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Geomembrane puncture and strains from stones in an underlying clay layer

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A B S T R A C T

Results from physical experiments are presented to assess the possible puncture of a 1.5-mm-thick HDPE geomembrane and, if not punctured, the maximum tensile strains in the deformed geomembrane from intentionally placed stone particles in an underlying compacted clay liner when subjected to applied vertical stresses. The influences of applied pressure, clay water content, stone size, stone burial depth and protection layer on the geomembrane tensile strains are reported. Except in one test conducted to a pressure of 2000 kPa, the geomembrane was not punctured in the short-term tests conducted; however, it was subjected to local indentations and tensile strains from the underlying gravel particles that may exceed proposed allowable long-term strain limits. Tensile strains for the specific 35 mm stones tested when initially flush with the clay surface were negligible, even up to pressures of 1000 kPa, provided the initial water content of clay was 12%. Increases in water content or stone size were found to increase the tensile strain. Placing the clay at the lower limit of acceptable water content was found to be beneficial in terms of reducing strains from buried stones; however, this was also found to make the geomembrane more susceptible to stone particles sitting on top of the clay surface and hence careful site inspection is required to remove all visible stones that sit on top of the clay surface.

1. Introduction

A composite liner consisting of a high-density polyethylene (HDPE) geomembrane overlying compacted clay can be a very effective barrier to the migration of contaminants in solid waste landfills. Advective contaminant transport is limited to leakage through holes in the geomembrane and the presence of low permeability clay beneath the geomembrane greatly reduces the magnitude of any such leakage (e.g., see Rowe et al., 2004; Rowe, 2005; Saidi et al., 2008).

It is not uncommon for the clay layer to be made from glacial till, which may contain grain sizes ranging from clay size to cobbles and boulders. Landfill regulations in the Province of Ontario, Canada require that stones larger than 100 mm be removed from the clay (MoE, 1998). Cartaud et al. (2005) reported that it was common practice in France to install a geotextile beneath the geomembrane because of concern of geomembrane puncture from below. While much is known about geomembrane puncture and tensile strains from materials placed above the geomembrane (e.g., Narejo et al., 1996; Gudina and Brachman, 2006; Dickinson and Brachman, 2008; Brachman and Gudina, 2008), there is a paucity of data on the potential for geomembrane puncture from stones buried in the clay beneath the geomembrane.

In one experiment conducted by Gudina (2007) to examine the puncture resistance of a 1.5-mm-thick HDPE geomembrane from overlying coarse gravel when subjected to a vertical pressure of 3000 kPa for 10 hrs, the geomembrane was also found to be punctured from undetected stones in the underlying compacted clay layer (Fig. 1a). Four punctures from below, producing elliptical holes with areas of 80, 570, 750, and 820 mm^2 were observed from stones smaller than 10 mm in diameter in the clay layer. The largest of these punctures is shown in Fig. 1b.

The working hypothesis is that when subjected to vertical pressure, stones in the clay may lead to local irregularities in settlement, producing local indentations in the geomembrane that may lead to tensile strains in the geomembrane, and if sufficiently large, may lead to geomembrane puncture. To illustrate this further, consider the schematic in Fig. 2 where a stone with vertical dimension D is buried in the clay beneath the geomembrane. The stone is initially flush with the clay surface (Fig. 2a). When subjected to uniform vertical pressure, points a through d deform to a' through d' as shown in Fig. 2b. Points a and b beneath the stone would be expected to settle by the same amount (provided that the stone does not significantly alter the stress acting beneath the particle) with the magnitude of this settlement, Δ, governed by the vertical pressure and the thickness and compressibility of the underlying clay. Since the stone is incompressible relative to

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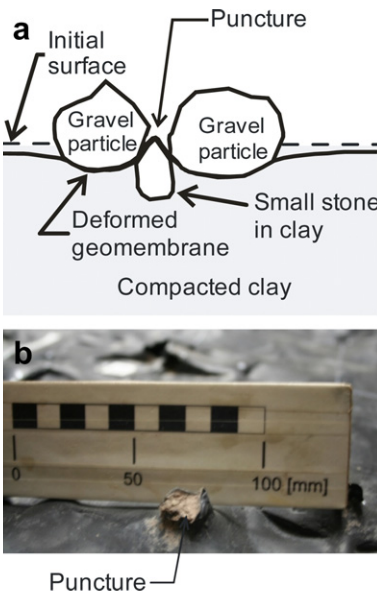

Fig. 1. a) Illustration of a geomembrane puncture from a stone in an underlying clay layer. b) Photograph of a puncture in 1.5-mm-thick high-density polyethylene geomembrane from a stone in the underlying clay following application of a vertical pressure of 3000 kPa (Gudina, 2007).

