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Gravel contacts and geomembrane strains for a GM/CCL composite liner

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ABSTRACT

A method to record the shape, size, and spacing of gravel contacts that act on a geomembrane from an overlying granular drainage layer is presented. The gravel contacts acting on a 1.5-mm thick, high-density polyethylene geomembrane are then quantified for two poorly graded, angular gravels (GP1 and GP2 with nominal grain sizes of 50 and 25 mm) with compacted clay beneath the geomembrane and when subjected to an applied pressure of 250 kPa. The geomembrane indentations and strains are also reported. Five types of contacts were defined: point, edge, area, perimeter and composite. Point contacts were the most frequent and, along with edge contacts, caused the steepest indentations and the largest strains. The average spacings between gravel contacts were found to be 55 mm for GP1 and 37 mm for GP2. Without a protection layer, the largest tensile strains in the geomembrane were 32 and 16% for GP1 and GP2, respectively. A nonwoven needle-punched geotextile was found to reduce the contact pressure acting on and the resulting strains in the geomembrane. However, none of the geotextiles tested (with masses up to 2240 g/m^2) were able to limit the tensile strains below proposed allowable levels for long-term strain even for the short-term conditions examined.

1. Introduction

Geomembranes are thin planar structures (1.5–2.5 mm thick) that are commonly used with a low permeable layer (e.g., compacted clay or a geosynthetic clay liner) to act as a composite liner in modern engineered landfills. These composite liners provide an excellent hydraulic barrier provided that there are no holes in the geomembrane. Holes can arise from damage during installation and possibly from cracking under long-term tensions induced by overlying gravel drainage materials (e.g., see Rowe et al., 2004) and these holes can lead to liquid and gas movement through the composite liner (e.g., Bouazza et al., 2008; Saidi et al., 2008; Rowe et al., 2007, 2004; Barroso et al., 2006; Touze-Foltz et al., 2006; Rowe, 2005). Protection layers consisting of sand, geotextile, and/or geocomposite materials are therefore required to prevent short-term puncture of the geomembrane and limit long-term tensions in the geomembrane.

However, quantifying long-term tensions in geomembranes is challenging and, at present, only an estimate of short-term tensions can be obtained from large-scale laboratory tests (e.g., Brachman and Gudina, 2008; Dickinson and Brachman, 2006; Gudina and Brachman, 2006; Tognon et al., 2000) or smaller scale tests (e.g., Darbyshire et al., 1997; Müller, 2007). The paucity of data on the nature, size, spacing and magnitude of gravel contacts acting on the geomembrane (or the protection layer) is one obstacle to quantifying long-term tensions in the geomembrane. The nature of gravel contacts acting on a geomembrane may be expected to be influenced by the grain size, grain size distribution, grain shape and void ratio of the gravel.

It is desirable to use coarse gravel in the overlying leachate collection system to minimize the implications from biologically induced clogging (Fleming and Rowe, 2004). For example, landfill regulations in Ontario (MoE, 1998) require the drainage gravel to have 85% of the particles by mass not less than 37 mm, and 10% of the particles by mass not less than 19 mm (i.e., $D_{85} > 37$ mm and $D_{10} > 19$ mm). Use of such coarse gravel results in larger and more widely spaced contact forces on the geomembrane (and hence larger strains) relative to finer gravel or sand. In many places, such coarse gravel is manufactured from crushing limestone, resulting in irregularly shaped, rough and angular particles overlying the geomembrane.

Knowledge of the nature of gravel contacts and associated strains is essential prior to numerical modelling of physical interactions between the gravel, protection layer and the geomembrane as it represents the top boundary condition acting on the composite liner. Knowing what a typical gravel contact is and what sort of contact leads to the largest geomembrane strains would also be valuable in designing simpler experiments (possibly only involving a single gravel particle) as well as aid in the interpretation of index tests where steel plates with fabricated

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protrusions have been used in experiments to simulate gravel particles (Brummermann et al., 1994; Narejo et al., 1996).

The objective of this paper is to quantify the gravel contacts that directly act on a geomembrane and the resulting geomembrane strains. Details of the experimental technique are reported. One particular high-density polyethylene (HDPE) geomembrane without any protection layer overlying compacted clay is examined at an applied vertical pressure of 250 kPa. Two different coarse gravels are examined. The effectiveness of nonwoven needle-punched geotextiles to reduce the geomembrane strains is also presented.

2. Experimental details

2.1. Test apparatus

The details of the experiments are reported by Gudina (2007) and only a brief overview is given here. The test apparatus is shown in Fig. 1. A uniform vertical pressure is applied across the top surface by using a flexible rubber bladder, while horizontal pressures develop (corresponding to zero lateral strain conditions) by limiting the outward deflection of the test apparatus. The vertical stress reaching the geomembrane is reduced by less than 5% from friction along the vertical boundaries by using the system of Tognon et al. (1999) consisting of two layers of 0.1-mm thick polyethylene sheets lubricated with grease.

The vertical pressure was applied in 50 kPa increments every 10 min until a maximum of 250 kPa was reached, and then held constant for 10 h. For reference, this corresponds to a waste height of approximately 18 m if the unit weight of the waste is taken to be 13 kN/m^3 and accounting for 5% loss in the applied pressure to boundary friction. All experiments were conducted at a temperature of 21 ± 2 °C.

