Circular Defect as Potential Pathway in Polyethylene Forming Part of a Geo-composite Lining System

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Abstract. Geo-composite barriers under leachate leakage through circular defects in a geomembrane were tested in a small-scale laboratory model. A soil barrier- 24 mm thick, polyethylene plastic-2mm thick with centered 5 mm hole simulated the circular defected geomembrane and a 225 mm thick buffering profile (BP) completed the experimental setup. A Modular Consolidometer-Percolation Column Hybrid model of 160 mm diameter is coupled to a hydraulic pressure frame capable of applying up to 1000 kPa pressure to the liner. Leakages through barrier-BP system were evaluated for tests under pressure of up to 150 kPa. Measured leakage rates for good geomembrane/soil interface contact conditions were found to be valid whereas that of a perfect contact condition was unachievable in this study. However, outcomes show notable reduction in leakage rates with increased pressure, p, on the geomembrane. This is plausibly due to reduced barrier system transmissivity, \( \theta \), and densification of the barrier. Concentrations of dreaded Organic matter in the BP after percolation tests confirmed leakage through the defected polyethylene-soil liner and showed poor buffering abilities of three natural soils investigated in this study to migrating organics.

Keywords: leachate, organics, buffer, geo-composite, geomembrane, pressure

1. Introduction

Most by-products of human activities are usually generated as solid wastes and it has become critical that these waste products are properly disposed in engineered containment systems considering the difficulties of handling via other means. Land disposal has come a long way as an approach to ridding of various generated waste and it will for a long time remain the most common form of disposal. Landfill waste containments produces gases and leachates whose infiltration into surrounding soil and ground water must be prevented or curtailed at worse in order to minimize environmental impacts [1]. Rain, runoffs, waste containing high moisture and bacterial activities triggers the generation of contaminants in landfills. Therefore, protection of important soil and ground water resources against pollution from landfill leachates is of great concern. Geo-composite barriers are now been well employed in managing the transportation of contaminants from disposal sites. In rare cases geomembrane; as part of a geo-composite may be defected from fabrication, installation or over time due to ultraviolet radiation. In some other cases, constructing disposal systems around vital water sources cannot be escaped but it is only ensured that the protection of important soil and ground water regimes from waste bodies are competently done [2]. This is achievable by utilizing compacted clay liners (CCL) as components of geo-composite lining systems to control any migrating contaminant entering the defected barrier i.e., Geomembrane (GM) or Geosynthetic Clay Liner (GCL). Hence, Geomembrane/soil liners are recommended globally and are at present actively used in the construction of

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waste containment systems which forms a significant component for many multiple systems in engineered landfills. As recorded by [3] the use of geosynthetic materials are recognized in designs and are quickly expanding as manufacturers source, develop new and improved materials and engineers/designers develop new analysis routines for better services. However as already stated, in-situ defects in geomembrane cannot be completely avoided [4]. The daily disposal of more than 41 thousand tonnes of solid waste in South Africa with Gauteng province and Johannesburg city ridding more than 17 and 4 thousand tonnes respectively is a thing of worry [5]. This waste disposal causes health, environmental and aesthetic challenges. Pollution of vital subsurface and groundwater resources is one of the many problems thus, the need for the study. Applied pressure on leakage rate through geomembrane defect, Organics transport mechanism through geo-composite barrier with natural soils as CCL and the buffering capabilities of natural soils have not been sufficiently documented. However, about 75% of Municipal Solid Waste (MSW) in South Africa is dumped in landfills. The barrier liners are under pressure, p, from the mountain of waste. Pressure on the lining systems is estimated to be around 150 kPa for waste heights and thicknesses of 8-10 m. This study therefore conducted small-scale model tests on leachate leakage through defected geomembrane as part of a geo-composite lining system underlain by soil barrier as CCL and BP. The pressure influence on leakage rate, organic contaminant transport and the buffer capability of the natural soils were investigated.

