Seismic Response of Landfills with Geosynthetic Liners

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ABSTRACT: Geosynthetic liners can have important effect on the seismic response of a landfill. Slip deformations occurring along a geosynthetic interface can limit the earthquake energy transmitted to the overlying waste or soil. A dynamic response analysis procedure is described in which a geosynthetic liner is replaced by an equivalent soil layer. The dynamic material properties of the equivalent soil layer were developed such that the response of the layer to earthquake excitation is similar to that of the geosynthetic liner it replaces. An example landfill cross section is analyzed using equivalent soil layers representing geosynthetic liners and the earthquake-induced accelerations within the landfill are calculated. The results obtained from the dynamic response analysis, that included the geosynthetic liners are compared with those that ignored the liners. It is demonstrated that smooth HDPE geomembrane/geotextile liners significantly reduce the landfill acceleration, beyond an input base acceleration of 0.2g. Hence, a dynamic response analysis that assumes a complete shear transfer through the geosynthetic liners (not allowing slip) can significantly overestimate landfill accelerations. Such overestimation of landfill accelerations can lead to unrealistic values of landfill side slope displacements.

KEYWORDS: Friction Layer, Geomembranes, Geotextiles, Landfills, Seismic Design

1 INTRODUCTION

Earthquake ground motions when propagating through a landfill can induce permanent deformations of the waste fill, and slip displacements along geosynthetic liners used as impervious barriers. Such potential deformations, if excessive, can compromise the integrity of a landfill. To safeguard against this environmental hazard, in the U.S., federal regulations have been formulated that address the seismic vulnerability of new landfills.

The calculation of earthquake-induced permanent deformations of a landfill requires the investigation of the dynamic response of the landfill. In engineering practice, wave propagation analysis is performed to estimate the accelerations and shear stresses within the landfill that is experiencing a design level earthquake motion. In such an analysis, the presence of geosynthetic liners within the landfill cross section poses a significant challenge. Kavazanjian et al. (1991), Yegian et al. (1992), and Zimmie et al.(1994) have demonstrated that under dynamic excitations geosynthetic interfaces can transmit limited shear stresses. Stresses larger than this limiting level will induce slip displacements along the geosynthetic interface. In current engineering practice, to simplify the dynamic analysis of a landfill, the presence of geosynthetic liners is generally ignored. This practice effectively assumes that there is no slip induced along the liners during a seismic event. As will be illustrated in this paper, this assumption can lead to significant overestimation of the earthquake-induced shear stresses in a landfill, leading to unrealistic estimates of permanent deformations of the landfill.

This paper presents a brief description of a model that can be used to represent the dynamic response of geosynthetic liners in wave propagation analysis of landfill cross sections. The paper includes an example analysis of a landfill. A discussion of the results is included to demonstrate the effect of the geosynthetic liners on the seismic response of the landfill.

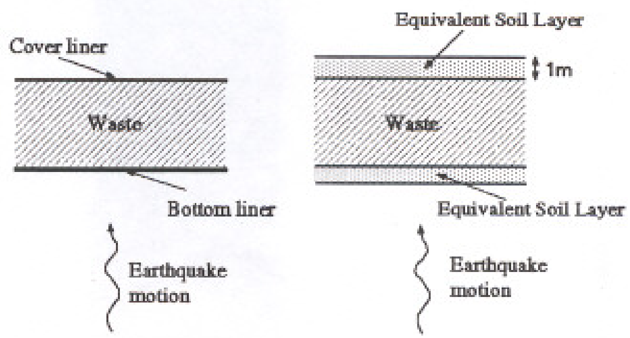

Figure 1. a) Waste fill with cover and bottom liners, b) Equivalent soil layers that replace the liners in dynamic response analysis.

