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Numerical and Experimental Studies of Seismic in-Soil Isolation of MSW Landfill by Geosynthetic Liners: Case Study of Kahrizak Landfill,Tehran, Iran

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ABSTRACT: The purpose of municipal solid waste landfills (MSWLF) is to dispose non-recyclable materials, gas extraction, composting, and controlling of pollutants that threaten human health and the environment, and finally providing useful areas after filling. Since Iran is located on the seismic belt and has experienced some high intense earthquake, the study of the Tehran's MSWLF landfill known as the Kahrizak landfill is important. Seismic loads may damage MSWLF through the relative movements within the waste, bottom lining system, cover system, foundation, and interfaces. The smooth synthetic materials might be placed beneath the structures to provide seismic protection by absorbing the imparted energy of earthquakes through the sliding mechanism. In the present study, experimental investigations were conducted in order to evaluate role of in-soil base isolation on seismic response of the Kahrizak MSW landfill. Shaking table tests were conducted on the MSW embankment isolated by semi-elliptic shaped liners and subjected to harmonic sinusoidal base excitations. Furthermore, the behavior of the physical shaking table model was investigated by numerical modeling. The results of the isolated and non-isolated cases are compared in terms of permanent displacement and seismic response. In this study, a good agreement was found between the results of the physical model and the large scale numerical model. Studies have shown that the use of a composite liner system with a further reduction in the friction coefficient results in a significant reduction in the amount of acceleration and displacement, and can protect the structure in seismic conditions. This method did not show a significant effect on the landfill settlement. The efficiency of this technique increases with increasing the amplitude of input motion employed in the current study. It was also observed that employing flat liner leads the movement of the ridge to the sides; and the concave liner prevents the wedge to move excessively.

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1. Introduction

Recent advances in municipal solid waste (MSW) management including safe burial process, different kinds of synthetic liners, and leachate collection systems (LCS) require precise assessment of load-induced deformations. Permanent displacement on the crest or side faces of MSW landfill may cause undesirable leakage which might contaminate groundwater [1-5]. The U.S. federal regulations for MSW landfills specify that the waste landfills located in seismic zones should be designed to withstand against the transmitted accelerations [6]. Seismic evaluation of solid waste landfills requires assessment of the earthquake-induced sliding displacement of the system. The seismically induced permanent displacement is a useful design index since it indicates the potential damage of MSW landfill during an earthquake. The resulted displacement and probable failures can damage the liner, and/or disrupt the function of the cover, or leachate, drainage, and gas collection systems. Seismic response of the landfills at Los Angeles area such as the Operating Industries Inc. (OII) landfill during the Northridge 1994 earthquake has provided valuable opportunities to examine the seismic performance of geosynthetic-lined landfills. The most common damage pattern was surficial cracks in the cover soil and changes in the landfill geometry [7]. Post-earthquake reconnaissance surveys indicate that the geomembrane liner system in one of the landfills at Los Angeles area suffered significant damage [8].

The United States Environmental Protection Agency [6] has indicated that new landfills which are located in certain seismic impact zones with more than 10% chance of exceedance for peak ground acceleration of 0.1 g in 250 years should be designed to withstand earthquake [9]. This definition covers about half the area of the United States and more than two-thirds of the territory of Iran. Seismic base isolation is a design concept that presumes decoupled response of structure from the potentially damaging earthquake ground motions. Fundamental period of the isolated structure can be several times greater than that of the superstructure [10]. In this regard, base isolation reduces seismic wave propagation into the structure. The key parameters that describe the performance of an isolated base structure are the maximum relative displacement between the structure and the ground. The influence of low shear strength in many geosynthetic interfaces supplies the feasibility of waste mass sliding with respect to lithified earth material for the site and, hence, the seismic hazard mitigation costs will effectively be reduced by base isolation technique. Yegian and Kadakal [11] conducted a suite of uniform sinusoidal loading tests at frequencies of 1, 2, 3, and 5 Hz with acceleration amplitudes varying from less than 0.1–0.7 g. The geotextile/ultrahigh molecular weight polyethylene (UHMWPE) interface showed a constant coefficient of friction independent of loading

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frequency, normal stress, and velocity of sliding [11].

The daily produced MSW in the Tehran city, with the population of more than 10 million, has caused major problems in the case of waste disposal. Since the existing landfill in southern Tehran (known as Kahrizak landfill) was not planned for the present rate of population growth (16%), its capacity might be inadequate for the future waste disposal. However, seismic stability analysis of the landfill was not suitably addressed while it is located in southern central Alborz mountain ranges which include several faults with considerable seismic hazards (e.g., [12]).

2. Methodology

In the present study, a geotechnical borehole was drilled on hill No. 65 in field phase and then physical composition, moisture content, and density of waste layers were estimated by examination of the acquired Shelby samples. Subsequently three sets of shaking table experiments have been conducted on the Kahrizak MSW contaminants in non-isolated condition and isolated by the semi-elliptic shaped liner where the liner has been induced by synthetic harmonic motion.

Seismic response of the model has been examined to evaluate the adequacy of base isolation for seismic protection of geosynthetic-lined MSW embankments. Results of geotechnical and geophysical site investigations in the Tehran's landfill area are presented in details. Subsequently, numerical modeling and validation procedure were carried out by recorded responses during experimental shaking table outputs and FLAC 2D software. The geomembrane sheets are modeled as structural beam elements with zero moment of inertia and with interface elements on both sides of the beam to represent the geosynthetic elements of the containment system. The present numerical model is used to parametric study of the Landfills.

3. Results and Discussion

Many researchers have suggested a slippery layer beneath the structures to provide in-soil base isolation for seismic demand reduction. In the current study, the potential for the use of a smooth synthetic liner is treated experimentally and numerically to reduce earthquake horizontal ground motions propagating through the waste mass profile. A series of shaking table tests were conducted on embankments constructed by the Tehran Kahrizak's MSW landfill materials in order to clarify the efficiency of in-soil base isolation technique. Results of the experiments indicated that the models with base isolation transfer considerably lower shocks to the upper layers than those without base isolation. Use of geomembrane sheets as a base isolation component reduced the interface friction angle; however, the cohesion was still considerable. Moreover, employing semi-elliptic shaped liner was caused the stability of mass to be increased by the prevention of mass throwing

Subsequently, numerical models showed that the prototype model leads to better results than a small scale model. The reason for the undesirable performance of the small scale numerical model can be searched for in a real stress level. In this paper, a parametric study was conducted and variables like stiffness of the MSW material, aging of MSW, friction angle of the interface, etc. were studied.

4.Conclusions

In the present paper, the effect of seismic base isolation on dynamic response and permanent displacement of landfills were investigated in field, laboratory and numerical phases. The results showed that the strong motions were amplified during the propagation from the bed to the crest of landfill, where resulted accelerations were larger than yielding acceleration of the probable rupture wedges into the waste mass. Using the geosynthetic liner with a slippery interface affected the amount of transient acceleration and frequency content of the transposed motions. Thus, the following results are obtained, in summary:

(1) The base isolation mechanism reduces the level of transmitting acceleration and seismic displacements by reducing the friction coefficient.

(2) Cohesion and high friction coefficient reduce efficiency of base isolator, In other words, reducing the shear strength of slippery interface, leads to reducing horizontal displacement and crack width.

(3) Increase of compaction effort and shear modulus (Gmax), reduces the quantity of amplification and total relative displacements significantly.

(4) Fresh wastes have the maximum value of spectral amplification in the crest and as the age of the wastes increases, the spectral amplification of acceleration decreases. At the same time, the total displacement and crack width increase in both isolated and non-isolated states.

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