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Engineered Geo-composite Liner: An Empirical Look at Contaminant Travel through a Circular Punctured Defect in a Lining System

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Abstract. Small-scale laboratory tests on the effect of contaminant travel in geo-composite liners through circular punctured geomembrane were conducted in a modeled device. The influence of pressure on contaminant flow rate, contaminant transport and the buffering ability of natural soil profile were investigated. Flow through the geo-composite liner-buffering profile (BP) system was measured for tests with the punctured geomembrane under loads of up to 150 kPa. Results and analysis showed significant reduction in flow rate with increased pressure on the system. This reduction is attributed to the reduced barrier system transmissivity, θ and soil liner compressibility. The flow rate data for tests with geomembrane in this study were compared with predicted values using equations from Forchheimer (1930) and Giroud et al., (1989). The comparison showed inapplicability to this study and in practice if perfect contact conditions at the geomembrane/soil interface are assumed. However, equations from Giroud (1997) for good contact conditions gave reasonable flow rate predictions through punctured geomembrane of geo-composite liners.

Keywords: geo-composite, contaminant, buffer, leachate, geomembrane

1. Introduction

From decades ago till date, the most common form of waste disposal involve the use of land. As recorded by [1] waste disposal by landfill produces gases and leachates/contaminants, whose escape from containment facilities must be controlled to restrict or eradicate impact on the environment. Hence, to ensure the protection of soil and ground water resources from landfill contaminants, geo-composite liners are often considered. Geomembrane/mineral composite liners are mostly used in waste containments and will remain significant components as barrier systems in landfills. On site however, defects in geomembrane cannot be avoided. In most instances, geomembrane forming part of a geo-composite liner may fail due to defects on or out of site from fabrication, installation or aging [2]. As such, to evaluate contaminant travel through a defected geomembrane underlain a mineral/soil barrier is vital to landfill designs. Locating landfills around important water sources is unavoidable in some instances, and in such cases the separation of waste body and ground water need be effective [3]. This is achievable by using compacted clay liners as part of the composite lining system to control any leachate that may infiltrate the defected barrier i.e., geomembrane (GM) or geosynthetic clay liner (GCL). Gauteng province and the City of Johannesburg (CoJ) account for virtually half the generated waste in South Africa. The increasing tonnages of disposed solid waste each day is rapidly becoming a challenge [4]. This waste disposal in turn often causes health, environmental and aesthetic problems. Among these is the pollution of vital subsurface and groundwater resources thus, the need for the study. Although there are several predictive equations proposed for similar problems, however

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[2], [5] reported that the predicted values vary over wide margins. The effect of pressure (simulating waste load) on contaminant flow through defected geomembrane, the transport mechanism in a geo-composite liner having natural soil as compacted clay liner (CCL) and the buffering capabilities of the natural soil have not been sufficiently documented. Thus in this work, small-scale model tests on contaminant travel through circular punctured defected geomembrane underlain by natural soil as CCL and buffering profile (BP) was conducted. The effect of applied pressure on leachate/contaminant travel rate, mechanism of travel and the buffering ability of the natural soil were investigated.

2. Material and Methods

2.1. Experimental Approach

A 24 mm thick soil barrier layer, 2 mm thick polyethylene plastic with 5 mm diameter hole placed at the center to simulate a puncture defected geomembrane and a 225 mm thick BP made up the test model setup. The bespoke device, a Modular Consolidometer-Percolation Column Hybrid with 160 mm diameter is attached to a steel loading frame capable of applying over 500 kPa pressure to the model composite barrier. A pictorial view of the bespoke device is shown in Fig. 1. The device consists of three parts: (i) the bottom part called the buffering chamber; which contained the natural soil serving as the natural earth/subsoil and BP below the geo-composite liner (see Fig. 2) (ii) the mid-block called the sample holder; contained the designed geo-composite liner (natural soil as CCL and defected geomembrane) sitting on the buffering chamber (as in Fig. 3) and (iii) the upper portion above the geo-composite liner; functioned as the leachate/permeant reservoir as shown in Fig. 4. The leachate reservoir was marked to hold a constant head of 250 mm through-out the tests. Soil layers were prepared inside the bottom chamber, the mid-block/sample holder and the defected geomembrane was placed on top of the soil liner. Moistened geotextile on a porous stone served as filter to prevent moving fines from clogging the outlet of the system. After the components were assembled, O-rings, gasket corks and silicon sealants were used to prevent leakages and maintain air-tight seals between the top, mid and bottom sections of the device. The loading frame was set up, the leachate added and the desired pressure was applied.