2.2. Materials tested

Table 1 summarizes the tests conducted. All tests were performed with a geomembrane (GM) overlying a compacted clay liner (CCL) and backfilled with a granular drainage layer as shown in Fig. 1.

The soil used as the compacted clay liner was obtained from a landfill site in Milton, Ontario, Canada. The index properties of the clay are summarized in Table 2. The clay was compacted in two 50-mm thick lifts at a target moulding water content of 16%, which for this clay, represents the upper range of water content for field placement (Benson et al., 1999). The actual water content of the clay for each test is given in Table 1.

A smooth HDPE geomembrane specimen with a diameter of 570 mm was placed on top of the clay. A 1.5-mm thick geomembrane was tested except in Tests 2 and 3 where 2.0- and 2.5-mm thick geomembranes were tested. Index tensile stress–strain properties of the geomembranes are summarized in Table 3.

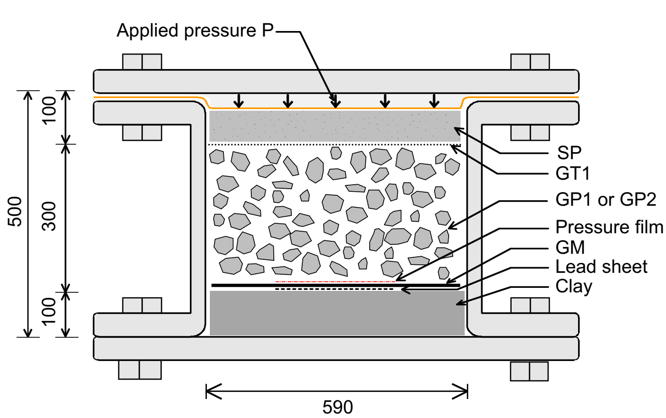

Fig. 1. Cross-section through experimental apparatus. Dimensions in millimetres.

Table 1
Summary of tests

Test	Gravel	Protection layer	Pressure film	Lead sheet	Clay water content (%)
1a	GP1	None	1	Yes	16.0
1b	GP1	None	1	Yes	16.3
1c	GP1	None	1	Yes	15.7
1d	GP1	None	1	Yes	15.5
1e	GP1	None	1	Yes	15.5
1f	GP1	None	1	Yes	16.1
1g	GP1	None	1	Yes	15.8
1h	GP1	None	1	Yes	15.9
1i	GP1	None	2	No	16.2
1j	GP1	None	2	No	16.6
1k	GP1	None	2	No	16.2
1l	GP1	None	2	No	16.8
1m	GP1	None	2	No	16.6
2a*	GP1	None	None	Yes	16.1
2b*	GP1	None	None	Yes	15.8
3+	GP1	None	None	Yes	16.4
4a	GP2	None	1	Yes	16.2
4b	GP2	None	1	Yes	15.7
4c	GP2	None	1	Yes	15.9
4d	GP2	None	1	Yes	16.0
4e	GP2	None	1	Yes	16.1
4f	GP2	None	1	Yes	15.6
4g	GP2	None	2	No	15.9
4h	GP2	None	2	No	15.8
4i	GP2	None	2	No	16.0
4j	GP2	None	2	No	15.9
4k	GP2	None	2	No	16.1
5a	GP1	GT1	1	Yes	16.3
5b	GP1	GT1	None	Yes	16.1
5c	GP1	GT1	None	Yes	16.0
5d	GP1	GT1	None	Yes	16.2
5e	GP1	GT1	None	Yes	15.9
6	GP1	GT2	None	Yes	15.8
7a	GP1	GT4	None	Yes	15.6
7b^t	GP1	GT4	None	Yes	16.4
7c^t	GP1	GT4	None	Yes	15.3
8a§	GP1	GT4	None	Yes	16.1
8b§	GP1	GT4	None	Yes	16.6
9a$^£$	GP1	GT4	None	Yes	16.2
9b$^£$	GP1	GT4	None	Yes	16.0
9c$^£$	GP1	GT4	None	Yes	16.6
10	GP1	GT5	None	Yes	15.6
11§	GP1	GT5	None	Yes	16.3
12	GP1	150 mm SP	1	Yes	15.7
13	GP2	GT3	None	Yes	16.1
14	GP2	GT5	None	Yes	16.2

Geomembrane thickness $t_{GM} = 2$ mm* and 2.5 mm$^+$, otherwise $t_{GM} = 1.5$ mm.
Pressure held for $t = 100$ h§ and 1000 h$^£$, otherwise $t = 10$ h.
Clay thickness $h = 150$ mm^t, otherwise $h = 100$ mm.

Two types of granular backfill materials denoted as GP1 and GP2 were tested. Grain size distributions are given in Fig. 2. GP1 is a nominal 50-mm poorly graded gravel that meets the requirements of Ontario landfill regulations (MoE, 1998), while GP2 is a nominal 25-mm poorly graded gravel that meets German landfill regulations (BAM, 1995). Both GP1 and GP2 were composed of crushed limestone. The gravel particles were irregularly shaped,

Table 2
Properties of clay used as a subgrade

Property	
Liquid limit (%)	27
Plastic limit (%)	16
Std Proctor optimum water content (%)	12.2
Std Proctor maximum dry density (g/m^3)	2.06
Dry density as placed in the test apparatus (g/cm^3)	1.84
Specific gravity of soil solids (–)	2.75
Percent finer than 0.002 mm by mass (%)	32