2. Material and Methods

2.1. Experimental Approach

Three soils were collected and used as CCLs and BPs in this study. The soils were obtained close to three different landfill sites at points remotely far from the actual dump in order to prevent impurities as seen in Fig. 1 and the samples were denoted A, B and C for the three sites respectively. In the first test conducted, soil-A was mixed with 50% coarse sand (equal proportion of particles passing 4.75 mm, 3.35 mm, 2.36 mm and 2.00 mm sieves as sample D). Adding coarse sand was mainly to increase permeability of the barrier and shorten tests. Gravelly back-fill material mixed with coarse sand (equal proportion of particles passing 4.75 mm and 3.35 mm formed sample E) served as BP. The soils were mechanical and chemical tested and Fig. 2 shows the grain size distribution curves of the soils, while the relationship between water content and the dry unit weight of the soils were determined by the compaction test in line with [6]. The standard proctor compaction test was done with a light rammer having self-weight of about 0.0244 kN and striking effort of about 595 kN-m/m$^3$. The respective compaction curves are shown in Fig. 3. The tests yielded optimum water contents of 8.7, 14.7% and maximum dry unit weights of 17.3, 16.2 kN/m$^3$ for soil-A + coarse sand and the gravelly soil respectively. While optimum water contents of 16.2, 15.4 and 15.7% and maximum dry unit weights of 15.2, 16.4 and 17.4 kN/m$^3$ were gotten for the respective natural soils. Values for permeability coefficient were measured by falling head test in consonance with [7]. The relationship between the permeability and dry unit weight of the natural soils is seen in Fig. 4.

In the testing periods, BPs were prepared had relatively low water content and lightly compacted to simulate in-situ conditions of natural soils. Saline water prepared from mixing 10 g of salt per 1 L of de-
ionized water was used as permeate in the first test. Other permeant used were collected from sites leachate basins (see Fig. 5) designed to collect leachate generated at the various landfills (from infiltrated storm water and/or intercepted subsurface water with the waste body). The leachate samples were labeled X, Y and Z to differentiate respective collection basins. Each sample was taken from a number of points within a basin and mixed together to get proper leachate composition. Table I shows the initial concentrations (mg/l) of the targeted chemical parameter from chemical analyses for the different leachates. The organic chemical matter were measured by full spectral analysis method on the influent and effluent and compared to standard drinking water as per [8], [9].

Table I: Analysis of leachate samples used for leaching tests

<table>
<thead>
<tr>
<th>Parameter</th>
<th>ASTM Test No.</th>
<th>Concentration (mg/l) of Sample X</th>
<th>Concentration (mg/l) of Sample Y</th>
<th>Concentration (mg/l) of Sample Z</th>
<th>Standard for Drinking Water (mg/l)</th>
</tr>
</thead>
<tbody>
<tr>
<td>TOC</td>
<td>D 2579</td>
<td>160</td>
<td>190</td>
<td>180</td>
<td>-</td>
</tr>
</tbody>
</table>

Source: (Water services authorities South Africa, 1997)

In the tests under pressure, densification of the soil barrier occurred due to changes in the applied loads. After unloading the system at the end of the test, the soil layers showed negligible changes. The 2 mm thick polyethylene plastic as defected geomembrane with 5 mm diameter centered hole was improvised due to material constraints. Other varieties of barrier lining designs could not be tested. Although this work was not to investigate different geomembrane liners. However, the complexity and nature of the contaminant species capable of being generated from the decomposition of solid waste in landfills and the insufficient spectral testing materials, made it impossible to detail all compositional features and characteristics of such products. Thus, only the dreaded organic matter was tested for intrusion and retention as Total Organic Carbon (TOC) in the BP from the countless chemical species present in the various leachate samples. The selection of TOC contaminants was relied on: (a) the potential hazardous effect expected in the case of the contaminant breakthrough to the subsurface environment based on; (b) the availability and concentration of chemical carbon present in the different leachate solutions generated at the landfill sites.

