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Modern Aseismic Applications of Geosynthetic Materials

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Abstract: Geosynthetic materials have great potential of use in civil engineering projects. A wide range of their applications in geotechnical, environmental, transportation and hydraulic fields has been developed during last decades. Beside these known functions, some modern concepts of applications are also proposed. Geosynthetic materials can be used as base isolation systems to protect structures against earthquakes. All these applications are emanated from the specific dynamic properties of geosynthetic materials. This paper describes on modern aseismic applications of these materials and reviews experimental studies carried out through shaking table tests. Based on the outcomes of this study, geosynthetic materials can be properly used in civil structures as seismic isolators providing suitable protection against seismic actions.

Keywords: geosynthetic materials; geosynthetic interfaces; aseismic applications; dynamic properties; seismic loading

1. INTRODUCTION

Geosynthetics are manmade materials used in soil-based works. With the advent of polymers in the middle of the 20th century, the geosynthetic materials as stable and durable planar products manufactured from synthetic polymers became available [1]. The polymeric nature of geosynthetics causes properly use of them in ground. Geosynthetic materials consist of eight main categories: geotextiles, geogrids, geonets, geomembranes, geosynthetic clay liners, geofoam, geocells and geocomposites. Geotextiles and geomembranes are the largest and most diverse groups of geosynthetics. A wide range of geosynthetics applications in geotechnical, environmental, transportation and hydraulic fields has been developed to achieve technical and/or economic benefits during last decades. Lower cost, simpler installation and ability to partly or completely replace natural resources such as gravel, sand, bentonite clay, etc. cause geosynthetics used in many areas of civil engineering [2]. Main routine functions of geosynthetincs in various fields of civil engineering projects can be summarized to separate soil layers, to provide a drainage for soil mass, to reinforce soil masses, to filter as controlling the transport of solid particles within the soil, to act as a flow barrier [3]. Erosion control and environmental protection are also the other general advantages of geosynthetics. None-corrosive, minimum volume, high flexibility, ease of storing and transportation, lightness, environment-friendly solution, speeding in construction process and high resistant to degradation are other properties of geosynthetics [4]. These materials were first applied as filter in the 1960s in United States and as reinforcement in Europe [1].

In the early 1990s, a novel approach of geosynthetics applications was developed by Hushmand and Martin [5] and Kavazanjian et al [6]. Geosynthetic interfaces were employed as foundation isolators. The geosynthetic interface as base isolator can reduce the peak intensity of motions above the interface and shift the predominant period of the response of the overlying structure [2]. The idea beyond this concept is to form a flexible, smooth and sliding layer including geosynthetic-geosynthetic layers under a mass by which a part of seismic energy is significantly dissipated through friction of two types of geosynthetic layers when lateral dynamic force is applied to system and the rest is dissipated through allowed slips [7]. Many experimental and analytical studies were performed to investigate the behaviour of soils modified by geosynthetic interfaces through shaking table tests. Preliminary shaking table tests on geomembrane-geotextile interface showed that using geosynthetics to isolate a structure (or a block on shaking table) from seismic energy incomes had great promise. In fact, geosynthetic liner described here makes a discontinuity between shaking table and overlying structure as well as other routinely used seismic isolators. Results of building model placed on a geosynthetic liner show proper potential of the liner as an energy absorbing system at which response of building can be significantly reduced. In this regard, dynamic properties of geosynthetics are key parameter to provide a properly seismic performance of them as base isolator. Therefore, the important property to develop geosynthetic interfaces as foundation isolation is their coefficient of friction. This coefficient should be small to reduce the transmitting energy through interface. Generally, favourable foundation isolation concept is achieved worldwide in high and also low seismicity regions when friction coefficient is between 0.05 and 0.15. In addition, friction coefficient should not be affected factors such as air conditions, normal stress, sliding distance and velocity to simplify introduction of foundation isolation in designing [8].

