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Development of geomembrane strains in waste containment facility liners with waste settlement☆

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A B S T R A C T

The development of tensile strains in geomembrane liners due to loading and waste settlement in waste containment facilities is examined using a numerical model. Two different constitutive models are used to simulate the waste: (a) a modified Cam-Clay model and (b) a Mohr-Coulomb model. The numerical analyses indicate the role of the slope inclination on the maximum geomembrane liner strains for both short-term loading (immediately post closure) and long-term waste settlement. A geosynthetic reinforcement layer over the geomembrane liner is shown to reduce the maximum geomembrane liner strains, but the strain level of the geosynthetic reinforcement itself may become an engineering concern on steeper slopes (i.e., greater than 3H:1V) for cases and conditions examined in this paper. The paper considers some factors (e.g., slope inclination, use of a high stiffness geosynthetic over the geomembrane liner) and notes others (e.g., the designer selection of interface characteristics below and above the geomembrane, use of a slip layer above the geomembrane) that warrant consideration and further investigation to ensure good long-term performance of geomembrane liners in waste containment facilities.

1. Introduction

Barrier systems involving a geomembrane liner as part of a composite liner are widely used in the base of waste containment facilities to minimize contaminant escape to groundwater and surface water (Rowe et al., 2004; Rowe, 2005). The liner system is usually overlain by a leachate collection and removal system. Over the past decade, much work has been done on the design and behaviour of leachate collections systems (e.g., Cooke and Rowe, 2008a, 2008b; McIsaac and Rowe, 2006, 2008; Yu and Rowe, 2012, 2013; Rowe and Yu, 2012, 2013a, 2013b, 2013c). Also, there has been considerable work on the components of the composite liner such as the geomembrane (e.g., Abdelaal et al., 2014b; Saheli and Rowe, 2016; Jones and Rowe, 2016; Rowe et al., 2016b; Kavazanjian et al., 2017; Rowe and Shoaib, 2017a,b; Touze-Foltz et al. 2016a,b; Saheli et al., 2017; Yang et al., 2017; Koerner et al., 2017) and GCL (e.g., Bannour et al., 2016; Chai et al., 2016; Malusis and Daniyarov, 2016; Shackelford et al., 2016; Ali et al., 2016; Rouf et al. 2017a,b,c; Bouazza et al., 2017; Lu et al., 2017; Setz et al., 2017), as well as on the interface behaviour for composite liners (e.g., Fox and Stark, 2015; Tano et al., 2017), the field performance of liners (e.g., McWatters et al., 2016; Gallagher et al., 2016; Rentz et al., 2016; Rowe et al., 2016a, 2017; Touze-Foltz et al. 2016a,b), and the interaction between the drainage layer and the geomembrane liner in terms of local strains induced by the drainage materials (e.g., Brachman and Gudina, 2008a, 2008b; Dickinson and Brachman, 2008; Brachman and Sabir, 2010, 2013; Hornsey and Wishaw, 2012; Sabir and Brachman, 2012; Rowe et al., 2013; Eldesouky and Brachman, 2018) for different geomembrane protection layers. It has been shown that tensile strains are critical to longevity of the geomembrane and should be kept below 5% by use of a suitable protection layer (e.g., Abdelaal et al., 2014a; Ewais et al., 2014). However, as important as local indentations are, they are only one potential source of tensile strain. Another key source is strains developed on slopes and at present there is very limited research regarding the performance evaluation and design of geosynthetic liner systems during waste filling and after closure of waste containment facilities.

Snow et al. (1994) reported a field case using the geosynthetic liner system in the Lopez Canyon Landfill in Los Angeles, California, USA where a geonet was placed over the geomembrane resulting in an interface with a much lower interface friction than any interfaces below the geomembrane. The purpose of introducing this slip surface was to allow the interface between the geonet and geomembrane to slip when waste settles and thus to minimize the tensile strains (loads) generated in the geomembrane. The potential advantage of the use of a

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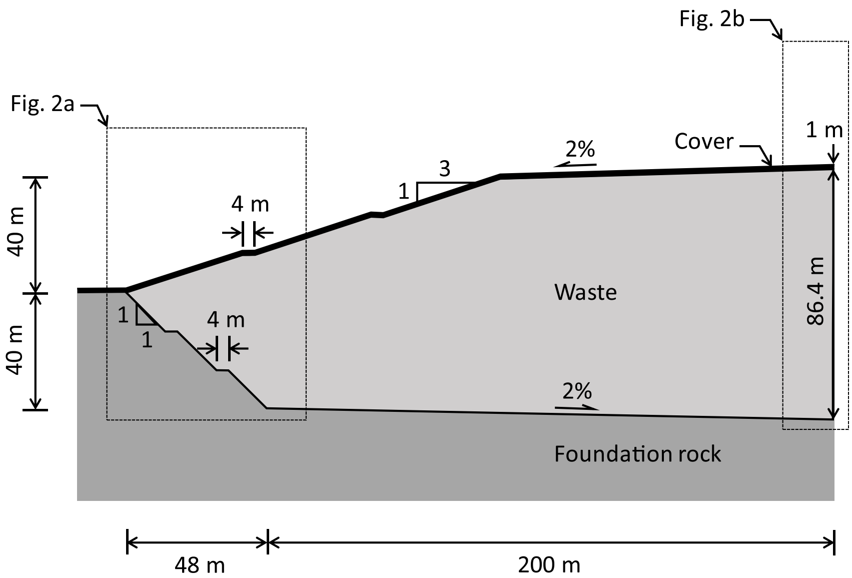

