Seismic Response of Buildings Resting on Geosynthetics Reinforced Sand Bed

M. V. Sreya(✉), B. R. Jayalekshmi, and Katta Venkataramana

Department of Civil Engineering, National Institute of Technology Karnataka, Surathkal, Mangalore 575025, India
sreya56vellur@gmail.com, brjaya@nitk.edu.in

Abstract. An earthquake is a significant disaster that destroys structures all over the world. The structure must be designed to resist the impacts of the earthquake. The present study analyzes the efficacy of an Ultra-High Molecular Weight Polyethylene (UHMWPE) liner to lower the amount of seismic energy conveyed and the dynamic response of buildings. Finite element simulation of the transient response of an integrated soil isolation-building system in which buildings are resting on a raft in medium dense sand beds, with and without a soil-seismic isolation system, has been performed with the help of a recorded accelerogram of the El Centro (1940) earthquake. Two sets of space frame building models (two and three storey) of single bay reinforced concrete frames have been considered to estimate seismic response. UHMWPE thickness has been varied from 0.0064 m to 0.15 m to investigate its impact on peak acceleration at building roof levels. The analysis results indicate that earthquake vibration energy transmission to the superstructure is limited by the use of a UHMWPE liner, as a soil isolation medium and the thickness of the soil isolation liner significantly influences the building response during an earthquake ground motion.

Keywords: Soil isolation-building system · Raft-foundation · UHMWPE · Finite element modeling

1 Introduction

A major disaster that destroys structures all around the world is an earthquake. The building should be built to withstand the earthquakes, or else the seismic isolators should be used to mitigate such destructive effects and provide safe environmental conditions. There are two types of seismic isolation systems: structural and soil isolation. In structural isolation, the lateral movements of the structure are isolated from that of the soil by a flexible mechanism between the structure and the foundation, reducing the damaging effects of earthquakes on the structure and its contents. But in soil isolation, earthquake energy is absorbed by soil-reinforced material before it reflects in the structure.

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There are so many seismic isolation methods available from previous research (Kavazanjian 1991; Kolathayar 2018). Yegian et al. (2004) examined the provision of smooth synthetic liners below the foundation or within the soil at a distance below the ground to dissipate seismic energy by sliding; and the provision of rubber sand mix (RSM) layers around and below the foundation of the structures to function as a cushion (Tsang 2008). Economic seismic isolation techniques can help countries where adequate resources and technology are not well developed to reduce the severity of earthquakes. Seismic isolation techniques that use geotechnical strategies are referred to as 'geotechnical isolation'.

Initially, Hushmand and Martin (1991) examined the benefit of using a geosynthetic reinforced isolation device to lower seismic responses of the superstructure. Yegian and Lahlaf (1992) investigated the dynamic shear strength property of nonwoven geotextile and geomembrane materials. Dynamic friction coefficients at the geomembrane and soil interfaces were also analyzed by Yegian et al. (2004). An experimental test on synthetic materials interfaces while those placed below the foundation to act as foundation isolation was performed by Yegian and Kadakal (2004).

It is noted from the literature review in this field that the isolation efficiency of geomembrane in the soil is studied before, but the effect of thickness of the membrane is not yet addressed.

2 Proposed Scheme of Soil Isolation

In geotechnical engineering, finding a high-quality equivalent soil reinforcement material that can operate as seismic isolation is difficult. The solution to such problems is the provision of specific lightweight isolation materials. The soil isolation technique suggested in this study is the application of ultra-high molecular weight polyethylene as a geo-material. When traditional structures rest directly on a non-isolated soil bed, all the energy of the incoming seismic vibrations is transmitted to the superstructure.

In the current study, 2-storey and 3-storey, three-dimensional RC framed models were modeled to evaluate the variation in seismic response at the roof of buildings rest on conventional and reinforced soil beds. Table 1 shows the parameters of the medium dense sand used in the model.

Structures with a 4 m bay length and a 3 m storey height built of RC frames were taken into consideration. And, 300 × 300 mm cross-sections were adopted for the building frames. The live load was set to 3 kN/m^2, and the floor finishing load was set to 1 kN/m^2. The size of the soil layer was 55 m × 55 m with a depth of 25 m. Raft foundation was provided with a dimension of 5 m × 5 m × 0.5 m. Table 1 shows the properties of soil, concrete, and geomembrane (Nanda 2017). The isolated soil-structure model used in this study is depicted in Fig. 1.

