*Physical Modelling in Geotechnics*


# Investigating performance of rubber-soil mixture as a geotechnical seismic isolation technique using geotechnical centrifuge

W.Y. Hung, T.A. Le & Y.H. Wang
*Department of Civil Engineering, National Central University, Taoyuan, Taiwan (R.O.C)*

C.H. Chen
*Division of Earth Sciences and Geotechnical Engineering, National Center for Research on Earthquake Engineering, Taipei, Taiwan (R.O.C)*

**ABSTRACT:** Rubber-soil mixture (RSM) is a geotechnical seismic isolation technique that uses mixture of tire rubber granulate and soil as base isolator. Rubber is a highly compressible material; it can absorb seismic energy from ground motions to reduce amplitude of seismic waves. Thus, RSM decouples structures from ground motions and prevent seismic waves from propagating to structures, reducing earthquake damage and its components. In this study, rubber-soil mixture was applied to improve the resistance of structure models against seismic motions. Two structure models were placed on a dry sand ground surface. RSM was prepared to surround and underneath the foundation of one structure model with a relative density of 60%. Thickness of the RSM layer was 3 m and the rubber content in RSM was 30% by weight. Test results showed that with the RSM layer, (1) horizontal acceleration at the top of the structure could be reduced up to 30% due to different levels of input motion. (2) The largest lateral displacement of structure could be reduced by 78~82% in 2 Hz shaking events. (3) RSM layer had low impact on permanent lateral displacement of the structure models.

**Keywords:** centrifuge modeling, geotechnical seismic isolation, recycled material, rubber-soil mixture, structural behavior.

## 1 INTRODUCTION

Hundreds of millions of people live under the threat of earthquakes and frequently take unprecedented damages. As in a recent report of the Food and Agriculture Organization of the United Nations (FAO), there are 3.5 million people affected annually by earthquakes.

Earthquake mitigation can help to reduce the casualties potentially caused by earthquakes. Structural mitigation is a common and effective solution used to increase the capacity of structures to resist seismic waves. There are many structural mitigation methods and seismic isolation is one of them. Under this method, a building is protected by isolators that decouple the building from ground motions.

Seismic isolation is a technique with a "cushion layer" between a structure and its foundation for energy dissipation. Some geotechnical materials are used as seismic base isolators in geotechnical seismic isolation.

Rubber-soil mixture (RSM) is a geotechnical seismic isolation technique that uses a mixture of tire rubber granulate and soil as a base isolator. In this withstanding earthquake method, rubber-soil mixture is positioned underneath the foundation of a structure to protect the structure. Rubber absorbs seismic energy of ground motions caused by earthquakes. Thus, RSM is likely to decouple a structure from ground motions and prevent seismic waves from propagating to the structure, reducing earthquake damage to the structure and its components. By using recycled material, the rubber-soil mixture is known as a green and low-cost solution.

This research investigated structure dynamic performance improvement of low-rise buildings during earthquakes. Several tests were conducted using geotechnical centrifuge and shaking table in National Central University.

## 2 LITERATURE REVIEW

In the past decade, several numerical researches were performed to study the effectiveness of RSM. Some numerical simulations showed a significant reduction in seismic response in the structure: RSM was placed around foundations of low-to-medium-rise buildings to reduce seismic demand. The results showed that 50–60% acceleration reduction on the upper structure could be achieved (Tsang 2019). Besides, physical modeling studies regarding this seismic isolation system can help to verify the numerical simulation results from previous studies.

## 3 EQUIPMENT AND MATERIALS

### 3.1 Equipment

The experiments were conducted by NCU geotechnical centrifuge with a capacity of 100g-ton in National Central University (NCU), Taiwan. The NCU geotechnical centrifuge has a nominal radius of 3 m and carried a 1-D servo-hydraulic actuator shaking table. NCU shaking table can operate under 80 g centrifugal acceleration field with maximum payload of 400 kg. It has a nominal shaking force of 53.4 kN, the maximum displacement is ±6.4 mm, and the nominal operating frequency range is 0-250 Hz. A rigid container with inner dimensions of 767 mm × 355 mm × 400 mm (Length × Width × Height) and the fixed boundary was used to contain the model ground.

