A numerical analysis has been done to assess its adequacy and robustness. The isolation layer of sand-scrapped rubber tyre blends is placed between the foundation structure and the ground. Considering past explores (Rahman and Berthelot 2011), it is laid out that a 1:3 shredded tyre-sand mixture is an ideal material for serving the purpose; RSM is viewed here as a pure sand and rubber mixture at a proportion of 75%. The only soil taken into account is sand. For soil and RSM, the densities are reported as 17.4 kN/m^3 and 9.5 kN/m^3, respectively (Masad et al. 1996; Edil and Bosscher, 1994). The soil and RSM Poisson's ratio are both scaled to a single magnitude of 0.3. Since it rarely affects the results, the different magnitude of Poisson's ratio for various materials is not considered crucial. (Tsang, 2008). For sand and RSM, the respective Young's Modulus considered in this study is 577.2 MPa and 19.5 MPa (Bałachowski and Gotteland, 2007).

3 Results and Discussion

3.1 Kocaeli Earthquake 1999

The ground motion of the Kocaeli earthquake in Turkey in 1999, at latitude 40.7270 and longitude 29.9900, is used for this investigation. The 1999 earthquake was part of a 60-year sequence of significant earthquakes along the North Anatolian Fault that began in 1939 and progressed progressively from east to west. It had a magnitude of 7.6 and a maximum Mercalli intensity of X (Extreme), with its epicenter located in Izmit. The tremors continued for 37 seconds. At the bedrock level, the input motion is applied. The PLAXIS 2D program is used to do a FEM analysis of the five-story constructions with and without the RSM layer. The geometry of the design incorporates a 3 m story level and a 10 m foundation width. The RSM layers' thicknesses are ordered as d=5unit and d=10unit. Three specific situations presented to actual seismic tremor excitations are examined using numerical models. Model 1 is concerned with fixed-based models, whereas Models 2 and 3 are based on isolation models. Model 2 depicts an RSM layer with a thickness of 5 units, whereas Model 3 depicts an RSM layer with a thickness of 10 units. Table 1 summarises the output obtained in this investigation.

Table 1. Output Parameter of Kocaeli Earthquake 1999.

Model	Model A	Model B	Model C
d/B ratio	0	0.5	1
Acceleration(g)	0.205	0.175	0.161
% Change	-	-14.63	-21.46

Results. Under the 1999 Kocaeli earthquake excitations, the numerical output of each model is shown in terms of acceleration responses. The fixed-based model PGA value is calculated to be 0.205g. With a thickness of RSM to the width of the foundation ratio (d/B ratio) of 0.5, the PGA value on the top of the isolated building model is 0.175g. When the ratio of RSM thickness to foundation width (d/B ratio) is increased to 1, the PGA value drops to 0.161g.

