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A comparison of single and multi-interface shear strengths at geosynthetic/geosynthetic interface

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ABSTRACT: In this study, an approach was developed to enable the comparison of the shear strength between the single and the multi-interface test configuration using the large direct shear test. The investigation utilised the peak and large displacement shear strength envelopes obtained from geosynthetic critical interfaces found in a landfill geosynthetic liner system. This analysis showed that shear strengths measured from the single interface were higher than those from the multi-interface test configuration, thus, suggesting that the multi-interface test yields a conservative shear strength of geosynthetics.

1 INTRODUCTION

The current design of a landfill liner system for safe disposal of solid wastes has evolved with the increase in environmental regulations, siting hearings, and increased public awareness. This has led many countries, including South Africa, to adopt the use of geosynthetic materials as contaminant barriers in landfills as opposed to conventional materials such as clay. However, when geosynthetics are installed on sites, particularly on landfill slopes, the interface interaction with the adjacent materials becomes the critical section where shear failure is likely to occur (Stark & Choi 2004, Stark et al. 2011). For this reason, their shear strength resistance is determined in the laboratory mainly using a direct shear device to obtain design parameters for stability analysis (Bouazza et al. 2002). These laboratory tests are preferably conducted in accordance with ASTM-D5321 and ASTM-D6243 standards.

According to Stark et al. (2011), it is evident that the laboratory interface shear behaviour between geosynthetics had been studied mainly using the single interface tests. The single interface test provides a better understanding of each shear interface characteristic of geosynthetics (Shenthan et al. 2019). This approach, however, can lead to an overestimation of the shear strength of some geosynthetic interfaces (Stark et al. 2011). It can also be an uneconomical method, in terms of time and cost, to fully understand the shear strength characteristics of the whole landfill liner system. This is because a composite liner structure consists of multiple interfaces that require testing (Stark et al. 2011). Therefore, multi-interface tests have been suggested by researchers such as Stark et al. (2011), Khilnani et al. (2017) and Shenthan et al. (2019). This test method has an advantage of directly determining the set of design values for the interface shear strength that are used in the slope stability analyses (ASTM D7702 2014). However, the comprehensiveness of this test in relation to the single interface test has not been explored. It was, therefore, for this reason that this investigation was undertaken.

2 GEOSYNTHETICS IN LANDFILLS

A landfill, according to the South African Department of Water Affairs and Forestry (1998), is an environmentally acceptable facility designed for safe disposal of solid waste. It is considered to be the cheapest and most convenient method of disposing of solid waste that cannot be reused, recycled or treated (Westlake 1995).

2.1 *Landfill composite liner systems*

The design of a landfill liner system may vary from country to country depending on the nationally adopted standards. In South Africa, the landfill liners are designed according to the category of waste to be stored. For instance, the traditional installation of materials in a hazardous waste landfill is as shown in Figure 1.

However, the construction of modern landfill liners is currently preferred as opposed to the traditional landfills. The modern hazardous liner system consists essentially of the same components, in the same order as in Figure 1, but with the compacted clay layer (CCL) being replaced with the geosynthetic clay liner (GCL). The GCL has been found to be easy and quick to install, relatively cheap, has a greater tolerance for differential settlement and a better self-healing ability as compared to the CCL (Oriokot 2018a).

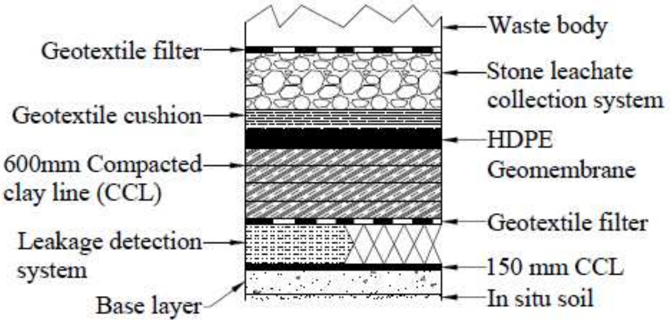


Figure 1. Installation layers for a tradition hazardous waste landfill (after DEA 2013).