2. ASEISMIC ISOLATION WITH GEOSYNTHETIC LINERS

Fig. 1 represents two types of isolation systems made up of geosynthetic liners proposed by Kavazanjian et al. [6]. The first system includes a Single Layer Synthetic Liner (SLSL) system at which geosynthetic liner in contact with a HDPE geomembrane liner are placed directly beneath of building foundation. A Layered Synthetic Liner-Soil (LSLS) system where a soil layer is placed between two geomembrane layers is the second system. The authors conducted a series of shaking table tests on a rigid block with different four combinations of geosynthetic interfaces including a glued geosynthetic to the bottom of the block and a second geosynthetic material secured to the top of the shaking table. Fig. 3 shows schematically the test facility [9].

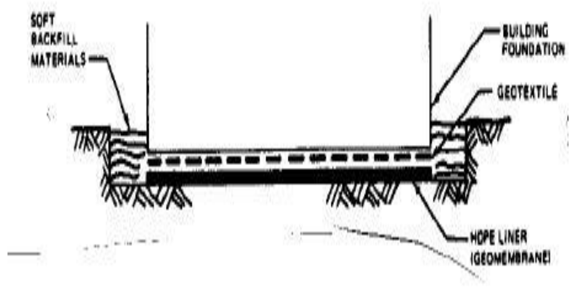


Figure 1. Application of geosynthetic liner base isolation: Single Layer Synthetic Liner (SLSL) system [6].

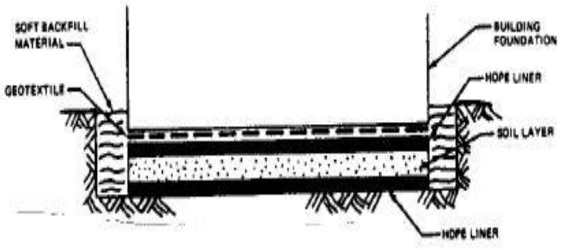


Figure 2. Application of geosynthetic liner base isolation: Layered Synthetic Liner-Soil (LSLS) system [6].

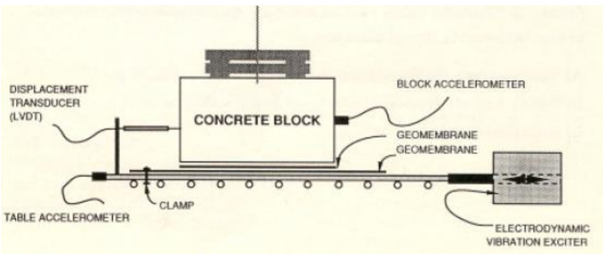


Figure 3. Shaking table facility under the geosynthetic isolator [9].

Yegian et al. [10] presented schematic drawing of a typical building founded on soil, on conventional base isolator and on geosynthetic foundation isolator as shown in Fig. 4. Through cyclic load tests the Ultra High Molecular Weight Poly Ethylene (UHMWPE) geomembrane-nonwoven geotextile interface with friction coefficient equal to 0.07 was identified to be ideally suited for foundation isolation. Fig. 5 shows a comparison of the model responses with and without foundation isolation applying Santa Cruz record scaled to 0.35g. In the case of foundation isolation, a reduction of 60% of peak acceleration at the roof level respect to faxed base condition is observed. In addition, results of column shear force ratio versus base acceleration subjecting three records were presented upon which at a base acceleration of 0.4g, the column shear force in the building model on UHMWPE-geotextile liner was 35% of that corresponding to a fixed base structure. This demonstrates the excellent energy absorption capacity of UHMWPE/geotextile interface.