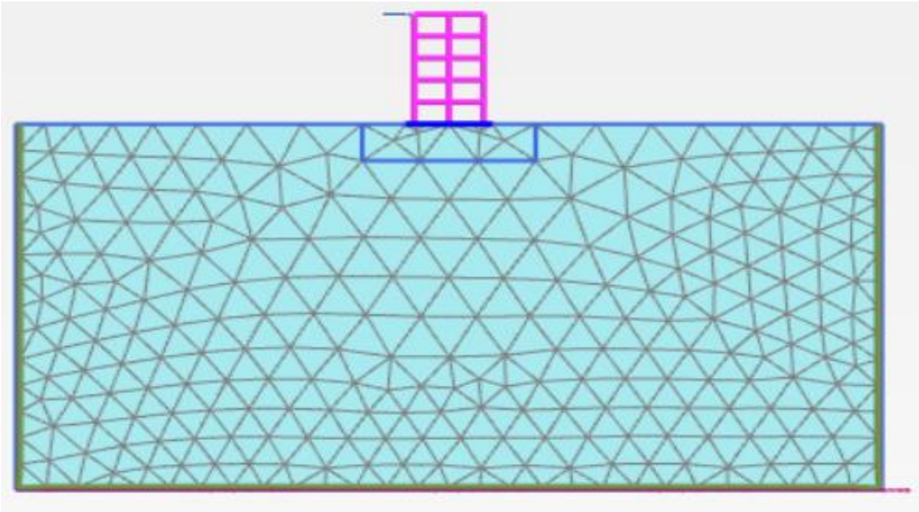

Fig. 1. Mesh of building model generated for Kocaeli earthquake in PLAXIS 2D

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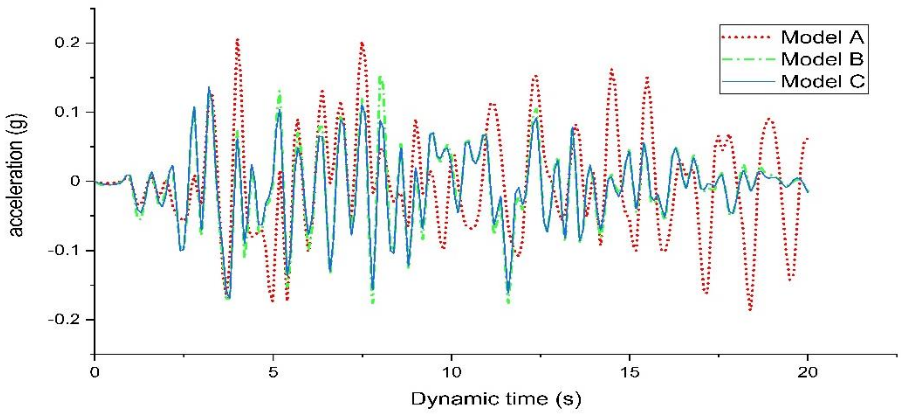

Fig. 2. Acceleration-time graph for Models A, B, and C.

Discussion of the Results. The model’s seismic performance was assessed by comparing transmitted acceleration values with respect to model A. Table 1 summarises the effects of including the RSM layer on accelerations. As the d/B ratio for building models increased from 0.5 to 1, the percentage decreases in the horizontal accelerations of the roof improved from 14 to 21 percent.

3.2 Loma Prieta Earthquake

For this analysis, the Loma Prieta Earthquake's ground motion of 1989 is used. The earthquake's epicentre was located at 37.04°N, 121.88°W on California's Central Coast. PLAXIS 2D software performs finite element analysis on two-story and four-story buildings with and without the RSM layer. The building's dimensions are storey height, h=3 m, and footing width, B=10 units. The RSM layers are developed with thicknesses of d=2-unit, d=4 units, and d=6 units. The impact of the number of floors and RSM layer thickness is investigated. Six separate instances are treated to real earthquake excitations during numerical simulations. The first three models represent the four-story building. The other models are for two-story buildings. Table 2 summarises the instances considered in this investigation.

Table 2. Output Parameter of Loma Prieta Earthquake.

Earthquake	Storey	Peak Horizontal Acceleration Without RSM(g)	Depth-to-width ratio (*d/B*)	Peak Horizontal Acceleration With RSM	Reduction (%)	Amplification factor
LOMA PRIETA	4	1.22	0.2	0.85	30.32	0.70
			0.4	0.68	44.26	0.56
			0.6	0.63	48.36	0.51
	2	0.82	0.2	0.42	48.78	0.52
			0.4	0.35	57.32	0.43
			0.6	0.29	64.63	0.35

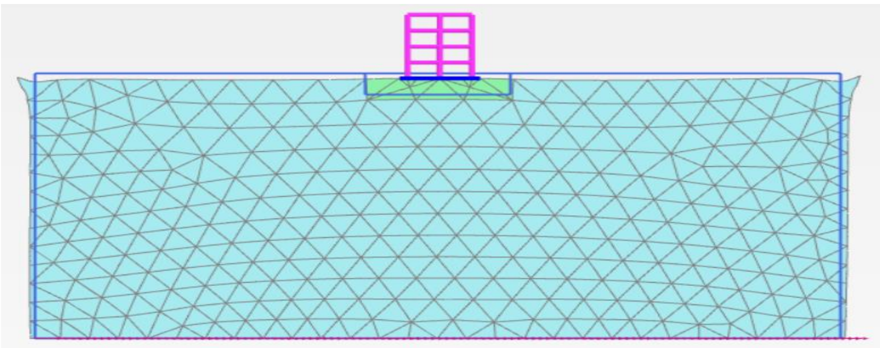

Fig. 3. A deformed mesh of building model generated in PLAXIS 2D.