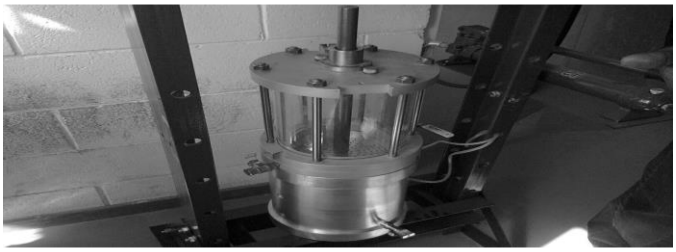
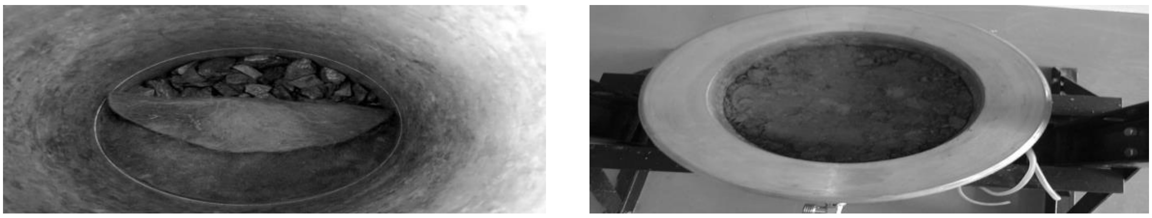
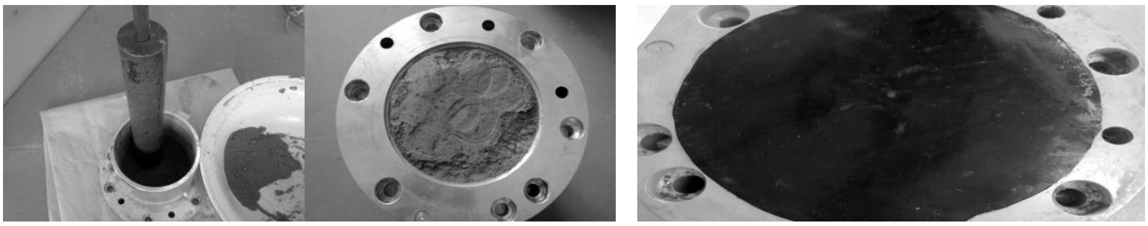


Fig. 1: Pictorial view of the modular consolidometer-percolation column hybrid device



(a) (b)

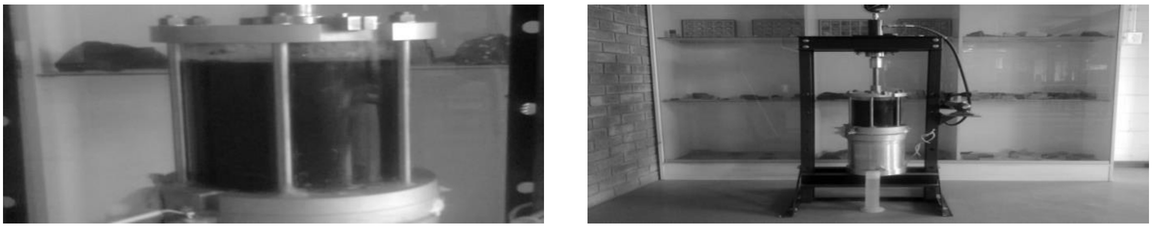
Fig. 2: (a) Wetted geotextile on porous stone to prevent outlet clogging (b) Lightly rammered BP to simulate loosed subsoil in the chamber



