

A new laboratory apparatus for testing geomembrane leakage with mine tailings under large earth and fluid pressures



Prabeen Joshi, Richard W.I. Brachman & R. Kerry Rowe
 GeoEngineering Centre at Queen's–RMC, Queen's University
 Kingston, Ontario, Canada

ABSTRACT

The design and development of a new high-pressure apparatus that is capable of simulating large effective stresses on a geomembrane liner is presented. The system is intended to be used for studying leakage from defects in geomembrane liners in large mine tailings application or dams. Results from a prototype test conducted on silty sand with a geomembrane with circular hole and finite element seepage analysis of the test is presented. Preliminary observations show that the apparatus is able to simulate the field conditions extremely well.

RÉSUMÉ

La conception et le développement d'un nouveau système d'application de haute pression pour simuler les grandes contraintes effectives subies par une géomembrane est présenté. Le système est destiné à être utilisé pour étudier les fuites liées à l'existence de défauts dans les géomembranes utilisées comme étanchéité dans les applications de stockage de résidus miniers de grande hauteur ou les barrages. Le résultat d'un essai de prototypage réalisé sur du sable limoneux avec une géomembrane présentant un défaut circulaire et une analyse par éléments finis de l'écoulement dans le test sont également présentés. Des observations préliminaires indiquent que le système est capable d'extrêmement bien simuler les conditions de terrain.

1 INTRODUCTION

Geomembranes can be very effective at controlling leakage for environmental containment where the escape of fluid under a hydraulic gradient is limited to flow through holes in the geomembrane. In municipal solid waste (MSW) landfills, there is typically a very highly permeable material above the geomembrane as a drainage layer (which limits the head acting on the liner) and a very low permeability, k , material below the geomembrane (e.g., a geosynthetic clay liner or a compacted clay liner) to limit leakage through any holes in the geomembrane, Figure 1.

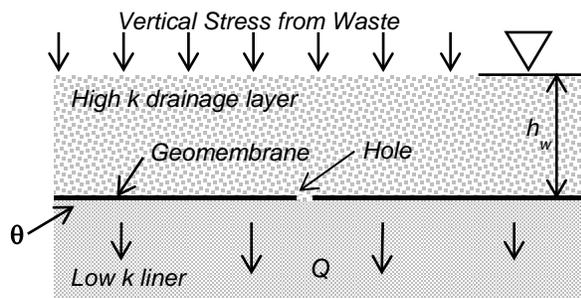


Figure 1 Geomembrane hole in a typical municipal solid waste landfill configuration.

Geomembranes have the potential to be used to greatly limit leakage of fluids from tailings storage facilities. Relative to MSW landfills, in many tailings containment applications (Figure 2): the vertical stress acting on the liner can be much higher (possibly affecting both k and interface transmissivity, θ), the pore pressures

acting on the liner can be much, much higher (with an increased hydraulic gradient and possible migration of fines with the high local seepage stresses), the hydraulic conductivity of the material above the geomembrane (i.e. tailings) is much lower (providing greater resistance to flow above the hole), and the hydraulic conductivity of the material below the geomembrane (i.e. engineered foundation layer) is not as low (providing less resistance to flow below the hole). However, the net effect of these differences on the resulting leakage for tailing applications is unknown. Measurements of leakage are required from experiments conducted under potentially high total stresses and high pore pressures.

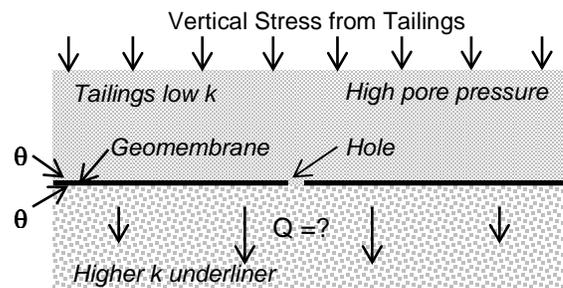


Figure 2 Geomembrane hole in a mine tailings containment configuration.

The objective of this paper is to report on the development of a new laboratory apparatus for testing geomembrane leakage for mine tailing applications under large earth and fluid pressures. The boundary conditions of the apparatus and experimental procedures are described. Results from prototype test with silty sand

above and below a 1-mm-thick linear low density geomembrane (LLDPE) geomembrane with a 10-mm-diameter hole are presented to illustrate its use at a total applied vertical stress of 3000 kPa and applied pore pressure of 1500 kPa.