In this study, the modern landfill configuration was used for the investigation. However, only the interface shear characteristics between two geosynthetics were considered as they are the most critical interface (Visser 2018).

3 EXPERIMENTAL STUDY

3.1 *Description of materials*

To replicate the anticipated landfill interface conditions, the following geosynthetics which are commonly used in landfill liners were utilized in the study.

3.1.1 *Geotextile*

The two different geotextiles (GTX) used in the tests were the bidim A10 (GTX-A) and F-25 SA (GTX-B). The GTX-A and GTX-B were manufactured in South Africa by Kaytech Engineered Fabrics Ltd and Fibertex (Pty) Ltd, respectively. These two were the most commonly used GTXs in South Africa (Stripp 2018, Oriokot 2018b). Table 1 shows the properties as given in the manufacturers' manuals.

Table 1. GTX properties (AKS and Kaytech, 2018).

Properties	Units	GTX-A	GTX-B
Mass per unit area	g/m^2	1080	140
Thickness	mm	6.4	0.7
Grab tensile strength	kN	4.70	0.58
Grab tensile elongation	%	50-80	45-65
Trap. Tear strength	kN	2.100	0.17
Punctured (CBR) strength	kN	11.7	1.70
UV resistance	%	70	70
Permeability	m/s	0.01	0.07
Pore size, O90W	µm	< 75	70

3.1.2 *Geomembrane*

A double textured, high density polyethylene (HDPE) geomembrane (GMB), manufactured by virgin polymeric resin under controlled conditions, was used in the study. The GMB had a core thickness of 2 mm and an average surface asperity height of 0.80 mm on one side and 1.81 mm on the other side. In Table 2, the physical properties of the GMB are shown.

Table 1. GMB properties (AKS 2018)

Properties	Units	M A R V	Standards
Density	g/cm3	0.946	ASTM D792
Carbon black	%	2.25	ASTM D4218
Tear resistance	N	249	ASTM D1004
Puncture resistance	N	645	ASTM D4833

3.1.3 *GCL*

A reinforced envirofix x800 GCL manufactured by Kaytech Engineered Fabrics Ltd in South Africa was utilised in this investigation. The material which was typically 2 mm to 2.7 mm thick in its un-hydrated state was made up of, from top to bottom: a white polypropylene non-woven geotextile cover, a light brown, dry sodium bentonite powder layer in the middle and a polypropylene slit film woven geotextile carrier layer (Kaytech Engineered Fabrics Ltd 2013). The GCL properties are shown in Table 3.

Table 3. GCL properties (Kaytech Engineered Fabrics Ltd 2013).

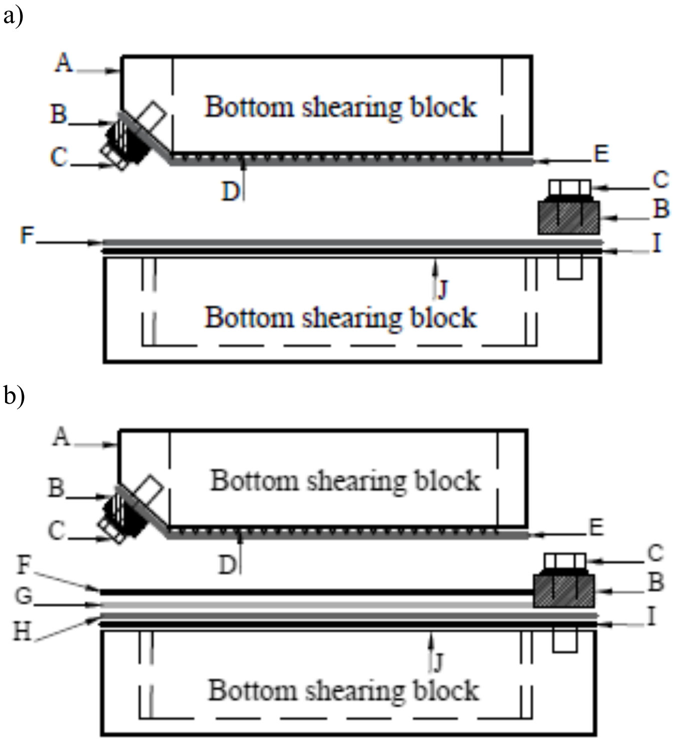
Properties	Units	M A R V	Standards
GCL Mass per Unit Area	g/m^2	4010	ASTM D5993
CBR Burst	N	1400	ISO 12236
Grab Strength (both directions)	N	600	ASTM D4632
Bentonite Layer (at 0% moisture content)	mℓ/2 g	≥ 24	ASTM D5890