Results. The acceleration responses are used to show the numerical findings of each model under the Loma Prieta earthquake excitations. With a thickness of RSM to the width of the foundation ratio (d/B ratio) of 0.2, the PGA value at the top of the building on the RSM layer equals 0.42g. The PGA value is reduced to 0.35g when the RSM thickness to foundation width ratio (d/B ratio) is increased to 0.4. When the d/B ratio is raised to 0.6, the PGA value decreases to 0.29g. Whereas for a 4 storey building with a thickness of RSM to the width of the foundation ratio (d/B ratio) of 0.2, the

PGA value at the top of the building on the RSM layer is 0.85g. The PGA value drops to 0.68g when the RSM thickness to foundation width ratio (d/B ratio) is increased to 0.4. The PGA value drops to 0.63g after reaching a d/B ratio of 0.6.

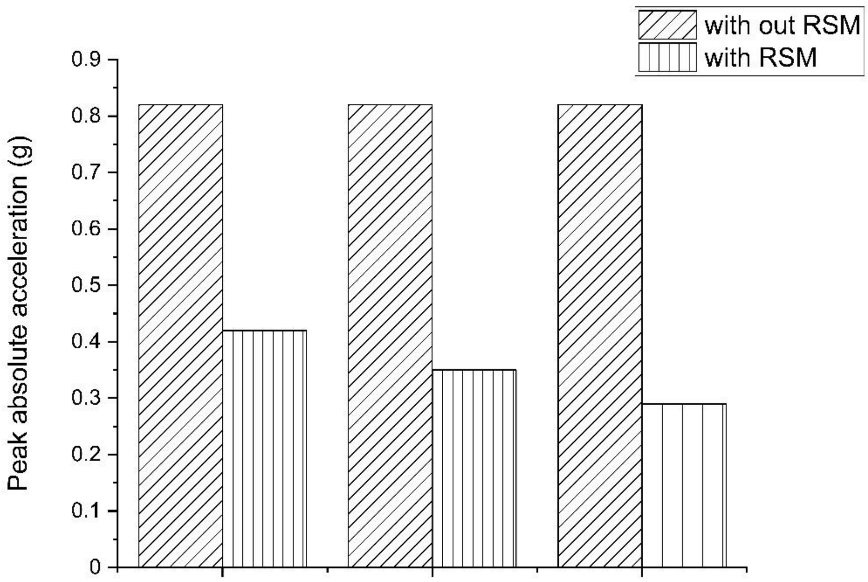

Fig. 4. Comparison of Peak absolute acceleration for 2, 4, 6 units thick RSM layer.

Discussion of the Results. The Model seismic performance is assessed by comparing transmitted acceleration values. The maximum transmitted acceleration to the peak input acceleration value is used to compute amplification factors (AF.). Table 2 summarises the effects of including the RSM layer on accelerations. The percentage decreases in horizontal roof accelerations increased from 48 percent to 64 percent and from 30 percent to 48 percent when the d/B ratio increased to 0.6 from 0.2 for 2-storey and 4-storey building models, respectively. The AF of the 2-storey and 4-storey building models is always lower than the fixed-based ones. Increasing the d/B ratio from 0.2 to 0.6 for two-story and four-story buildings, the AF values drop from 0.52 to 0.35 and 0.70 to 0.51, respectively. De-amplification is achieved in all circumstances using the RSM layer.

3.3 The 1992 Erzincan Earthquake

The ground motion of the 1992 Erzincan Earthquake was chosen for this study. It has a maximum Mercalli intensity of VIII and a moment magnitude of 6.7. and occurs at a depth of 20 km (Severe). The North Anatolian Fault is where it all started.