### 3.2 Materials

Rubber in RSM technique is not natural rubber but recycled rubber created by cutting and shredding waste tires. Whole waste tires are shredded into small pieces known as tire-derived products (cuts, shred, chips, granulate, powder, etc.). Granulate-size rubber and silica sand (Fig.1) were used in this research.

The specific gravity of rubber granulate and silica sand was 1.12 and 2.65. $D_{50}$ of rubber granulate and silica sand was 3.2 mm and 0.19 mm, respectively. Minimum and maximum unit weights of the rubber-soil mixture were 1.25 g/cm$^3$ and 1.35 g/cm$^3$.

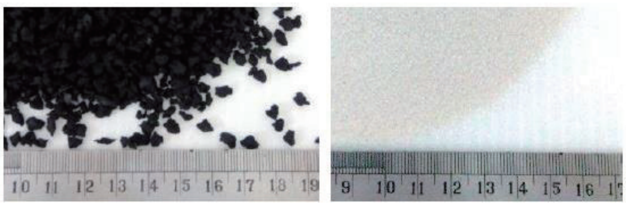

Fig.1. Rubber granulate and silica sand.

## 4 MODEL PREPARATION AND TEST PROCEDURE

### 4.1 Model preparation

A fairly uniform sand bed with a relative density of 80% was conducted by the air pluviation method, which is a simple idea of dropping sand from a higher elevation to a lower surface to create the desired relative density (80%). Sand was pluviated with a constant flow rate into the rigid container. The total thickness of soil layer was 170 mm (10.2 m in prototype scale).

In this study, rubber content in RSM was 30% by weight. In other words, in every 100g of RSM, there was 30g of rubber granulate and 70g of silica sand. RSM layer was formed using a rectangular plastic frame with inner dimensions of 190 mm × 160 mm × 30 mm (Fig.2a), which was printed out by a regular 3D printer. RSM layer was prepared layer by layer and compressed by some handmade wooden tools (Fig.2b) to reach the designed relative density of 60%. (Higher relative density of RSM formed by the employed materials could not be achieved). Plastic frame was carefully removed after a RSM layer (each 10 mm) was completed. The thickness of RSM layer in this test is 50 mm (3 m in prototype scale).

The model configuration is shown in Fig.4, and the raft foundation dimension is 110 mm × 80 mm (Length × Width). The structure models, was composed of aluminum alloy and steel, was 110 mm height. Contact pressure under the foundation of these structure models was approximated to 53 kPa. Several accelerometers (ACC) were attached at different elevations to observe the time history of acceleration during shaking events. Four linear variable differential transformers (LVDTs) were vertically instrumented on two structures and soil surface to record the settlement during after the shaking ceased. Four laser displacement transducers (LDTs) were installed at the side of the container to measure the lateral displacement of these structures.

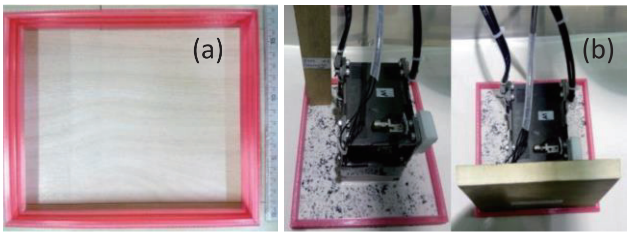


Fig.2. RSM layer preparation tools: (a) 3D printing rectangular plastic frame and (b) compressing RSM by handmade wooden tools.

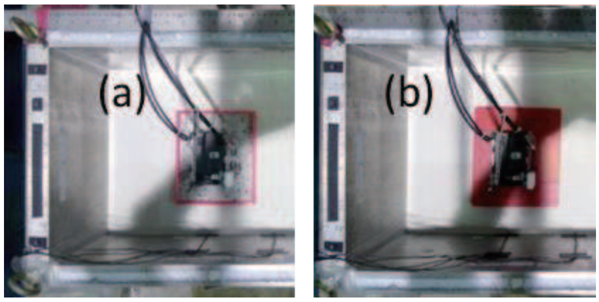


Fig.3. RSM preparation: (a) Using 3D printing frame to form the RSM layer and (b) Covering RSM by lightweight plastic plates.