3.2 *Test apparatus*

A 305 mm x 305 mm, Direct Shear Trac-III device developed by Geocomp was used in all the tests to measure the geosynthetic interface shear behaviour based on the design and testing standards recommended by the Department of Environmental Affairs (DEA) - South Africa (2013), ASTM D5321 (2017) and ASTM D6243 (2018).

3.3 *Test procedure*

Geosynthetic test samples were cut at random sections from supplied geosynthetic rolls, parallel to the factory roll direction to fit either the top or bottom shearing blocks of the direct shear apparatus. These sample sizes were sufficient to cover the entire top and/or the bottom shearing surface of the shear box such that no area correction was required (ASTM D5321 2017, ASTM D6243 2018). In Figure 2, the specimen arrangement followed during the experiments according to ASTM D5321 (2017) and ASTM D6243 (2018) is shown.



A = Top shear block
B = Clamp device
C = Bolt
D = Top gripping surface
E = Test specimen a
F = Test specimen b
G = Test specimen c
H = Test specimen d
I = Lower gripping surface
J = Metal substrate

Figure 2. Test specimen arrangement during the experiments: a) single interface and b) Multi interface test

The ASTM D5349/D6243 recommends that at least three normal stresses are needed to develop a shear strength envelope for geosynthetics. In this study, five normal stresses (50, 100, 200, 295 and 400 kPa) were selected to represent the range of stresses expected in a landfill having a unit weight of 9.81 kN/m3 and a maximum height of 30 m. The lowest normal stress, i.e. 50 kPa was used to represent the stress-dependent nature of the strength envelopes at lower effective stresses (Stark & Choi 2004).

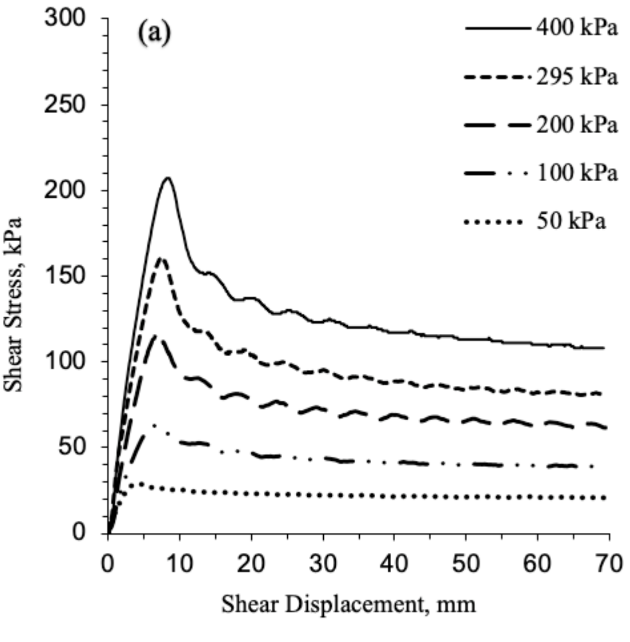
Hydration conditions, according to Fox & Stark (2004), are expected in a landfill. Therefore, all test samples were submerged in the water prior to testing to simulate the worse possible anticipated hydration in a landfill. The test specimens were fully submerged in the water for 24 hours under a normal stress of 17 kPa for all experiments involving GCL interface. The 17 kPa was used to simulate the possible initial load that would be imposed on the lining system before waste disposal (Eid & Stark 1997, Fox & Stark 2004). The test samples in the experiments that did not involve the GCL interface were hydrated for one hour under their respective shear-normal stress, i.e. 50, 100, 200, 295 and 400 kPa. Once the hydration phase was completed, a gap of approximately 5 mm to 10 mm, between the upper and lower shear blocks was created to prevent friction during shearing (ASTM D5321 2017).