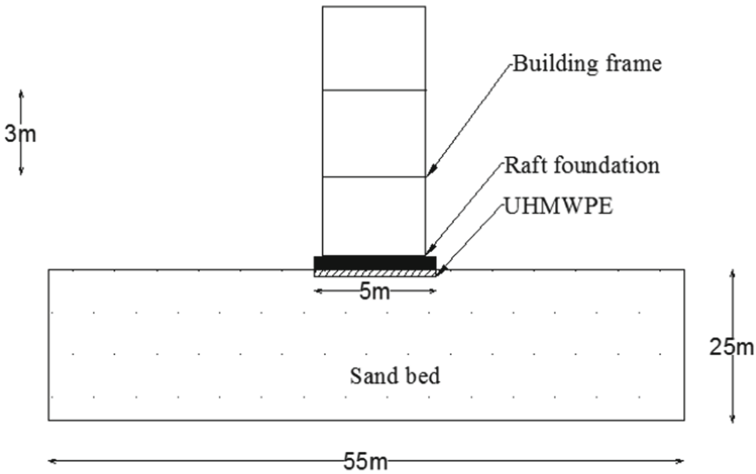

Fig. 1. Schematic illustration of the model.

3 Numerical Modeling

The three-dimensional finite element model of the structural systems was generated and the wave propagation was modeled in ANSYS software. SOLID 185, an eight-node first-order linear integration element was selected to discretize both the soil medium and raft foundation. This element is beneficial for convergence in contact analysis. The building frames were modelled using the BEAM188 element, a 2-node beam element that has linear behaviour. The bending behaviour of geomembrane under load was modeled with SOLSH190 element, three-dimensional finite strain 190 element. The geomembrane was laid down immediately at the bottom of the raft foundation for a width of B, where B is the width of the foundation. The depth of the geomembrane liner was obtained as the optimum value from the analysis.

In seismic analysis, soil bed having infinite lateral boundaries plays a significant role. Therefore, non-reflecting boundaries should be used to prevent waves from reflecting into the model. To fulfill this purpose, viscous boundaries were introduced on the lateral faces. The bottom of the underlying soil was restrained against the horizontal and vertical movement, resulting in a rock effect at the bottom boundary. To account for the frictional resistance at the interface of UHMWPE and sand, the frictional behaviour was modelled with the help of target and contact elements. At the sand-geomembrane contact, a value of 0.5 was given to the dynamic friction factor. Figure 2 shows the finite element soil-structure system model done in Ansys.

Table 1. Material properties used for soil-structure model

Properties of material	Geomembrane	Sand	Concrete
Density (kg/m^3)	930	1840	2500
Modulus of elasticity (MN/m^2)	750	55	25000
Poisson's ratio	0.3	0.3	0.15

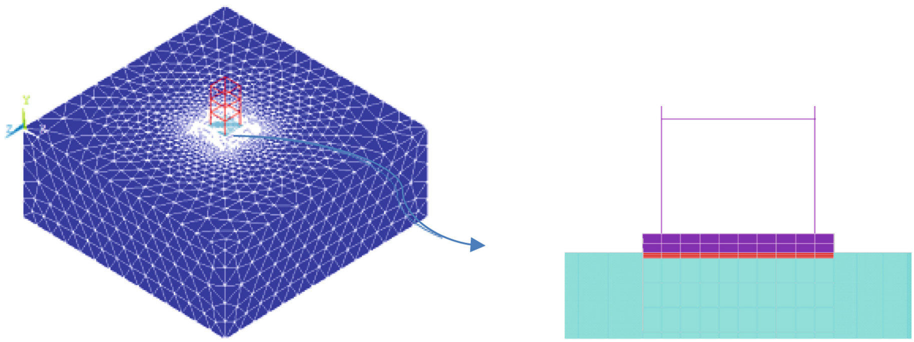

Fig. 2. 3-D finite element model of 2-storey building.