the clay, distances $\overline{ac}$ and $\overline{a'c'}$ will be the same and thus point c undergoes a vertical displacement of Δ to point c'. Point d moves to d' from settlement Δ plus the clay compression over distance $\overline{bd}$, where the latter component depends on: the particle size of the stone D, the vertical pressure and the compressibility of the clay beside the stone. The height of the local indentation in the geomembrane (Fig. 2c) is then the difference in elevation between points c' and d' and is equal to $\overline{bd}-\overline{b'd'}$ and is solely from the compression of the clay beside the stone particle. The height of this indentation is one factor that controls the local curvature and hence possible magnitude of tensile strain in the geomembrane. The width of the local indentation (controlled by the horizontal dimension of the stone) will also impact the magnitude of any local strain. Large and narrow indentations would be expected to produce the largest strains in the geomembrane. In reality, since the stone is much stiffer than the clay, the stone may locally attract force and press down into the clay such that the vertical displacement at point a may be larger than that at point b. This would lead to less relative displacement between the points c' and d' and hence a smaller local indentation than that shown in Fig 2.

If the tensile strains induced in the geomembrane exceed the rupture strain from short-term index puncture tests (e.g., ASTM D4833-07) then puncture of geomembrane would most certainly be expected. However, if there is no short-term puncture of geomembrane, but tensile strains exceed allowable long-term tensile strain limits (e.g., Seeger and Müller, 2003; Peggs et al., 2005) there is no available data to show that puncture of HDPE geomembranes would not occur, and hence, it may be prudent to limit these tensile strains to ensure adequate long-term performance as a contaminant barrier.

The objectives of this paper are to: (1) investigate whether a geomembrane is punctured from stones intentionally placed in an underlying clay layer during relatively short-term laboratory tests and (2) quantify the tensile strains in that geomembrane induced from the underlying stones in the clay. Results from physical testing are presented to examine the influences applied pressure, clay water content, stone size, stone burial depth and protection layer on the tensile strains in 1.5-mm-thick HDPE geomembrane when subjected to vertical pressures as large as 2000 kPa.

2. Method

2.1. Apparatus

A cross section through the test apparatus is shown in Fig. 3. It is a cylindrical pressure vessel with an inside diameter of 600 mm and a height of 500 mm. Vertical pressures were applied across the top surface by a rubber bladder pressurized with water in increments of 200 kPa each held constant for 12 h to allow the clay to reach at least 90% consolidation (verified by settlement plate readings located at the top of the clay). A saturated geotextile and thin sand layer beneath the clay allowed drainage of consolidation water through a port in the bottom of the cell.

Horizontal stresses corresponding to zero lateral strain conditions developed by limiting outward deflection of the test cell. Boundary friction was limited to less than 5° by using two 0.1-mm-thick polyethylene sheets lubricated with grease (Tognon et al., 1999). For its size and with the friction treatment, greater than 95% of the applied vertical pressure were calculated to act at the elevation of the geomembrane (Brachman and Gudina 2002). All tests were conducted at a temperature of 22 ± 2 °C.

2.2. Materials

As detailed in Fig. 3, the experiments consisted of a 1.5-mm-thick smooth HDPE geomembrane on top of a 150-mm layer of compacted clay. Index properties of the geomembrane are given in Table 1.

Silty-clay till of low plasticity obtained from a landfill site at Milton, Ontario was used for the compacted clay layer. The silty-clay till was dried and particles larger than 10 mm were removed. The resulting clay had a liquid limit of 26% and plastic limit of 16%. For standard Proctor compaction, the clay had a maximum dry density of 2.1 g/cm^3 at an optimum water content of 12%. Tests were conducted at initial nominal water contents of 12, 14 and 16%, to investigate the limits of acceptable water content for field

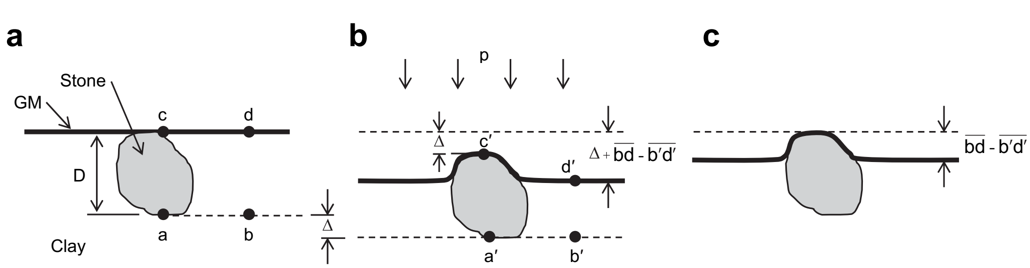

Fig. 2. a) Stone particle buried in clay beneath geomembrane (GM), b) deformed shape after application of vertical pressure (p), and c) local indentation in the geomembrane.