(a) (b)

Fig. 3: (a) Compacting the soil in layers (as CCL) in the barrier holder (b) Defected geomembrane with 5 mm hole placed over CCL

The vertical hydraulic conductivity, k_z value, in stratified soil (hydraulic conductivity of a barrier layer-attenuation layer) was calculated and used to determine the flow rate, Q. Consequently, samples collected from six sectioned cores of the BP were tested and measured for concentration of target source parameters/ions 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 in line with [6]. The natural soil (kaolinitic soil) used in the investigation as CCL and BP was collected around a landfill in the CoJ as shown in Fig. 5. The soil sample was mechanically and chemically tested. Fig. 6 shows the soil grain size distribution curve, while water content-dry unit weight relationship was determined by compaction test in accordance with [7].



(a) (b)

Fig. 4: (a) Leachate in reservoir (b) Set-up loaded by the hydraulic pressure system

Fig. 5: Pictorial view of soil sampling vicinities

The test yielded optimum water content and maximum dry unit weight of about 15.7% and 17.4k N/m^3 respectively. The compaction curve is shown in Fig. 7. The standard proctor compaction test was done using a light rammer with self-weight of about 0.0244kN and striking effort of about 595 kN-m/m^3. Values for permeability coefficient were measured by falling head test in accordance with [8] and lowest permeability, k value of 1.21×10^{-8} m/s (see Fig. 8) was obtained at MDD and OMC.

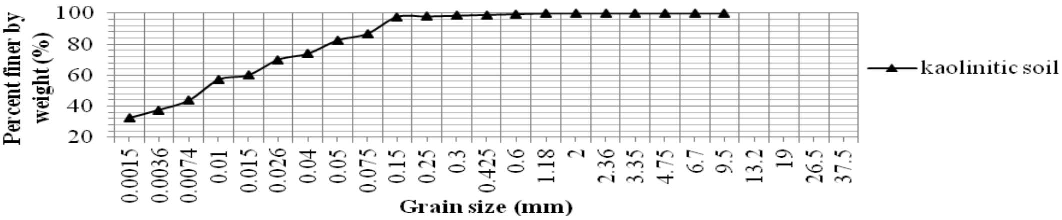


Fig. 6: Grain size distribution curve for the soil

The BP was prepared at relatively low water content and lightly compacted to simulate in-situ conditions of natural soils. Leachate used as permeant for this test was gotten from the landfill leachate pond (see Fig. 9) designed to collect generated leachate (due to infiltration of storm water and/or interception of the subsurface water with the buried waste). The permeant was taken from a number of points within the leachate pond and pooled together to ensure a proper leachate mixture. The chemical ions were measured by full spectral analysis method on the influent and effluent and compared to standard drinking water. The parameters analyzed included the following: Fe and Pb. This was conducted in conformance to [9], [10].