2 MODELLING OF GEOSYNTHETIC LINERS

In engineering practice, the dynamic response of a landfill cross section is investigated, typically by considering a one-dimensional column of layered soil/waste fill profile. The earthquake-induced accelerations and shear stresses in each layer are computed using the equations that govern wave propagation through elastic media. The computer program SHAKE is commonly used for this purpose. In this SHAKE

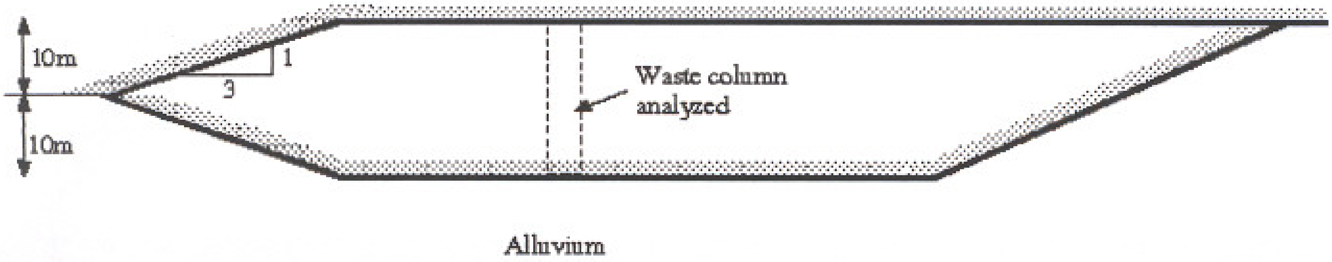

Figure 2. A simple landfill cross section analyzed to demonstrate the effect of geosynthetic liners on seismic response

analysis, the shear modulus and damping of each soil or waste fill layer are used together with the layer thickness and material unit weight. An earthquake motion is then specified, typically at the base of the landfill or at a nearby outcropping of rock, and the accelerations and the shear stresses within the landfill profile are calculated.

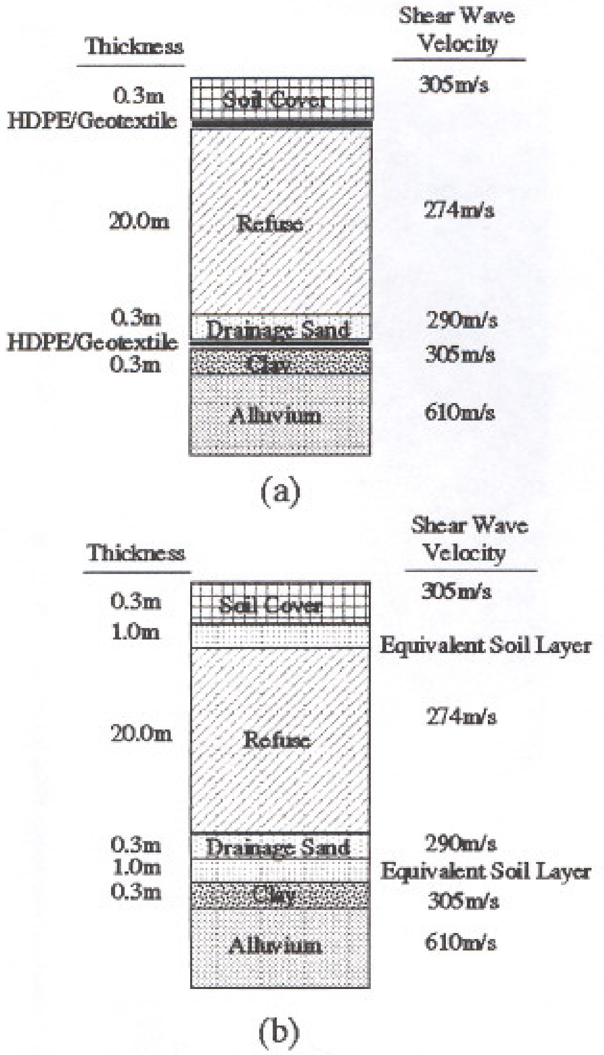

Figure 3. a) Soil/waste column analyzed, b) equivalent soil layers representing geosynthetic liners

To allow the performance of dynamic analysis of landfill cross sections that include geosynthetic liners ,a model has been developed by (Yegian at al. 1996) that can represent the dynamic response of the liners in the analysis. Figure 1a shows a schematic diagram of a simple landfill profile consisting of a layer of waste fill, and cover and bottom geosynthetic liners. In Figure 1b, the same profile is shown except that the liners are replaced by equivalent soil layers that have identical dynamic response characteristics as the liner interfaces as measured in shaking table tests. The use of equivalent soil layers permits the dynamic response analysis of a landfill to be performed easily with the computer program SHAKE.

To illustrate the application of the procedure and to demonstrate the potential effects of geosynthetic liners on the dynamic response of landfills, the following example landfill is investigated using the equivalent soil layer model.