2 LABORATORY APPARATUS

2.1 Boundary conditions

The laboratory apparatus adapted for measurement of leakage through geomembrane holes under high pressures is a cylindrical test cell with an inner diameter of 590 mm and height of 500 mm. It was originally developed by Brachman and Gudina (2002) to study the physical response of geosynthetic liners and was later used by Gudina and Brachman (2006) to simulate the physical response of geomembrane wrinkles under high pressures. It was also used to quantify local geomembrane strains for municipal solid waste (MSW) landfill applications by Brachman and Gudina (2008) and Dickinson and Brachman (2008) and mining heap leach pads by Rowe et al. (2013) and Brachman et al. (2014). A

cross section of the test cell with the new pressure application system designed for this study is shown in Figure 3. Total vertical stress is applied using hydraulic stress on a rubber bladder. The maximum vertical stress that can be applied is 3000 kPa. For a soil of unit weight 20 kN/m^3 , 3000 kPa corresponds to a total vertical stress at a burial depth of 150 m. Horizontal stresses corresponding to zero lateral strain conditions (i.e., K_0) are developed by having negligible outward deflection of the cell wall.

Friction treatment is placed along the inner wall of the cell to reduce sidewall friction (Figure 4). The friction treatment consists of two layers of 0.1 mm thick polyethylene sheets that are lubricated with a layer of high temperature grease. Tognon et al. (1999) showed that friction treatment reduces the side wall friction to less than 5° . For the dimensions of the test cell used in this study and with interface friction of 5° , Brachman and Gudina (2002) calculated more than 95% of the total stress applied on top acting at the elevation of the geomembrane.