The parameter analyzed for the organic matter was as: TOC. The leachate chamber was marked to hold a constant head of 250 mm through the test periods. A pictorial view of the model device is shown in Fig. 6. The device composed of three parts: (1) the bottom part called the buffering/attenuation chamber; which contained the natural soil layer acting as the natural earth and BP below the geo-composite system (as shown...
in Fig. 7) (2) the mid-block called the sample holder; contained the designed geo-composite barrier system (natural soil as CCL and defected geomembrane) which seats on the buffering chamber (see Fig. 8) and (3) the upper portion above the geo-composite barrier; functioned as the leachate reservoir/chamber (as per Fig. 9). Soil layers were prepared inside the bottom chamber, the mid-block/sample holder and the defected geomembrane was placed on top of the soil layer. After the components were assembled, O-rings, gasket corks and silicon sealants were used to prevent leakages and maintain tight seals between the top, mid and bottom sections of the device. The loading frame was set up (for tests which required applied pressure), the leachate added and the desired pressure, p, was applied. The vertical hydraulic conductivity, $k_z$ value, in stratified soil (hydraulic conductivity of a barrier layer-BP) was calculated and used to determine the leakage rate, Q. In the first test conducted with saline water, no pressure was applied. Consequently, samples collected from six sectioned cores of the BP were tested and measured for concentration of target source TOC in the pore water using pulverized pore fluid extraction method and silver thiourea method. The analyses were conducted using the 902 Double Beam Atomic Absorption Spectrophotometry as in [10].

3. **Result and Discussion**

3.1. **Column-Hybrid Leaching Tests**

Besides the confirmatory tests carried out in this study, four main leaching tests were conducted. The first test was done with samples D (a mixture of soil-A + coarse sand) to form the soil barrier and sample E
(gravelly soil + coarse sand) served as BP with saline water as the leachate and no pressure applied to the system. Successive tests were for the respective samples collected at the different landfills. Table II summarizes the test features; durations and materials under which each test was carried out. In the first test with saline water (with and without geomembrane), leakage rates were measured, ion concentrations and conductivity values from effluent were taken using an ion meter. The results are shown in Fig. 10a and b.

Table II: Test features

<table>
<thead>
<tr>
<th>Test No.</th>
<th>Barrier Lining System (Natural soil as CCL)</th>
<th>Buffering Profile (Natural soil as BP)</th>
<th>Geosynthetic material</th>
<th>Defect Size, Type and Position</th>
<th>Pressure, p (kPa)</th>
<th>Test Period</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>D</td>
<td>16.2</td>
<td>E</td>
<td>13.6</td>
<td>2mm thick polyethylene plastic as Geomembrane</td>
<td>5mm circular hole in the centre</td>
</tr>
<tr>
<td>2</td>
<td>A</td>
<td>15.2</td>
<td>A</td>
<td>11.9</td>
<td>,,</td>
<td>,,</td>
</tr>
<tr>
<td>3</td>
<td>B</td>
<td>16.4</td>
<td>B</td>
<td>12.7</td>
<td>,,</td>
<td>,,</td>
</tr>
<tr>
<td>4</td>
<td>C</td>
<td>17.4</td>
<td>C</td>
<td>12.3</td>
<td>,,</td>
<td>,,</td>
</tr>
</tbody>
</table>

Test to determine the TOC concentrations and migration through the BP was measured to investigate the mechanism of contaminant travel through the barrier and the buffering power of the soils. This was done at the end of every test and results for the leakage rate through the linings are seen in Fig. 11a to e. From Fig. 10a, the leakage rate for test without geomembrane did not reach steady state due to suspected clogging by moving fines. However, in subsequent tests this was controlled by using moistened geotextile on a porous stone which served as filter to prevent fines from clogging the outlet of the chamber. The concentration and conductivity of the effluents from tests with and without geomembrane revealed a steady increase over the test periods as seen in Fig. 10a and b. For subsequent samples, steady or quasi steady state was reached in about 20 days into the test and the leakage rate was observed and measured over a period of 30 days. The leakage rate, Q, was seen to gradually increase to a steady value. However in Fig. 11a to e, changes in the flow rate were observed as pressure was applied. The first pressure, p, of 25 kPa was applied to the systems of the three samples. Steady state was reached after about 18-20 days as shown in Fig. 11b and the flow rate was monitored and measured for a period of 30 days. To further investigate the effect of pressure, on the systems leakage rate, the pressure was increased from 25 to 50, 100 and 150 kPa to simulate waste load imposing the barrier liners of a typical landfill. The leakage rates, Q, were measured for each pressure and Fig. 11c to e shows the measured relationship between leakage rates, Q, versus time, t, for pressure values of.
50-150 kPa. An increasing pressure on the geomembrane showed the leakage rates to gradually reduce to a steady value. Fig. 12 shows the relationship between the measured leakage rates, Q, against pressure, p.