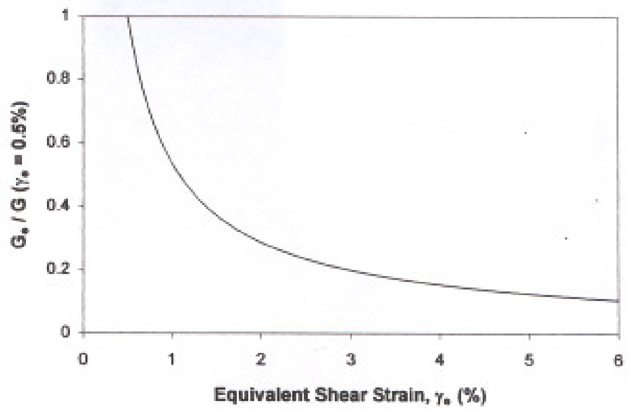

Figure 4 Shear modulus of equivalent soil layer normalized with respect to G_e at $\gamma_e = 0.5\%$

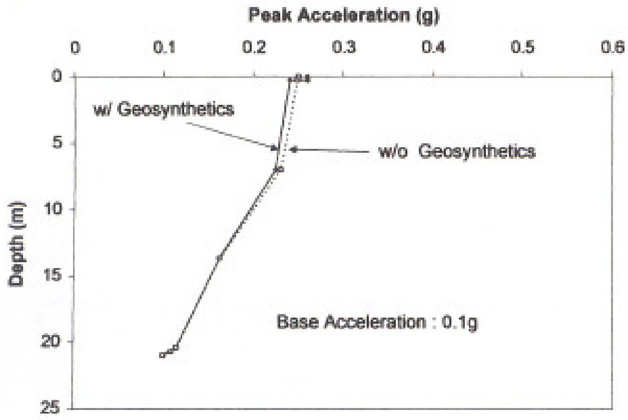

Figure 5. Peak accelerations with depth of landfill calculated with and without geosynthetic liners, and base acceleration of 0.1g

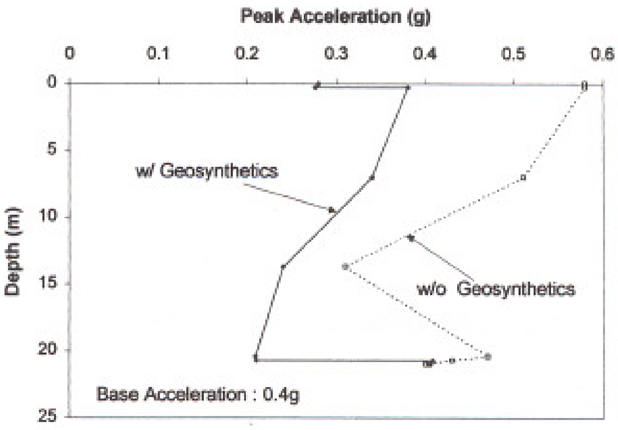

Figure 6. Peak accelerations with depth of landfill calculated with and without geosynthetic liners, and base acceleration of 0.4g

3 EXAMPLE ANALYSIS OF A LANDFILL

Figure 2 shows a simple cross section of a landfill with cover and bottom geosynthetic liners. The dynamic response of this landfill profile was investigated by selecting a one-dimensional column as shown in Figure 2. The layer thickness and material properties of the landfill column are shown in Figure 3. In this landfill column, the geosynthetic liners (smooth HDPE geomembrane /geotextile) are replaced by equivalent soil layers. Figure 4 shows the equivalent shear modulus versus shear strain curve (of the selected interface) normalized by the shear modulus at an equivalent shear strain of 0.5%. In this example analysis the equivalent shear modulus at a shear strain of 0.5% were 8622kN/m^2 and 210kN/m^2 for the bottom and cover liners, respectively.

Using the equivalent shear moduli of the two liners and a damping ratio of 0.43, as determined from shaking table tests, the dynamic response of the landfill column was performed using the SHAKE program. The earthquake motion from the 1988 Spitak earthquake was normalized to 0.1g and 0.4g and used as input at the base of the landfill. Figure 5 shows the computed peak accelerations (with and without considering the geosynthetic liners) as a function of depth when the input earthquake motion had a peak acceleration of 0.1g. The results show that the presence of the geosynthetic bottom and cover liners has no discernible effect on the acceleration within the landfill. This is not surprising because shaking table tests by Yegian and Harb (1995) show that slip deformations along smooth HDPE geomembrane/geotextile interfaces occur only at accelerations larger than about 0.2g. Hence, if landfill accelerations are less than 0.2g, ignoring the presence of smooth HDPE geomembrane/geotextile liners in the dynamic analysis of a landfill is reasonable.