### 4.2 Test procedure

After the instruments were connected to the acquisition system, the centrifuge spun up to 60 g with 10 g increments step-by-step. The model was subjected to three shaking events (Fig.5) with 2 Hz frequency and the peak base acceleration (PBA) was 0.14 g, 0.19 g, and 0.23 g, respectively. PBA values of the three shaking events, 0.14 g, 0.19 g, and 0.23 g implied, the minor, intermediate, and major levels of the input motions.

 *ISBN 978-89-952197-7-5*

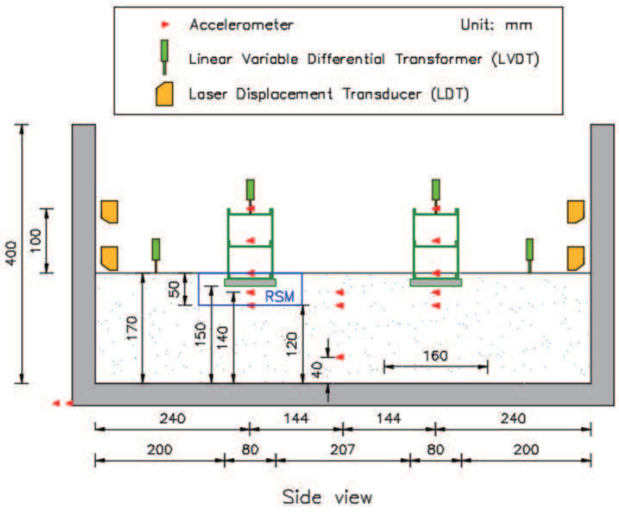


Fig.4. Configuration of the model.

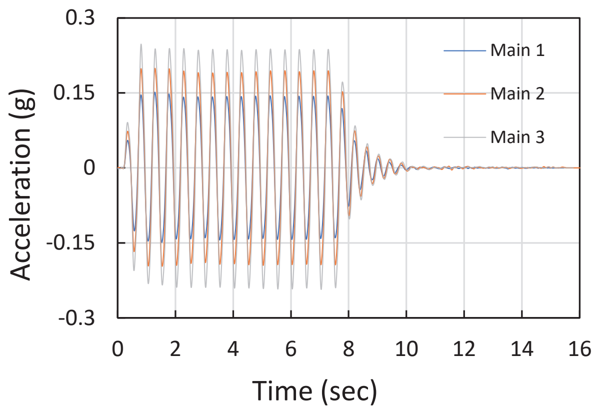


Fig.5. Acceleration time history of three input motions.

# 5 TEST RESULTS

## 5.1 Acceleration time history of the structures

There was a significant difference in acceleration response between the structure with RSM and without RSM in all the shaking events (Fig.6). Based on the acceleration time histories, horizontal ground motions propagate to the upper structure were significantly reduced with the stand of the rubber-soil mixture. Acceleration at the top (at 6 m height) of the structure with the RSM layer was less than 0.08 g while acceleration at the top of the other structure was around 0.12 g in Main1 (PBA=0.14 g). The same behavior of the two structures was also observed in Main2 (PBA=0.19 g) and Main3 (PBA=0.23 g), the accelerations measured at the top of the RSM structure and the other are 1.2 g and 1.6 g, respectively. Fig.7 shows the acceleration amplification factor during Main1 (PBA= 0.14 g). The top of the structures is subjected to 5.3 times and 9 times larger acceleration than input motion with and without the RSM layer. According to the acceleration results, rubber in the mixture absorbed energy from the seismic wave, thus reducing horizontal acceleration around 30%.