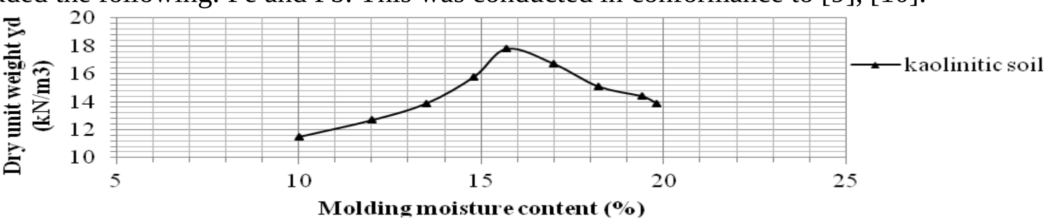


Fig. 7: Compaction curve for the kaolinitic soil

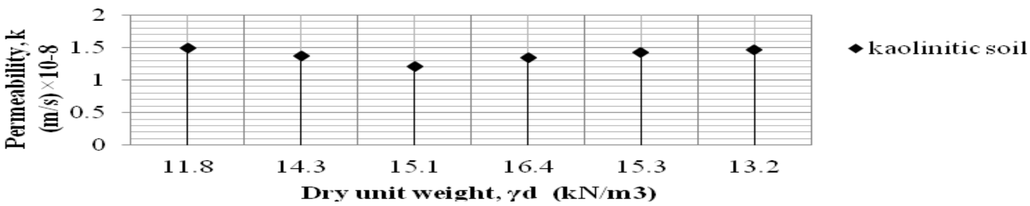


Fig. 8: Permeability variation of the kaolinitic soil sample


Fig. 9: Permeate collected from different leachate ponds

Table I shows the initial concentrations (mg/L) of the targeted chemical parameters/ions from chemical analyses for the leachate. A 2 mm thick polyethylene plastic as geomembrane with a 5 mm diameter hole at the center to simulate defect was improvised due to material constraints. A single complete percolation test lasted for a period of up to 90 days.

Table I: Analysis of Leachate Sample Used for Leaching Test

Parameter	ASTM Test No.	Concentration of sample (mg/l)	Standard for Drinking Water (mg/l)*
Fe	D 1068	6.0	15
Pb	D 3551	1.2	0.05

*(Water services authorities South Africa, 1997)

3. Result and Discussion

3.1. Flow Rate Measurement through Circular Puncture

Table II summarizes the test features, test duration and materials under which the percolation test for the natural soil was conducted. The test herein was for the sample collected around the landfill site. The leachate flow rate for the sample was measured after which concentration of migrated heavy metals through the BP was determined to investigate the mechanism of contaminant transport through the geo-composite liner as well as the buffering capabilities of the natural kaolinitic soil.

Table II: Test Features

Test No.	Barrier Lining System (Natural soil as CCL)	Geosynthetic material	Defect Size, Type and Position
	Dry Unit Weight (kN/m^3)		
1	16.2	2 mm thick polyethylene plastic as Geomembrane	5 mm circular hole in the centre
Test No.	Attenuation Profile (Natural soil as CCL)	Pressure, p (kPa)	Test duration
	Dry Unit Weight (kN/m^3)		
1	12.3	0→25→50→100→150	90 days

This was done at the end of the percolation test. Result for the leachate transport rate through the geo-composite liner is shown in Fig. 10. Steady to quasi steady state was reached in about 20 days into the test for a pressure value = 0 kPa and the flow rate was monitored and measured for a period of up to 30 days as shown in Fig. 10 before pressure was applied to the system. The flow rate, Q, was seen to gradually increase to a steady value. However, changes in flow rates were observed as pressure was applied. The first pressure, p, of 25 kPa was applied to the system. Steady state was reached after about 18-20 days and the flow rate was monitored and measured for another period of 30 days. To further investigate the effect of pressure on the systems flow rate, pressure was increased from 25 to 50, 100 and 150 kPa to simulate waste load imposing the barrier liners of a typical landfill. The flow rates, Q, were measured for each applied pressure and the duration of the entire test lasted over 90 days. An increasing pressure value on the geomembrane, showed the flow rates to gradually reduce significantly to a steady value. Fig. 11 shows the relationship between the measured flow rates, Q, against applied pressure for the natural soil.