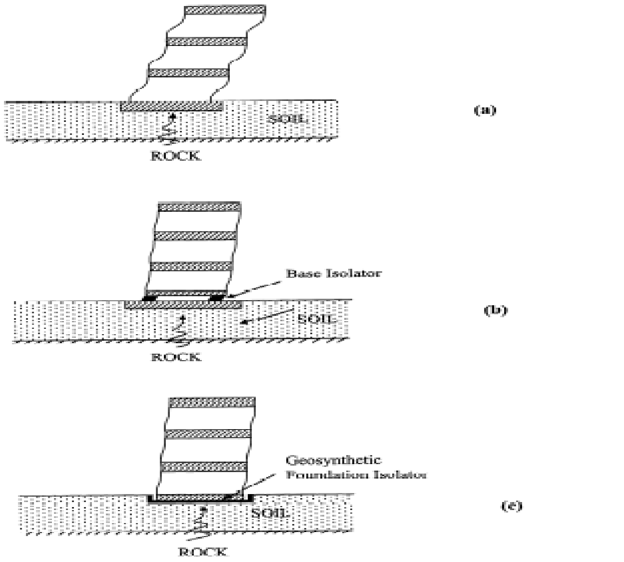


Figure 4. Seismic response of a typical building (a) founded on soil, (b) with base isolation and (c) with geosynthetic foundation isolation [10].

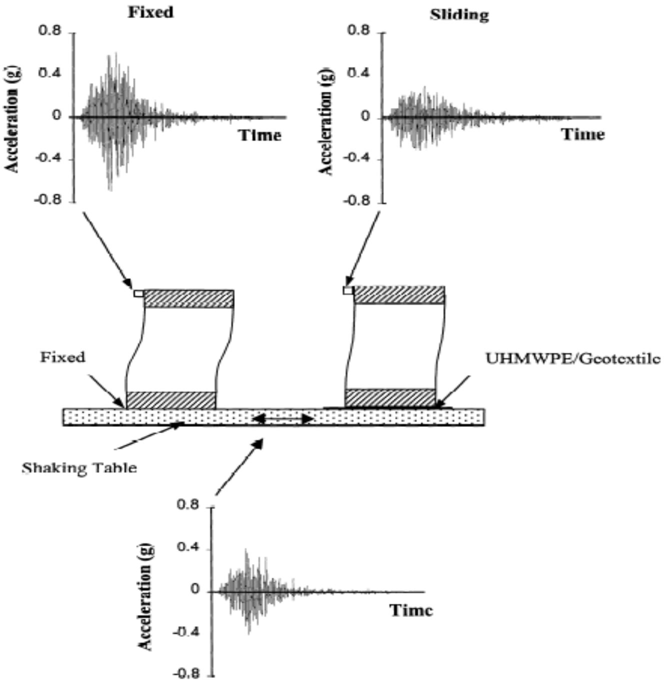


Figure 5. Comparison of the model responses with and without foundation [10].

After these initial studies in which the fundamental dynamic characteristics of geosynthetic isolated systems were determined and their potential applicability for seismic isolation was verified, more detailed tests were needed on liners composed with different combinations of different types of geomembranes and geotextiles to determine the most suitable combination. Such an investigation was conducted by Yegian and Kadakal [11]. They explored a scheme to use of the smooth synthetic liner immediately underneath of foundation of a structure which was referred to as "foundation isolation" as shown in Fig. 6. Based on shaking table tests it was revealed that the Typar 3601 type geotextile placed over UHMWPE geomembrane let to minimum friction coefficient. Hence, the interface would provide the maximum reduction in the earthquake induced forces. Different cyclic load tests were carried out to evaluate the effect of number of cycles, normal stress and sliding velocity on the four different combinations of interfaces. Results showed that the only combination which was nearly independent of the all mentioned parameters together with the minimum friction coefficient was geotextile-UHMWPE interface. As shown in Fig. 7 rigid block test set up was prepared to apply harmonic and earthquake type excitations on determined interface. Under different frequencies of harmonic loads the acceleration after the slip point (0.08g) did not increase with increasing table acceleration.

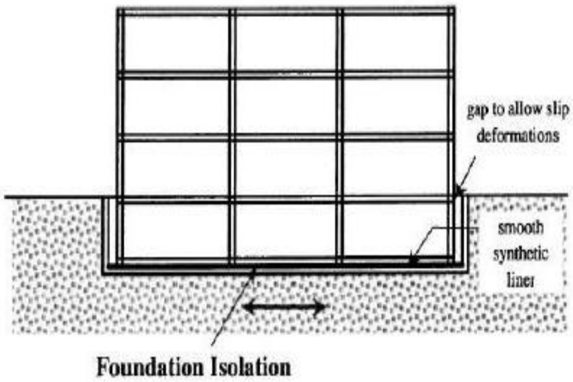


Figure 6. Foundation isolation for seismic protection of buildings using smooth synthetic liner [11].