The increase in pressure caused a change in density which led to a decrease in the permeability of the soil barrier. Furthermore, the applied pressure to the system may have created a fair contact between the geomembrane and the soil barrier thereby reducing the interface transmissivity; reducing the interface thickness and transmissivity, \( \theta \), which explains the gradual decrease to a steady state of the leakage rates, Q.

### 3.2. Soil Buffering Capability of Transported TOC

Leachate solution generated from the dissolution of the buried solid waste at sanitary landfills is usually characterized by the presence of a high concentration of organic compounds. The organic content in most cases accounts for about 40 to 60% of the total constituents. However in the cases at hand (the three landfills), the organic fraction was relatively low: only 10 to 15%. These organic compounds usually consist of the remains of biologically-produced compounds of low molecular weight, principally fulvic acid, in
addition to a variety of synthetic organic contaminants. Such organic substances were found to be mobile in mineral/clay-water system and presented an absolute threat to ground water quality even in minute concentrations. Results from the percolation tests then confirmed that these mobile substances do not migrate in any peculiar manner through the respective soils. The effluent relative concentration for TOC with respect to the pore volume for the three soils after reaching steady state is shown in Fig. 13.

Fig. 12: Leachate leakage rate against p values for the different samples

Fig. 13: Relative conc. of TOC in effluent (Co and Ce = initial and final conc.)

Fig. 14a: Migration profiles of TOC through the BP in soil-A

Fig. 14b: Migration profiles of TOC through the BP in soil-B

Fig. 14c: Migration profiles of TOC through the BP in soil-C

Hence, the attenuation observed in the organic load contained in the leachate solution as it seeped through the column hybrid containing the three soil types was vital to the study. Little attenuation was found for the organic load measured as TOC. The breakthrough point for TOC was recorded at an early pore volume passage and this was in agreement with the results reported by [11], who recorded a poor removal of chemical oxygen demand (COD) when leachate was passed through soils. In the leaching tests, the three different landfill leachates, with initial TOC values of 160, 190 and 180 mg/l for (samples-A, B and C, respectively) with other ionic contaminant species, percolated the respective assigned soil layers with and
without the effect of pressures. An average of 15 to 20% TOC removal was observed in the course of the experimental study and to a great extent, very little difference was noticed between all three soil samples; which could be as a result of the individual chemo-characteristic differences between the respective soils. These data indicate that the exchange capacity and the chemical characteristics of the soils are the dominant features controlling the buffering ability of the soils. Results obtained from the chemical analysis of the pore fluid extracted from six core sections of the BP were consistent with the soil column effluent concentrations. Results showed that significant removal of TOC could be attributed to the complex formation of organic metallic ions, since organic matter adsorbs metal ions better than clays. Generally, the natural soils exhibited poor buffering capabilities to the migration of Organic loads through the BP and the migration profiles for the different soils is shown in Fig. 14a to c.

4. Conclusions

Series of tests on geo-composite systems under leachate leakage from defected geomembrane were conducted in a Modular Consolidometer-Percolation Column Hybrid laboratory model device. Pressure effects, imposing the leakage rate, migration and attenuation of contaminants (TOC) were investigated. From analysis of findings, the increase in pressure on the lining system was observed to significantly reduce the leakage rates; with clear indication that the reduction was as a result of reduced geomembrane/soil interface transmissivity, $\theta$, and the soil liner densification. The tests with geomembrane showed interface flow between the geomembrane and soil barrier; that a perfect geomembrane/soil barrier contact was not achieved with results from the leaching tests and pore fluid concentration of the transported TOC confirming the flow through the geomembrane-soil interface. The concentration of TOC in the six sectioned cores of the BP after the leaching tests showed the natural soils to have poor buffering power towards the organic matter-TOC; the results showed that significant amounts of TOC migrated the BP and only little attenuation occurred across the samples. However, further study needs to be conducted on the influence of pressure on interface contact behaviour for other lining designs as well as the buffering of different contaminant specie.

5. Acknowledgement

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6. References