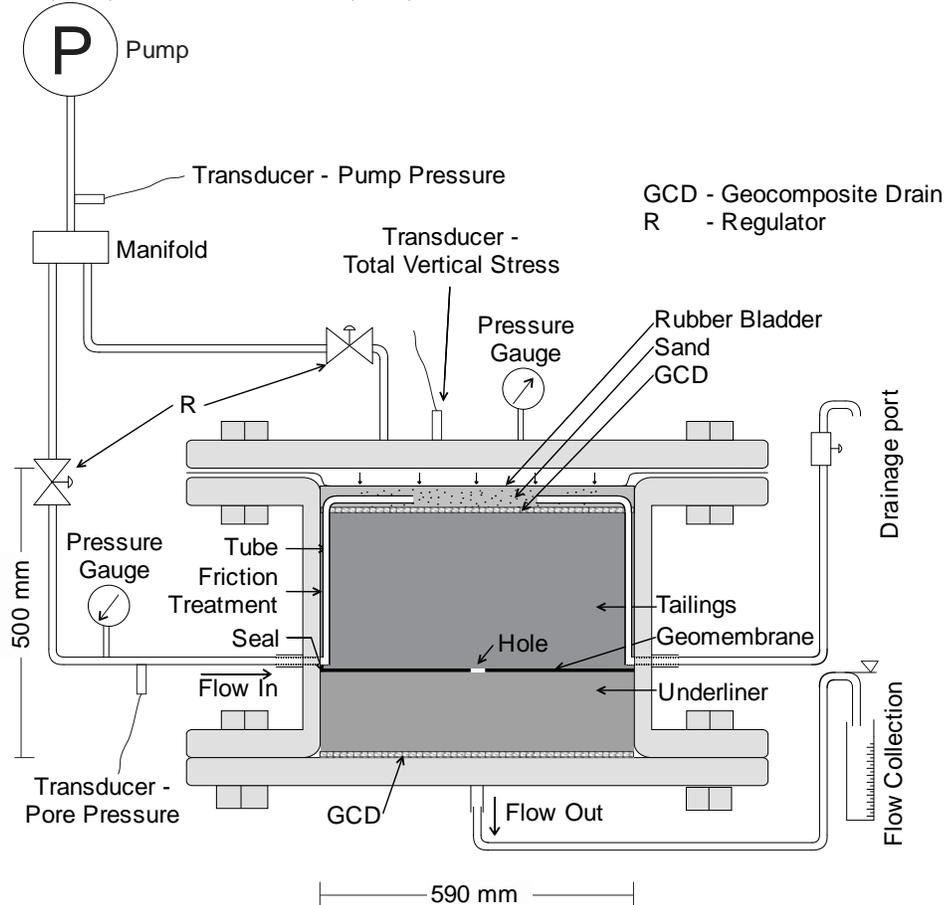


Figure 3 Schematic of the test system

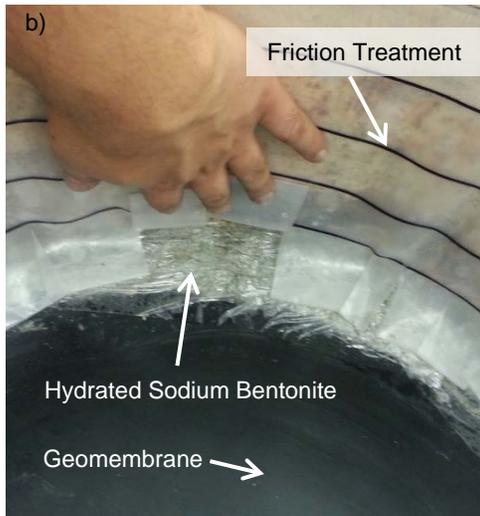
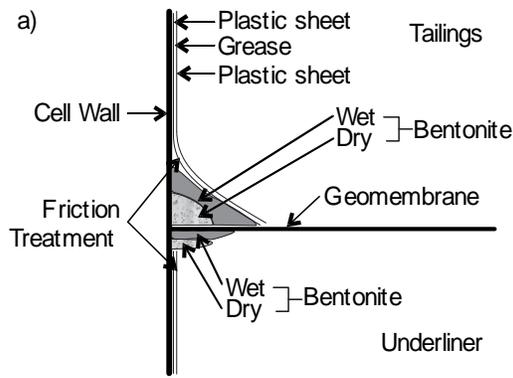


Figure 4 (a) Cross section showing friction treatment and seal details, (b) Picture showing the seal and friction treatment

Pore pressures are applied by pressurizing the fluid in a thin (0.05 m thick) saturated layer of sand between the bladder and a 0.3-m-thick layer of tailings. Since the head loss is expected to be localized around the small hole in the geomembrane, having distances of 0.3 m above the hole and nearly 0.3 m radially to the lateral boundaries should provide a reasonable physical simulation of flow.

Results from preliminary finite-element seepage analysis shown in Figure 5 support that head loss is local and concentrated around the hole. Since radially symmetric, results are shown along a vertical plane for one-half of the cell (where $r=0$ is along the centre and $z=0$ is along the base of the cell). These results were obtained for the dimensions of the apparatus with a prescribed total head of 150.3 m along the top surface (i.e. along $z=0.45$ m), a prescribed total head of 0 along $z=0$ and $r = 0.05$ m to simulate the bottom drainage port in the cell, and all other perimeter boundaries modelled as zero flow boundaries. From the bottom-up, the model included: a 0.06 m thick geonet ($k = 0.5$ m/s), a 0.04 m thick geotextile ($k = 5.7 \times 10^{-3}$ m/s), a 0.14 m thick underliner layer ($k = 2.2 \times 10^{-9}$ m/s), a 1mm thick LLDPE with a 10 mm diameter hole, and a 0.3 m thick overliner (k

$= 2.2 \times 10^{-9}$ m/s). For this particular case, 97% of the head loss occurs within a radial zone 10-times the hole radius (i.e., within 50mm; Figure 5). Post-test finite-element seepage analysis will be conducted following leakage experiments with actual tailings to further quantify the effect of the distance to the upper prescribed total head and lateral zero flow boundaries.

2.2 Procedure

For a typical test setup, a saturated geonet-geotextile drainage composite is first placed at the bottom of the apparatus to get a uniform known head as a bottom boundary condition. An underliner (0.14 m) is then placed and compacted at to a target initial dry density (with the intent to simulate a firm engineered foundation layer beneath the geomembrane). The underliner is saturated from below.

A layer of geomembrane with a circular defect of diameter 1.5, 10 or 20 mm at its centre is placed on top of the underliner. Two different types of geomembrane commonly used as liners in containment facilities, high-density and linear-low-density polyethylene (HDPE and LLDPE) will initially be tested. Further, to study an effect of thickness of geomembrane, 1 and 2 mm thick geomembrane of both types will be tested.