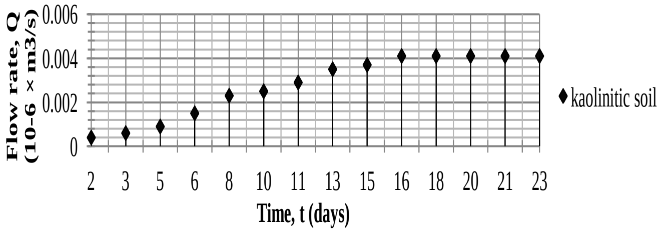


Fig. 10: Leachate flow rate against time at p = 0 kPa

The increase in pressure caused a change in density which led to a decrease in the permeability of the soil barrier. Furthermore, the pressure to the system may have created a fair contact between the geomembrane and the soil layer thereby reducing the interface transmissivity; reducing the interface thickness and transmissivity, θ. This accounts for the gradual decrease to a steady state of the flow rate.

4. Empirical View at Predicting Leachate Flow rate

The leachate transport rates through defected geomembrane have several proposed predictive equations. These equations were divided into two groups by [2], [5] based on assumed geomembrane/underlain soil contact conditions namely; perfect contact and imperfect contact. The former assumes that there is no flow at the geomembrane/soil interface, while the latter assumes that there is flow at the interface between the geomembrane and the soil barrier. As stated previously, the variation of flow rate can be caused by the change of the interface transmissivity, θ, and the permeability, k, of the soil barrier.

The representative equations for perfect contact conditions are given as follows;

$$Q = 4r_0k_Lh_{Wfig} \tag{1}$$

$$Q = 2\pi r_0k_Lh_w \tag{2}$$

In equation (1) and (2) r_0, k_L and h_w, are; radius of circular defect, hydraulic conductivity of the underlying soil barrier and leachate head on the composite liner respectively.

Equation (1) is a proposition by [11] while (2) was proposed by [12].

As for imperfect interface contact condition, [13] further divided it into good and poor contacts. The proposed empirical equation by [14] is under the assumption that there is flow at geomembrane/soil interface for a given head distribution and it is expressed as follows;

$$Q = 1.12C_{qo}[1+0.1(h_w/H_L)^{0.95}]r_0^{0.2}k_L^{0.74}h_w^{0.9} \tag{3}$$

In equation (3) C_{qo} and H_L, are; constant of 0.21 for good contact and 1.15 for poor contact, and thickness of the underlying soil barrier respectively.

Other parameters are taken as already defined. The units from equation (3) are; m in the case of h_w, H_L, r_0 and m/s in the case of k_L and should be used as such.

The predicted values from equations (1) to (3) are expressed in Fig. 11. The observations made thereof from the comparisons between the predicted values and the measured/test data can simply be interpreted as follows; that (i) using equations (1) and (2) in the case of a perfect contact condition showed inapplicability in practice and to the small-scale test conditions due to the wide variations experienced and that (ii) for a case of a good contact condition, equation (3) fairly predicts the measured/test data.

It must therefore be noted that the influence of applied pressure, p, was not taken into account in the predictive equations as compared to the test results in this study.

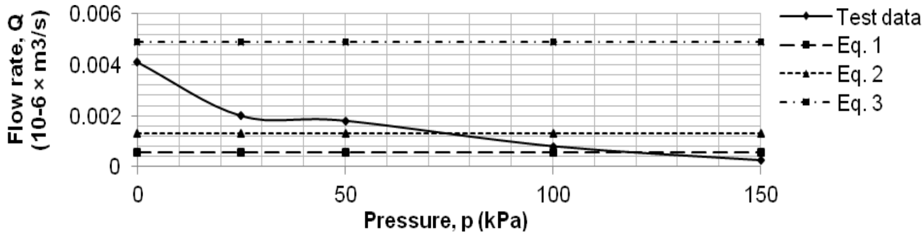


Fig. 11: Leachate flow rate against the respective pressures

5. Soil Buffer and Concentration of Transported Contaminants

From the leachate sample analyses and characterization it was found to have relatively low trace elements including heavy metals. Results from the percolation tests confirmed that these small amounts of trace elements do not migrate in any significant manner through the natural soil cores examined. Effluent and relative concentration profiles for the heavy metals; Fe and Pb with respect to the pore volume for the natural soil after reaching steady state is shown in Fig. 12. There was no recognized significant difference in the transportation of the heavy metals through the soil. Results from the BP showed the heavy metals in the natural soil to be mobile.

