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Geomembrane strains from wrinkle deformations

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ABSTRACT

Methods to compute geomembrane strains caused by the deformation of a geomembrane wrinkle when subject to vertical overburden stress are examined. Thin shell theory, small strain–displacement, and large strain–displacement methods are developed to compute geomembrane strains from wrinkle deformations. The implementation of each method is validated for three hypothetical trial cases against results obtained with finite element analysis. It was found that it is necessary to employ large strain-displacement theory and explicitly consider both vertical and horizontal components of wrinkle displacement to compute strain. Results are then presented from six physical experiments where the vertical and horizontal components of wrinkle displacement were measured under simulated landfill base liner conditions. For the particular conditions tested, it was found that without a thick sand protection layer on top of the geomembrane, the largest calculated tensile strain due to wrinkle deformations of 8% was much less than the tensile strain caused by overlying gravel particles, and thus local strains from gravel contacts would govern in the assessment of maximum geomembrane strain; whereas, with a thick sand protection, the maximum tensile strain was from wrinkle deformations, but the measured values were below a proposed long-term allowable strain of 3%.

1. Introduction

Wrinkles are out-of-plane buckles that may develop in high-density polyethylene (HDPE) geomembranes (GMs) during installation from restrained thermal expansion caused by solar exposure (Pelte et al., 1994; Koerner et al., 1999; Rowe et al., 2004; Giroud, 2005; Take et al., 2007; Chappel et al., 2010). Fig. 1 illustrates a wrinkle in a geomembrane. The primary implication of wrinkles in geomembranes is increased leakage through any small holes that are located at, or near, the wrinkle because of essentially unopposed lateral flow beneath the width and length of the wrinkle (Rowe, 1998, 2005; Rowe et al., 2004).

Wrinkles do not disappear when buried beneath overburden material (e.g., a granular leachate collection system and municipal solid waste). In terms of the deformed shape of the wrinkle and the fate of the gap beneath the wrinkle, both Soong and Koerner (1998) and Gudina and Brachman (2006) showed that with sand above and below the geomembrane wrinkle, the height and width of the wrinkle decreased, but the gap beneath the wrinkle remained – even for vertical stresses as large as 1100 kPa. Gudina and Brachman (2006) found that when compacted clay (CCL) is below the geomembrane wrinkle (e.g., as in Fig. 1), in addition to a decrease in wrinkle height and width, the gap beneath the wrinkle could be eliminated, depending on the applied pressure and water content of the clay, because of extrusion of clay into the low stress region beneath the wrinkle. With a geosynthetic clay liner (GCL) on top of a firm sand foundation beneath the geomembrane wrinkle, Brachman and Gudina (2008a) reported wrinkle deformations that were more similar to the case with sand below the geomembrane but, additionally, the GCL itself could experience local changes in thickness, as quantified by Dickinson and Brachman (2006).

Local tensile strains in the geomembrane from gravel particles of an overlying granular leachate collection system are also made worse by the presence of a wrinkle (Gudina and Brachman, 2006; Brachman and Gudina, 2008a). When wrinkled, the maximum tensile strains in the geomembrane from the overlying gravel occurred directly beside the deformed wrinkle, as illustrated in Fig. 1. The stress free region beneath the wrinkle leads to higher contact stresses on either side of the wrinkle and the decrease in width of the wrinkle produces a horizontal component of displacement of nearby gravel particles, both of which contribute to increased local tensile strains with a wrinkle relative to a flat geomembrane. It has been suggested that these tensile strains be limited to minimize the potential for long-term puncture of the geomembrane. For example, Seeger and Müller (2003) have proposed a 3% long-term tensile strain limit, whereas Peggs et al. (2005) have proposed a 6–8% limit.

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