To prevent any sidewall leakage between the edge of the geomembrane and the cell, a hydraulic seal made out of layers of dry and wet sodium bentonite is applied. The seal is separated from the tailings on top by a layer of 0.1 mm thick polyethylene sheet (Figure 4 b).

After placing and sealing the geomembrane, the 0.3 m thick layer of tailings is then placed. In these simulations, it was decided to place the tailings as a slurry and then consolidate them to a desired effective stress prior to permeation. Another geonet-geotextile drainage composite is placed on top of the tailings, to serve as an upper drainage boundary during consolidation and to assist with apply a uniform distribution of head on top of the tailings, followed by a sand layer.

Access to the sand layer, for either injecting or removing fluid, is through existing ports near the middle of the apparatus. These ports permit removal of entrapped air from the system to ensure complete saturation (Figure 3). Air is purged after set-up and before starting each test.

After purging, the soil layers are consolidated by applying desired total stress. During consolidation, the tailings are allowed to drain to the sand above, while the underliner is allowed to drain through the bottom of the apparatus. Following the consolidation stage, both total stress and pore pressure are then increased to achieve the desired effective stress. The permeation phase would then start and leakage is measured.

A data acquisition system to monitor and record the pressures in real time is included in the setup. The pump pressure, total stress, and pore pressure is monitored using pressure transducers and dial gauges that are fully calibrated to the range of stresses to be applied. An online monitoring system is also developed to remotely monitor the tests.