During the shearing stage, the bottom shear box was allowed to move relative to the upper shear box at a constant shear rate to reach a shear displacement of 70 mm. Thus, the reduced mobilized shear strength condition was referred to as the large displacement (LD) strength (Rouncivell 2005, ASTM D5321 2017, ASTM D6243 2018). The shear rate used in interface tests involving the GCL test specimens was 0.1 mm/min while 1.0 mm/min was utilised in the rest of the experiments. This was to ensure that no excess pore pressures were built-up at the interface during the tests (ASTM D5321 2017, ASTM D6243 2018).

4 TEST RESULTS

In Figure 3, the shear stress-displacement results from both single and multi-interface tests are presented. For each interface test considered, a separate graph was produced. The interface tests were conducted at five normal stresses i.e. 50, 100, 200, 295 and 400 kPa, represented by five curves in each graph as shown in the legend.

It is evident in all plots that the rate of the shear stress development increased with increasing shear displacement until reaching the maximum/peak interface shear strength, regardless of the test configuration utilised. Beyond the peak strength, a clear shear strength reduction (shear strain softening) was observed with further shear displacement to achieve the large displacement (LD) strengths (see Fig. 4-1). At a shear displacement of 70 mm, all the experiments ended, and the measured shear stress responses were all non-linear, irrespective of the test configuration. These shear stress curves followed a similar pattern to the corresponding findings of other researchers such as Bacas et al. (2011), Bacas et al. (2015) and Buthelezi (2017).



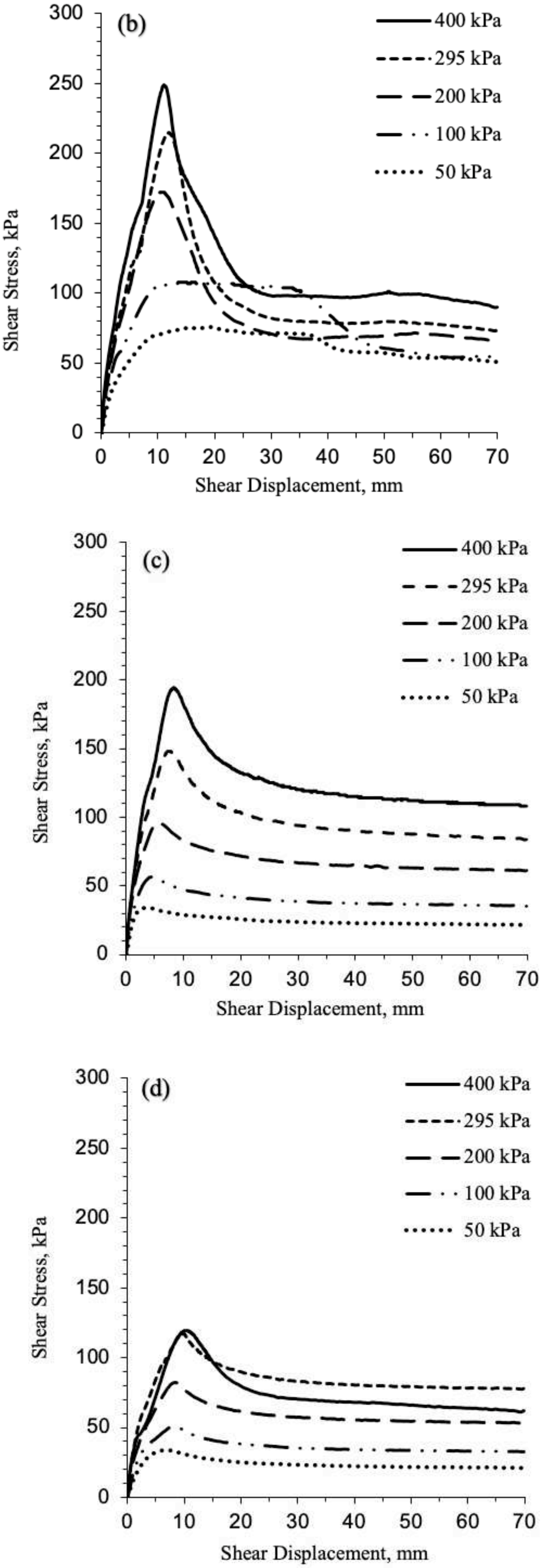


Figure 3. Shear Stress-displacement results; a) to c) single interface test and d) Multi-interface test.