Figure 6 shows peak accelerations, with and without geosynthetic liners, computed using an input motion scaled to 0.4g. In this case, the bottom and cover geosynthetic liners have played an important role in modifying the earthquake motion propagating through the landfill. For example, the acceleration at the base of the waste fill is 0.47g, if the geosynthetic liners are ignored in the analysis. Including the liner responses by using equivalent soil layers reduces the acceleration at the base of the waste fill by a factor of 2, to about 0.21g. Similarly, if the liners are ignored the acceleration on top of the landfill is 0.58g, and if the liners are included 0.28g. Clearly, when the base acceleration is larger than 0.2g, slip occurs along the geosynthetic liners thus limiting the accelerations transmitted through the liner interfaces. Ignoring this can unreasonably overestimate the landfill response.

Figure 7 summarizes the results of the dynamic analysis with and without considering the geosynthetic liners. The average acceleration of the waste fill is a parameter of importance in the calculation of the permanent deformations of the waste fill, and in the estimation of slip displacements along the side slope. In the example where the base acceleration was 0.4g, the average acceleration of the waste fill is about 0.46g, if the liners are ignored, and about 0.3g if the liners are modeled in the dynamic response analysis of the landfill. These values of the average accelerations of the waste fill were used to calculate slip displacements along the side slope of the example landfill. The procedure of Yegian and Harb (1995) was used for the calculation of the side slope slip, assuming that the liner is an HDT geomembrane/geotextile. The results again indicate that ignoring the dynamic response of the geosynthetic liners can lead to unrealistically large slip displacements (21 inches). Whereas, including the liner response the slip displacement on the slope is estimated to be less that an inch($<$ 1 inch)

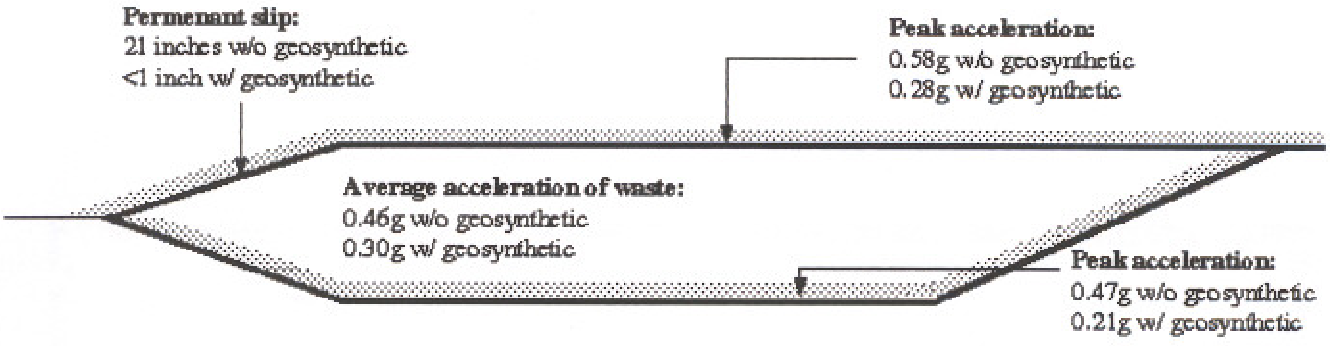

Figure 7. Results from seismic analysis of the example landfill showing the effect of geosynthetic liner on the landfill accelerations and side slope slip deformations

4 SUMMARY

To perform realistic analysis of the seismic response of a landfill it is very important that geosynthetic liners are properly modeled. Beyond an acceleration of 0.2g, slip displacements may occur along geosynthetic liner interfaces. This paper presents a model that can be used to represent the dynamic response of smooth HDPE geomembrane/geotextile liners in the seismic analysis of landfills.

Example analysis of a simple landfill profile is presented. The results demonstrate that smooth HDPE geomembrane/geotextile liners significantly reduce the accelerations and shear stresses transmitted through the landfill profile, especially when the base acceleration exceeds 0.2g. Ignoring these effects can result in unrealistic estimates of seismic accelerations, shear stresses and permanent deformations in a landfill.

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