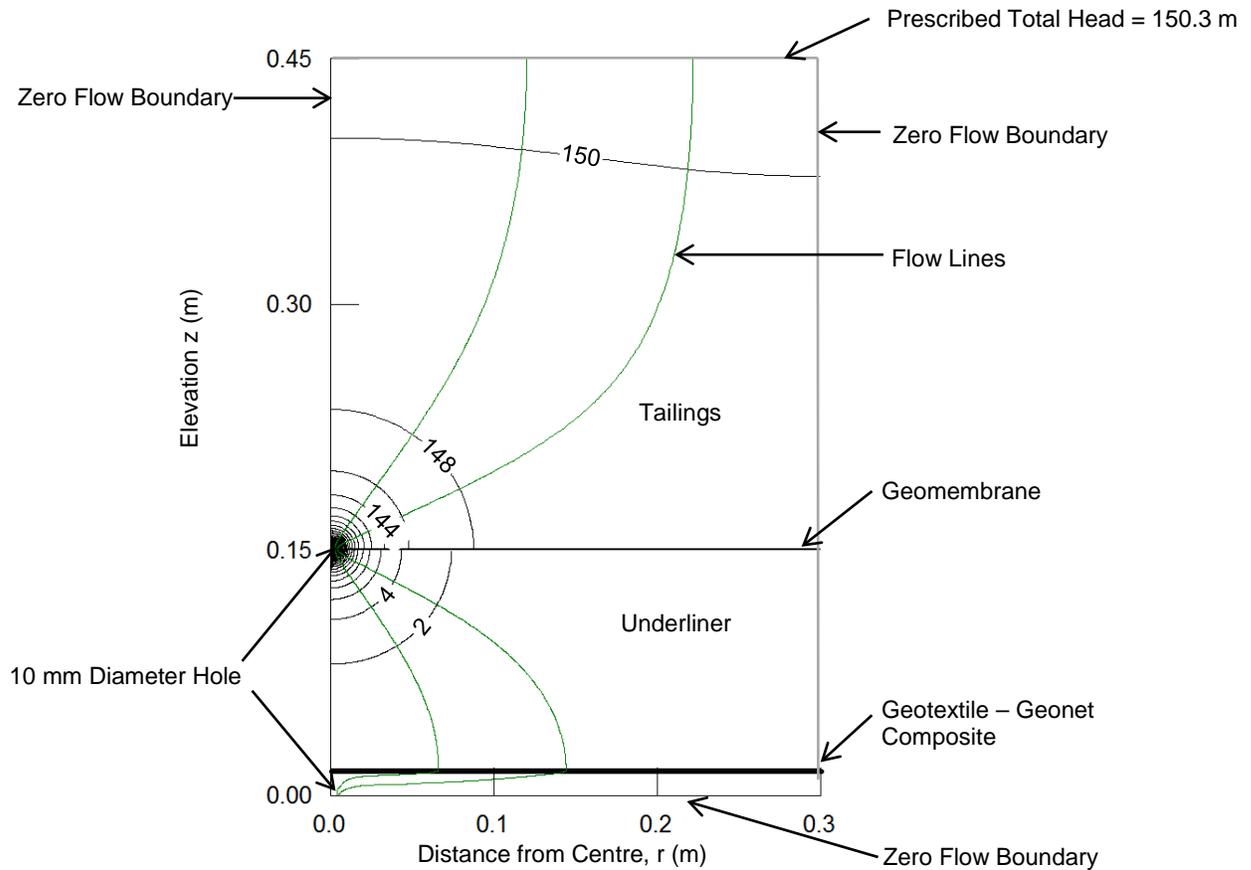


Figure 5 Flow lines and select contours of total head (in m) from axisymmetric seepage analysis of leakage experiment

3 PROTOTYPE TEST

A prototype test was conducted to verify the ability of the new pressure application system and experimental procedures to permit a physical simulation of leakage through holes in a geomembrane with low permeability soil both above and below the geomembrane. It was conducted not with tailings, but with a silty sand on top and bottom of an LLDPE geomembrane. This soil consisted of 3% medium sand, 62% fine sand and 35% non-plastic silt by mass. The geomembrane was 1 mm thick and had a 10 mm hole located at the centre.

An underliner (0.14 m thick) was prepared by compacting the silty sand in three lifts to achieve an initial dry density of 1.83 kg/m^3 at a moisture content of 11% (both corresponding to its Standard Proctor maximum dry density). The underliner was then provided with water from below (via the port in the bottom of the cell) using a reservoir with water head at the top level of the subgrade to increase its initial degree of saturation. The volume of water required to saturate the underliner was recorded and found to be comparable with the volume of water

required to achieve saturation of the underliner. The silty sand selected for the prototype test had lower hydraulic conductivity than the underliner and the typical tailings materials that will be subsequently used in this study.

After preparation of the perimeter seal and placement of friction treatment, the overliner (0.3 m thick) was mixed as slurry at 25% gravimetric water content was placed on top of the geomembrane liner.

During the consolidation stage, total stress was applied at an incremental rate of 200 kPa per day for first 7 days with a final increment of 100 kPa to reach a total stress of 1500 kPa (Figure 6a). Consolidated water was collected separately from the permeant collection system at the bottom of the cell and from the drainage port at the top of the overliner for a period of 24 ± 4 hours for each increment of total stress which are plotted in Figure 6d. Once consolidated to total vertical stress of 1500 kPa, total stress was increased to 3000 kPa and simultaneously a hydraulic head of 150 m (1500 kPa) was applied on top of the overliner keeping the effective stress constant at 1500 kPa.