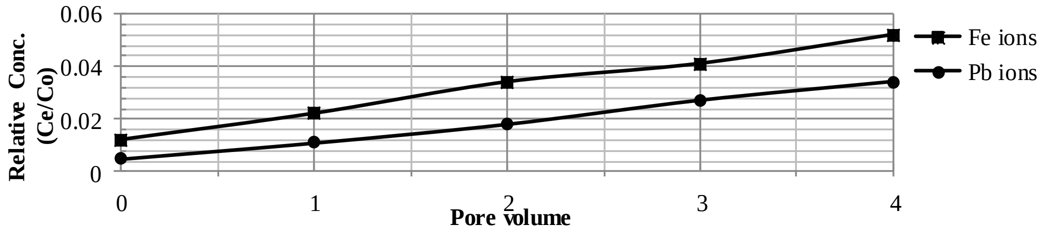


Fig. 12: Relative conc. of heavy metals in effluent (Co and Ce = initial and final conc.)

These data indicate that the exchange capacity and the chemical characteristics of the soil are the dominant features controlling the buffering of heavy metals. 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 as seen in Fig. 13.

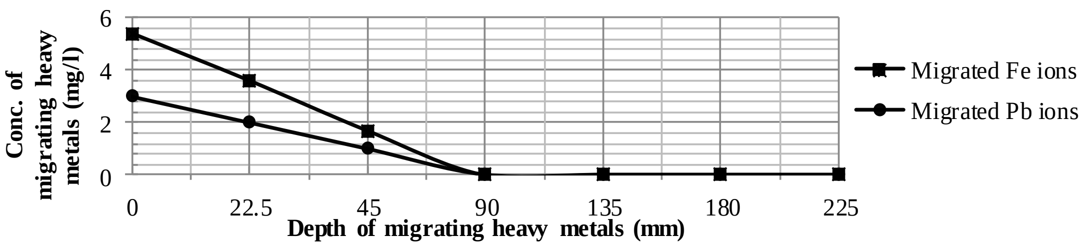


Fig. 13: Migration profiles of heavy metals through the BP

The results showed that significant amounts of heavy metals were retained in the top portions of the soil as revealed in the concentration depth profiles shown in Fig. 13. The Fe ions appeared to be more mobile than Pb ions found in the leachate, especially in the case where a more acidic environment prevailed. Therefore, the natural soil exhibited good buffering tendencies to the migration of heavy metals through the BP.

6. Conclusions

A test on geo-composite liner with circular puncture defected geomembrane under the effect of contaminant travel was conducted in a small-scale bespoke device called a Modular Consolidometer-Percolation Column Hybrid. Effect of pressure on the leachate flow rate with the transport mechanism and buffering of heavy metals were investigated. From tests and analysis of results, the following conclusions were reached;

The increase in applied pressure on the liner systems was observed to significantly reduce the leachate flow rate; and from analysis, there was clear indication that the reduction was as a result of the geomembrane/soil interface transmissivity, θ, reduction and thickness reduction of the soil barrier.

The assumption of perfect geomembrane/soil interface contact condition is not applicable to leachate flow through a defected geomembrane with underlain soil barrier. Giroud (1997) empirical equations for good contact condition provided a reasonable prediction for this problem under very low pressure (close to 0 kPa). However, the influence of pressure was not catered for by the predictive equation in their work.

The measured pore fluid concentration of the transported contaminants, confirmed there was flow through the geomembrane-soil interface; the concentration of selected contaminant ions in sectioned cores of the BP after percolation test revealed the natural soil to have good buffering abilities towards the selected chemical species/ions. However, further study needs to be conducted on the influence of pressure on the interface contact behaviour and modification is required for Giroud (1997) empirical equations such that the effect of pressure need be taken into account.

7. Acknowledgement

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8. References

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