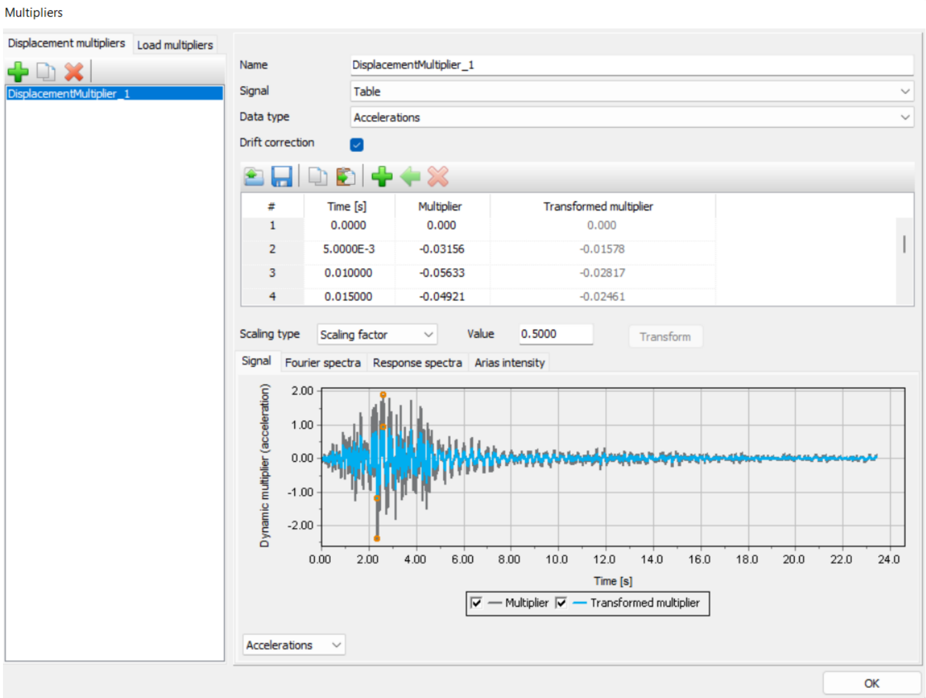

Fig. 5. Synthetic accelerogram Acceleration- Time History in PLAXIS 2D interface.

Table 3. Output Parameter of Erzincan earthquake.

Model	Acceleration(g)		
Synthetic accelero-gram	0.5A amplitude earthquake motion	1A amplitude earth-quake motion	2A amplitude earth-quake motion
Non-Isolated	0.24	0.41	0.85
Isolated	0.18	0.29	0.49
Reduction (%)	20.83	29.13	42.35

Results. When the RSM layer is used, the observed acceleration values are decreased by 20 to 42%. The acceleration measurements recorded at the roof of the isolated building model show a de-amplification. As the amplitude of the applied input motion decreases, the reduction in accelerations measured using the isolation layer decreases. Table 3 summarises the effects of including the RSM layer on accelerations.

3.4 Upland Earthquake

The ground motion of the 1990 Upland earthquake was chosen for this study. On February 28, 1990, the Upland earthquake struck with a maximum Mercalli Intensity of VII (Very strong) and a magnitude of 5.7. West of the San Andreas Fault System, a left-lateral strike-slip earthquake occurred. It occurs at a depth of 10 kilometres.

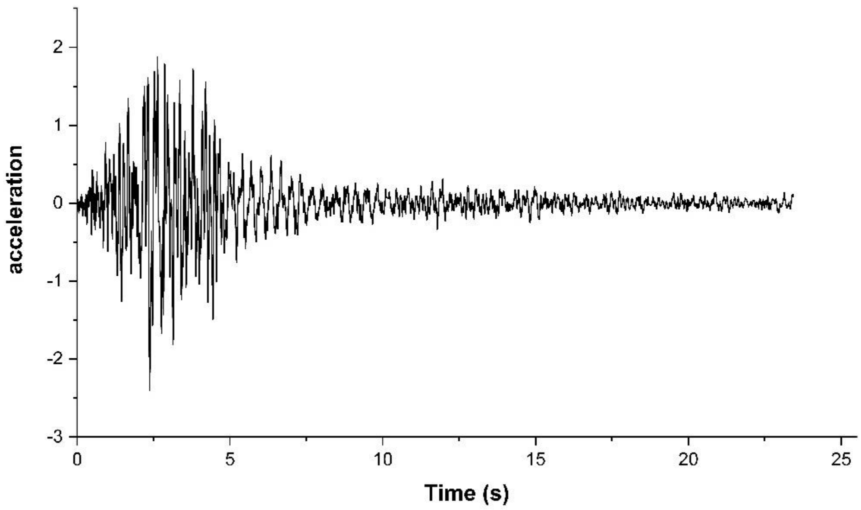

Fig. 6. Time-history of Upland seismic acceleration.

Table 4. Output Parameter of Upland Earthquake.