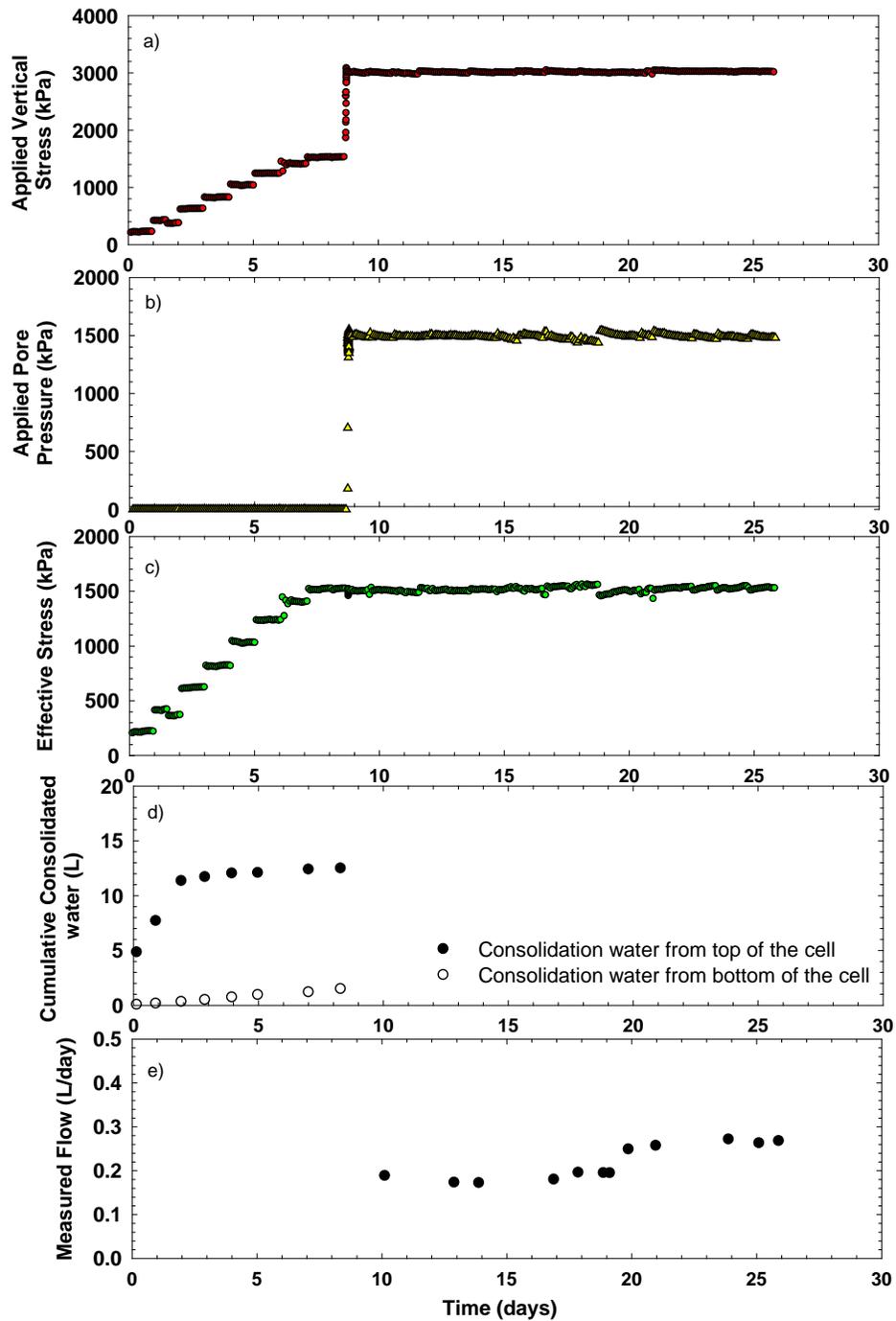


Figure 6 Plots of: (a) Applied vertical stress, (b) Applied pore pressure, (c) Effective stress, (d) Cumulative Consolidated water, and (e) Measured flow versus Time

The new pressure application system reached a steady total stress and pore pressure within 1 hr after application of target pressures. The applied bladder and pore pressures were maintained to be within ± 30 kPa of the target pressures for the last 5 days of the prototype test (i.e., within 1% and 0.5% of the target total vertical

and pore pressures). Subsequent revisions to the pressure application system (including upgrades to the pump and a manifold system that permits up to three simultaneous tests) increased the precision to less than ± 20 kPa.

The permeation stage was run for 17 days. The measured average flow rate for the last 5 days of permeation was 0.26 L/day.

After termination of the test, careful observations were made. The settlement of the consolidated overliner was uniform at 4 cm across the top surface. This shows that the side wall friction treatment was effective at reducing boundary friction, even at the high pressures tested.

There was no evidence of preferential flow from side wall. The bentonite used at the perimeter seal was well consolidated. The powdered dye that was sprinkled between the bentonite and thin plastic cover was neither dissolved nor washed out suggesting there was no direct contact of moisture with the perimeter seal.

SUMMARY

The development of a new laboratory apparatus for testing geomembrane leakage for mine tailing applications under large earth and fluid pressures was reported. The boundary conditions of the 0.59-m-diameter and 0.5-m-high apparatus were described and experimental procedures were detailed. Results from prototype test with silty sand above and below a 1-mm-thick LLDPE geomembrane with a 10-mm-diameter hole were presented to illustrate its use at a total applied vertical stress of 3000 kPa and applied pore pressure of 1500 kPa. Additional experiments are underway to quantify the leakage rates with tailings.

ACKNOWLEDGEMENTS

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