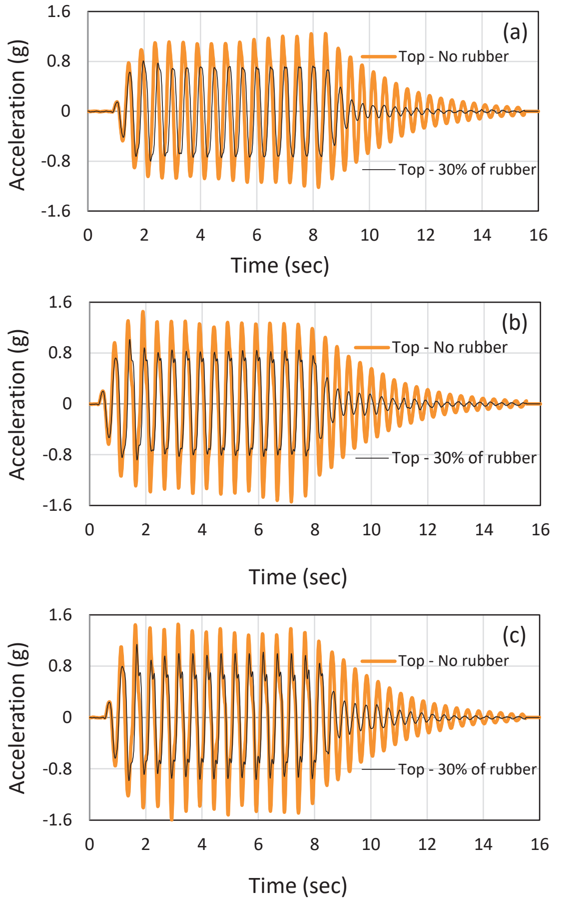


Fig.6. Acceleration time history of the structures (at 6 m height): (a) Main1, (b) Main2, and (c) Main3.

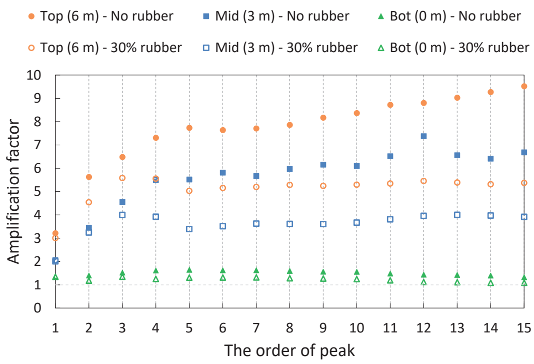


Fig.7. Amplification factor of the structures in Main1.

### 5.2 Lateral displacement of the structures

Laser displacement transducers (LDTs) were used to measure lateral displacements at a high and a low elevation target on the structure models. This study had two types of lateral displacements: largest lateral displacement and permanent lateral displacement. The largest lateral displacement, was recorded during the shaking period of a shaking event, measured the maximum value of lateral displacement. The permanent lateral displacement described final position of the structure models when the shaking period was over.

Test results are shown in Fig.8. The structure with the RSM layer has a smaller value of the largest lateral displacement than the structure model without the RSM layer. The largest lateral displacement of the structures can be reduced by 78~82% in 2 Hz shaking events. As can be seen, the RSM layer has low impact on the permanent lateral displacement.