	Model No.	*d/B*	Number of Storey	Peak Horizontal Acceleration	Reduction (%)	Amplification factor
Non-isolated	Model 1	0	5	0.48		
	Model 2	0.5	5	0.251	47.71	0.52
Isolated	Model 3	0.7	5	0.244	49.17	0.50
	Model 4	1	5	0.232	51.67	0.48

Results. The acceleration responses of each model under the Upland seismic excitations are depicted numerically. The fixed base building model's PGA values are found to be 0.48g. The PGA value at the top of the building on the RSM layer with a thickness of 5 units and an RSM to the width of foundation ratio (d/B ratio) of 1 is 0.251g. The PGA value drops to 0.244g when the RSM layer thickness is increased to 7 units. The PGA value drops to 0.232g when the RSM layer thickness is increased to 10 units.

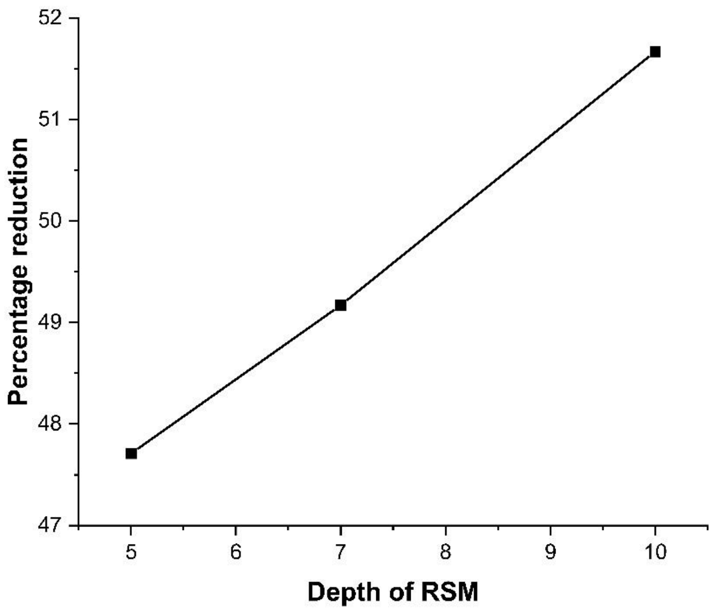

Fig. 7. Percentage Reduction of Acceleration vs Depth of RSM.

Discussion of the Results. The Model seismic performance is assessed by comparing transmitted acceleration values. The maximum transmitted acceleration to the peak input acceleration value is used to compute amplification factors (A.F.). Table 4 summarises the effects of including the RSM layer on accelerations. The percentage decreases in horizontal roof accelerations improved from 47 percent to 51 percent when the RSM layer thickness increased from 5 to 10 units for building models. As observed, the AF of building models is always lower than that of fixed-based models. When the RSM layer thickness for buildings is increased from 5 to 10 units, the AF values drop from 0.52 to 0.48. De-amplification is achieved in all circumstances using the RSM layer.

4 Conclusions

This numerical analysis is performed using PLAXIS 2D for a typical structure with a mixture of sand and shredded rubber tyres as an isolation layer of varied thickness for notable earthquake excitation. The efficiency of the Geotechnical Seismic Isolation system is studied in this study using numerical models that are built. The acceleration measurements made at the model's peak for the isolated building exhibit a de-amplification. As the size of the applied input motion reduced, so did the drop in accelerations recorded by the isolation layer. This study demonstrates that the isolation mechanism used here is quite successful. The isolation mechanism absorbs greater earthquake energy as the more profound the RSM layer is deployed. The system's effectiveness is higher for low-rise buildings and greater RSM depth. Furthermore, the installation process with this technology is much simpler as the original soil is replaced by a modified mixture of sand and shredded rubber tyres beneath the foundation. As a result, utilizing this sort of seismic separation can be a more economical and easier substitute for traditional base isolation procedures for earthquake hazard mitigation.

Based on the analysis results, the isolation system adopted here is highly effective.

- The RSM layer of the tyre-sand combination is capable of absorbing earthquake energy. The deeper the RSM layer is used, the more earthquake energy is absorbed by the isolation system.
- It was discovered that using RSM can successfully reduce the acceleration response at all levels of the building models.
- It was found that changes in the thickness of the RSM layer had the most significant impact on the results for horizontal roof accelerations.
- The performance of the geotechnical seismic isolation system with RSM is affected by the RSM layer's thickness and the intensity of input ground shaking.

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