Figure 7. Rigid block test setup [11].

Yegian and Catan [8] demonstrated another scheme in which the liner is placed within the soil rather than just below the building and named this system as "soil isolation" as shown in Fig. 8. As can be seen, cylindrical-shaped and tube-shaped configurations were appropriate for this approach. Laboratory test setup of cylindrical-shaped interface is also shown in Fig. 8 for the cylindrical-shaped system.

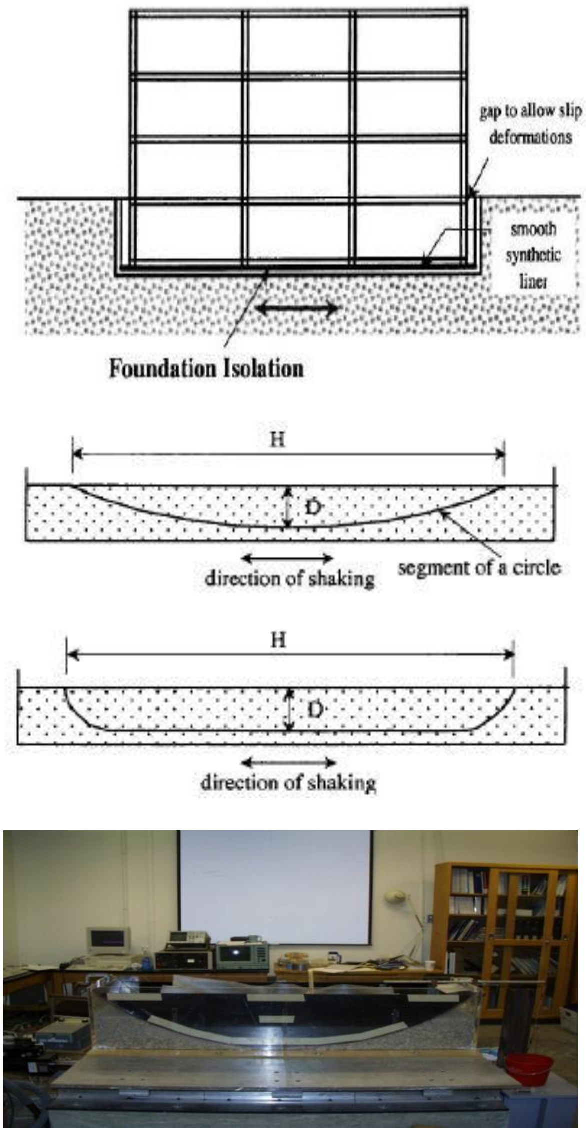
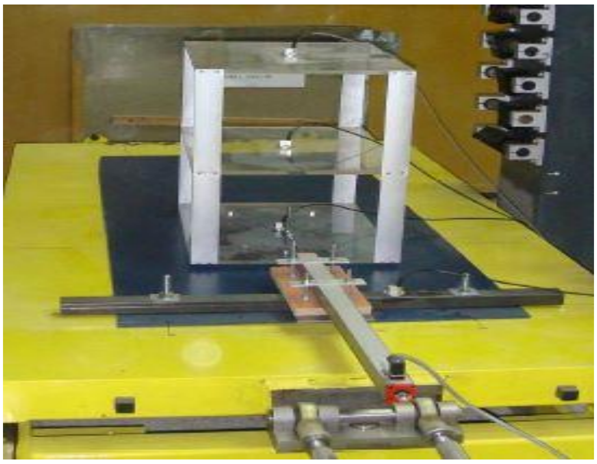


Figure 8. cylindrical- and tube- shaped Soil isolation for seismic protection of buildings [8].