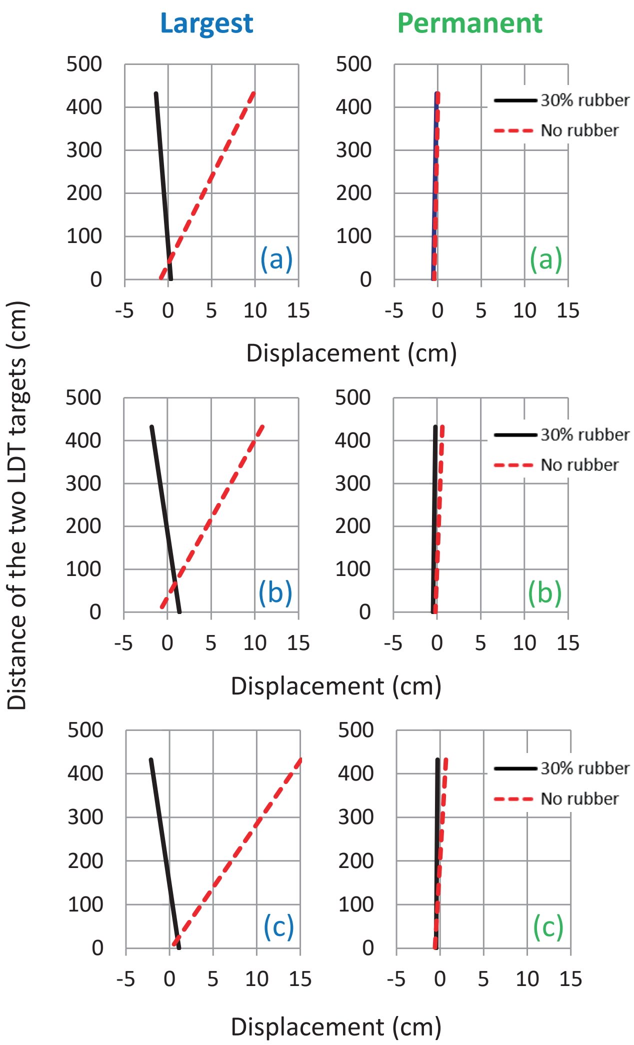


Fig.8. The largest lateral displacement and permanent lateral displacement: (a) Main1, (b) Main2, and (c) Main3.

### 5.3 Settlement of the structures

The settlement of the structures and soil was measured by the linear variable differential transformers (LVDTs). After subjecting to three shaking events, the settlement of the structure with and without the RSM layer was similar and less than 2 cm in the prototype.

## 6 CONCLUSIONS

In this study, a dynamic centrifuge test was performed to investigate the performance and effectiveness of rubber-soil mixture as geotechnical seismic isolation below foundation of some structure models. The impact of RSM layer in reducing horizontal acceleration was displayed in acceleration time histories, while it was proved through acceleration amplification factor. Horizontal acceleration at the top of the structure could be reduced up to 30% due to different levels of input motion. The largest lateral displacement of structure reduced by 78~82% in 2 Hz shaking events with the application of RSM. RSM layer has low impact on the permanent lateral displacement of structure models.

## ACKNOWLEDGEMENTS

The authors would like to express our gratitude for the National Center for Research on Earthquake Engineering and the technical support from the Experimental Center of Civil Engineering, National Central University. These supports made this study and further research possible and efficient.

## REFERENCES

Anastasios, A., Kostas, S., Kyriazis, P., "Small-strain shear modulus and damping ratio of sand-rubber and gravel-rubber mixtures," Geotech Geol Eng, Vol. 30, pp. 363-382 (2012).
Gotteland, P., Lambert, S., Balachowski, L,. "Strength characteristics of tyre chips-sand mixtures," Studia Geotechnica & Mechanica, Vol. 27, pp. 55-66 (2005).
Juan, B.S., John, M., Daniel, B., Marina, M., and Aikaterini, M., "Dynamic behaviour of shredded rubber soil mixtures," 16th European Conference on Earthquake Engineering (2018).
Kostas S., Anastasios A., Kyriazis P., "Dynamic properties of dry sand/rubber (SRM) and gravel/rubber (GRM) mixtures in a wide range of shearing strain amplitudes," Soil Dynamics and Earthquake Engineering, Vol. 33, pp. 38-53 (2012).
Tsang, H.H. and Kyriazis, P. "Mechanism of geotechnical seismic isolation system: Analytical modeling," Soil Dynamics and Earthquake Engineering, Vol. 122, pp. 171-184 (2019).
Tsang, H.H., Tran, D.P., Hung, W.Y., Kyriazis, P., and Gad, E.F., "Performance of geotechnical seismic isolation system using rubber-soil mixtures in centrifuge testing," Earthquake Engng Struct Dyn, pp. 1-19 (2020).
Tsiavos, A., Alexander, A.N., Diambra, A., Ibraim, E., Vardanega, J.P., Alicia, G.B., and Sextos, A., "A sand-rubber deformable granular layer as a low-cost seismic isolation strategy in developing countries: Experimental investigation," Soil Dynamics and Earthquake Engineering, Vol. 125 (2019).