In Table 4, a quantitative summary of the peak and LD strength values obtained from both single and multi-interface experiments is presented. The single interface produced higher peak and LD strengths than the multi-interface, except for tests conducted at a normal stress of 50 kPa were the GTX-A/GMB interface had the lowest peak strength value. This dissimilarity in the shear stresses increased with an increase in the applied normal stress, thus, indicating that the shear strength is also stress dependent.

Table 4. Summary of the peak and LD strength

	Single Interface						Multi-interface	
σ_n	GTX-A/GMB		GMB/GCL		GCL/GTX-B			
	Peak	LD	Peak	LD	Peak	LD	Peak	LD
50	29	20.6	75.8	51	33.9	21.5	33.4	20.9
100	63	39.2	108	54.8	56.3	35.3	50.7	32.9
200	116	61.6	172	66	95.8	61.2	82.6	53.5
295	161	81.4	215	73	148	83.9	118	72.5
400	207	108	249	89.8	194	108	119	61.9

σ_n = Normal stresses applied

The higher peak and LD strengths observed in the single interface tests can be related to the clamping devices which confined each of the two test specimens to one end of the shear block during shearing (see Fig. 3). The clamping device according to, ASTM D5243/6243, provides enough shear resistance to prevent non-uniform displacement of the tested geosynthetics. This resulted in the 'entire' applied normal stress being transferred within the tested interface (Fox et al. 2004), thus, achieving a higher shear resistance as geosynthetics are stress-dependent. Furthermore, the failure of the tested specimen occurred at a pre-determined interface as the test samples were fixed to the shear blocks (Fox et al. 2004). In multi-interface tests, however, only the top and bottom test samples were clamped, hence leaving the two middle test specimens (i.e. GMB and GCL) unconfined. As a consequence, the test samples were able to slip between each interface and failure could have occurred at any of the available interfaces depend on whichever plan was the weakest. This represented a better simulation of the field configuration for a composite liner system where multiple layers of geosynthetics are installed (Stark et al. 2015).

The results, therefore, suggested that the use of multi-interface shear test can lead to a conservative estimate of the peak and LD strength. This is consistent with the findings of previous researchers i.e. Eid & Stark (1997) who reported that single interface testing has a disadvantage of overestimating the interface shear resistance of some geosynthetics (Stark et al. 2011).

5 CONCLUSION

This study compared the geosynthetic shear strength determined using the single and multi-interface test configuration on a 305 x 305 x 100 mm direct shear apparatus. The investigation utilised the critical interface found in a modern hazardous landfill liner system. This analysis provided key findings of the importance of using one testing method i.e. single interface as opposed to another i.e. multi-interface in determining the shear resistance of geosynthetics. Based on the test results, the following conclusions can be drawn:

- The shear strength responses achieved were all non-linear for both the single and multi-interface test configuration.
- The measured shear stresses increased with increasing normal stress, thus, indicating that the shear strength of geosynthetics is stress dependent.
- The magnitude of shear strengths determined using a single interface test approach is higher than the multi-interface test configuration.
- The high shear strength obtained in single interface can be related to the clamping which confined each of the test specimens to one end of the shear block during shearing. This resulted in providing enough shear resistance to prevent non-uniform displacement of the tested geosynthetics, consequently, transferring the applied normal stress within the pre-determined failure plan which was not the case with multi-interface tests. In multi-interface tests, only the top and bottom test samples were clamped, hence, leaving the middle test specimen unconfined. As a consequence, failure could have occurred at any of the available interfaces depending on which plane was the weakest.
- Multi-interface tests yielded a conservative estimate of the shear strength for the tested geosynthetics in this study.

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