A nonlinear finite difference time domain analysis using the computer program FLAC was conducted by Arab [12]. Experimental results of previous studies were favorably compared to numerical model analyses calculated for a geomembrane-geotextile lined base isolated block on a horizontal plane. A good agreement was observed. Kalpakci [13] then experimentally studied dynamic response of 3 story and 5 story isolated model-scale structures shown in Fig. 9 with composite liner composed of geotextile over UHMWPE geomembrane under both harmonic and earthquake motions. Based on the results, as expected, use of composite liner system provided a significant reduction in the accelerations and inter-story drift ratios.



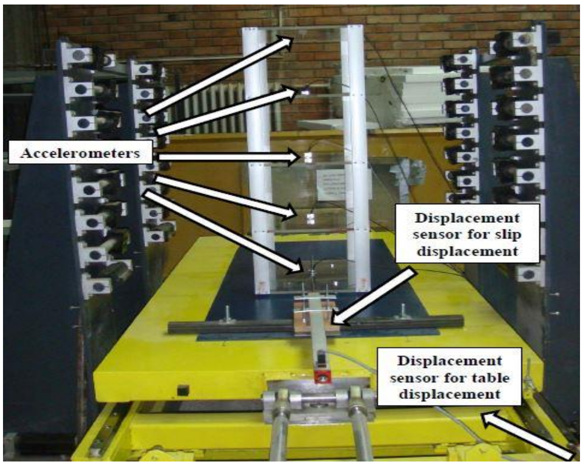


Figure 9. The test setup for the 3- and 5- story model structures isolated by geosynthetic liners [13].

A detailed numerical study was also presented by Tsantis et al. [14]. The finite element model built in ABAQUS is shown in Fig. 10. Results showed favorable effect of application of synthetic isolation system.

3. ASEISMIC ISOLATION WITH RUBBER-SOIL MIXTURES

A similar approach compared to aseismic isolation with geosynthetic liners is the rubber-soil mixture, also known as rubber-soil cushion [15 and 16]. In addition, such an approach can be accompanied by the means of sleeved piles [17].

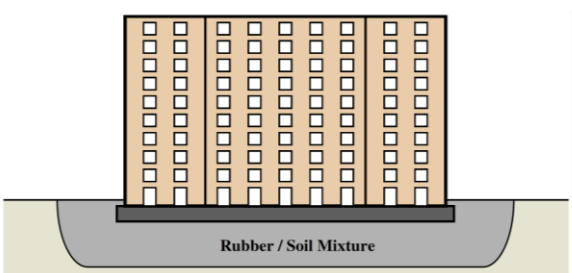


Figure 10. Rubber-soil cushion [16].

Fig. 10 shows the schematic of rubber-soil mixture for aseismic isolation, when the improvement by the means of using sleeved piles is also shown in Fig. 11.

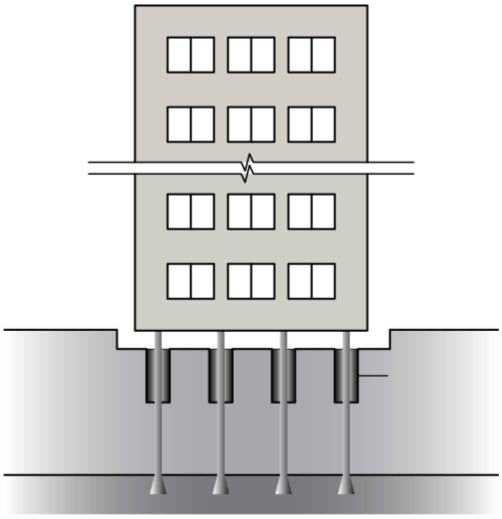


Figure 11. Sleeved piles accompanied by rubber-soil mixture to isolate buildings from ground motions [17].

4. CONCLUDING REMARKS

Geosynthetics can be used for earthquake protection of structures. Geosynthetic liners make the sliding possible under the structure and reduce the hazardous effects of earthquakes. A similar approach is to mix underlying soil with granular rubber, which can be accompanied by sleeved pile for more efficiency. Alternative models and further improvements in this field are expected due to the usefulness of geosynthetics for aseismic isolation.

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