4 Seismic Analysis

The El Centro Earthquake accelerogram recorded at Imperial Valley on May 18, 1940, scaled to 0.3 g PGA was considered as the input ground motion to the soil medium. Figure 3 illustrates the recorded acceleration input time history. Using this recorded

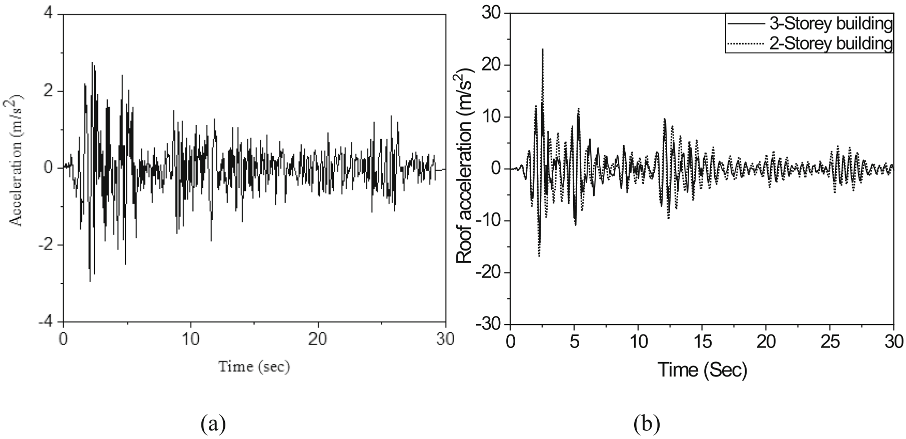

Fig. 3. (a) Acceleration time history of input ground motion (b) Roof acceleration response of 2-storey and 3-storey building on isolated (reinforced with UHMWPE) soil.

accelerogram, the soil isolation approach with varying thicknesses of UHMWPE was numerically examined. UHMWPE of different thicknesses such as 0.0064 m, 0.05 m, 0.0125 m, and 0.15 m were used in the dynamic simulation. Under the seismic ground motion, the structural response of 2-and 3-storey buildings was evaluated and compared in both conventional and isolated soil conditions. Since the bending moment, as well as shear force exerted in the base column of the structure, are proportional to the roof acceleration in the building, roof acceleration is the significant responsive structural quantity to assess the efficiency of the isolation system.

5 Results and Discussions

The study investigates the efficacy of UHMWPE liner as a seismic isolation material and the effect of variation in the thickness of this material in reducing the building responses by evaluating the seismic response in three-dimensional finite element models of RC building-foundation-soil system with and without soil-isolation. The peak acceleration responses under seismic loading were estimated at the roof of buildings. It is noted that compared to the 3-storey building, the seismic response observed in the 2-storey building is more (Fig. 3b). Figure 4a and 4b depicts the reduction in seismic energy transferred to the structure in both isolated case and conventional soil cases. The variation in the seismic responses in 2-storey and 3-strorey buildings under the same earthquake motion is obtained because of the difference in the natural frequency of structures. When the natural frequency of input motion matches with the natural frequency of structures, higher responses will be observed in the structures (Resonance).

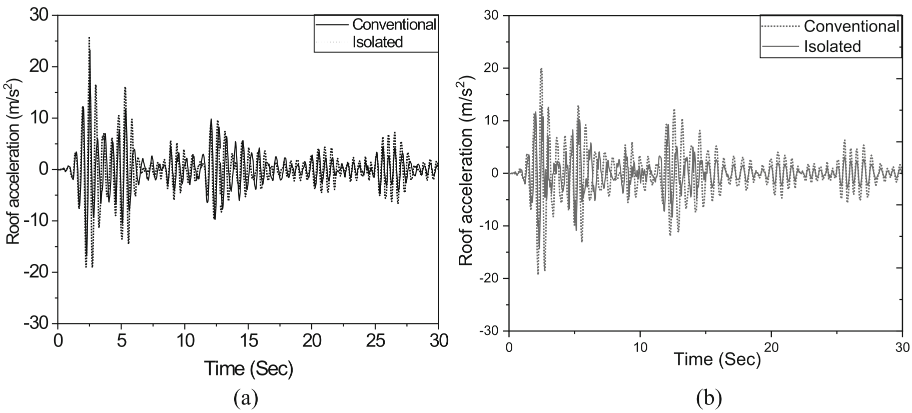

Fig. 4. Roof acceleration response in buildings for both isolated (reinforced with UHMWPE) and conventional soil cases; (a) 2-storey building (b) 3-storey building.

Figure 5 shows the influence of variation in the thickness of UHMWPE on the seismic behavior of 2-storey and 3-storey buildings under ground motion. As the thickness increases, acceleration decreases both for 2-storey and 3-storey buildings. It is found that the highest reduction in roof acceleration is observed with 0.15 m thick UHMWPE in the isolated case. In an isolated soil model with UHMWPE reinforcement, an almost 30% reduction in the magnitude of maximum acceleration at the roof is seen compared to the conventional model and that was obtained with 3-storey building.