Fig. 1. Base case landfill profile with a slope inclination of 1H:1V and two 4-m wide intermediate benches below the ground surface (average 1.2H:1V including benches).

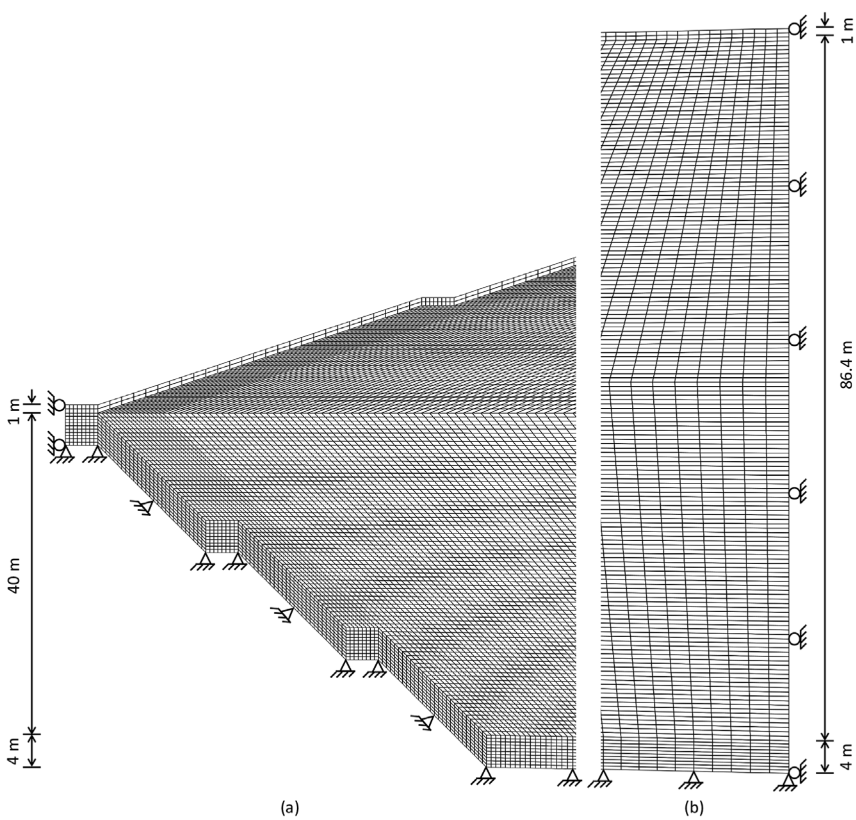

Fig. 2. Example of numerical mesh for base case landfill profile on (a) left and (b) right side of the model.

preferential slip surface approach by providing an interface above the geomembrane with a shear strength less than any interface shear strength below the geomembrane has been recognized (e.g., Cowland et al., 2006; Thiel et al., 2014). Thiel et al. (2014) further proposed an enhanced method by using a veneer-reinforcement layer with enough tensile strength and stiffness above the primary geomembrane liner and below the slip layer to resist the downdrag shear force generated by waste settlement. However, the interaction between the veneer-reinforcement layer and geomembrane was not explicitly considered and the geomembrane strains were not evaluated by Thiel et al. (2014).

The geosynthetic liner system can fail even during waste filling. A well documented example is the slope failure of the waste at the Kettleman Hills Landfill where the tear and/or multiaxial tensile break strength of the geomembrane was exceeded causing liner failure which was associated with waste lateral displacements and surface depressions of as much as 10.7 m and 4.3 m, respectively (e.g., Seed et al., 1990; Mitchell et al., 1990; Byrne et al., 1992). This represents an extreme case of a slope stability failure. This risk is now well recognized and considered in good designs. However, slope stability failure is not the only cause for concern. A facility which is "safe" from a slope stability perspective, has the potential to fail in the long-term due to environmental stress cracking at strains well below the yield strain.

Although geosynthetic liner systems are used in most modern waste containment facilities, reported field experiments associated with the performance of geosynthetic liner systems are limited (Villard et al., 1999; Zamara et al., 2014), and field performance data such as