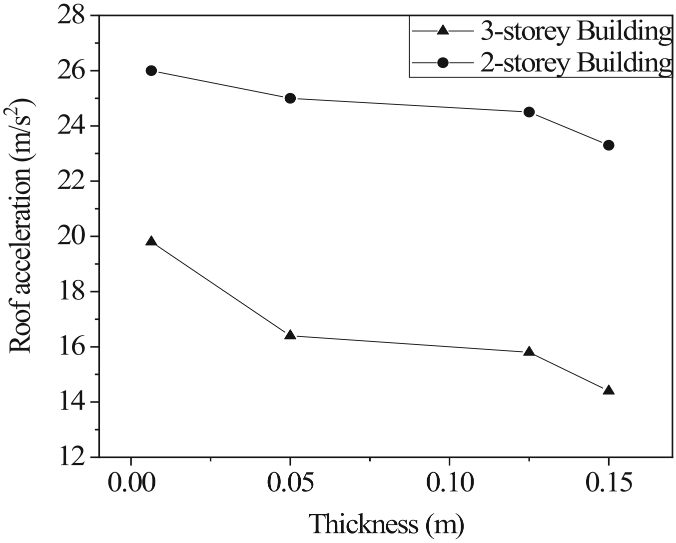

Fig. 5. Variation in the peak roof acceleration response in building with different thickness of UHMWPE for 2-storey and 3-storey buildings.

6 Conclusions

The present numerical analysis investigates the effect of seismic isolation with geomembrane (UHMWPE) placed under the foundation as isolation material. The efficacy of the technique of soil isolation is demonstrated by performing a finite element transient analysis of three-dimensional soil-structure systems in ANSYS. Here are the conclusions derived from the study:

- The geosynthetic reinforced soil shows the potential to lower maximum roof acceleration by an average of 30% compared to a conventional building.
- On the top of both 2-storey and 3-storey buildings, the highest reduction in acceleration was obtained with a 0.15 m thick UHMWPE reinforced in soil.
- Seismic isolation with the soil reinforcement by geomembrane is thus proposed as an easy and effective method to reduce the adverse effects of earthquakes on buildings compared to the conventional base-isolation techniques available.

References

Hushmand, B., Martin, G.R.: Layered soil-synthetic liner base isolation system. Final Report, NSF Small Business Innovation Research Program (1991)

Kavazanjian, E., Hushmand, B., Martin, G.R.: Frictional base isolation using a layered soil-synthetic liner system. In: Proceedings of the 3rd US Conference on Lifeline Earthquake Engineering. Published by ASCE (1991)

Kolathayar, S.: Vibration isolation of foundation using HDPE and natural geocells - a review. In: Choudhury, D., El-Zahaby, K., Idriss, I. (eds.) Dynamic Soil-Structure Interaction for Sustainable Infrastructures. GeoMEast 2018. SUCI. Springer, Cham. https://doi.org/10.1007/978-3-030-01920-4_7

Nanda, R.P., Dutta, S., Das, A., Khan, H.A.: Geosynthetic liner as foundation isolation for seismic protection. Int. J. Geosynthetics Ground Eng. **3**(3), 1–7 (2017). https://doi.org/10.1007/s40891-017-0098-2

Taylor, A.W., Igusa, T. (eds.): Primer on seismic isolation. ASCE Publications (2004)

Tsang, H.H.: Seismic isolation by rubber-soil mixtures for developing countries. Earthq. Eng. Struct. Dyn. **37**(2), 283–303 (2008)

Yegian, M.K., Catan, M.: Soil isolation for seismic protection using a smooth synthetic liner. J. Geotech. Geoenviron. Eng. **130**(11), 1131–1139 (2004)

Yegian, M.K., Kadakal, U.: Foundation isolation for seismic protection using a smooth synthetic liner. J. Geotech. Geoenviron. Eng. **130**(11), 1121–1130 (2004)

Yegian, M.K., Lahlaf, A.M.: Dynamic interface shear properties of geomembranes and geotextiles. J. Geotech. Eng. **118**(5), 760–779 (1992)

Yegian, M.K., Lahlaf, A.M.: Geomembranes as base isolation. Geosynthetic fabric report. J. Geotech. Eng. **4**(18), 643–645 (1992)

Yegian, M.K., Lahlaf, A.M.: Dynamic interface shear strength properties of geomembranes and geotextiles. J. Geotech. Eng. **118**(5), 760–779 (2004)