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Assessment of Protection Efficiency of Geotextiles using Adapted Geomembrane Strain Testing Methods for Evaluation of On-Site Conditions

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Abstract

Limiting strain formation in geomembranes used in a composite barrier system is critical to ensure a long-term barrier performance. This issue becomes a particularly important consideration when a designer opts to use protection geotextiles in lieu of a silty sand protection layer between leachate collection stone layers and the primary geomembrane, as strain due to gravel contact points under load can reach up to 20% if not designed correctly.

This paper aims to unpack this design consideration, and report on lessons learnt by the author through the detailing of findings, and test results and comparing these with trends from a number of in-situ strain testing results through his work in the past 5 years, using different protection geotextiles, protection layers and stone sizes.

Keywords: *Geomembrane, Strain, Gravel Contact Points, In-Situ Testing, GN 636, Compliance*

1 Introduction

In South Africa, as per the governing Norms and Standards for Disposal of Waste to Landfill published in 2013 by the Department of Environmental Affairs, all but Class D lining systems receiving Type 4 inert waste streams must incorporate a composite hydraulic barrier as part of its design. Composite lining systems involve a geomembrane (GMB) acting in conjunction with a layer of low-permeability soil, usually a compacted clay layer with inherent low hydraulic conductivity (CCL) or a geosynthetic clay liner (GCL).

Strain development in geomembrane liners directly increases the risk of early onset stress cracking, which in combination with chemical attack, and elevated temperatures as waste undergoes biological and chemical degradation, can lead to reduced service life and potential early failures of a pollution control barrier system.

Strain can be induced in a geomembrane liner via number of mechanisms; however, one of the primary mechanisms is mechanical damage due to stress contact points from other earth layers. Other common mechanisms include differential settlement and downdrag however these are far more prevalent in piggyback type designs, or when contemplating vertical expansions. To ensure sufficient service life for the duration of a facilities operational life, designers therefore attempt to limit the development of strain in the geomembrane component of the composite lining system, by designing other complementary layers to either reinforce or protect the geomembrane from strain development.

While piggyback designs and vertical expansions are becoming more common, almost all pollution control barrier systems in waste disposal facilities must include a leachate collection system, usually incorporating a 150-300mm thick layer of coarse large diameter gravel, which has made the consideration of strain development due to stress contact points from the leachate collection layer a mandatory consideration in most designs. Previous issues with biological clogging, and silt build up resulting in leachate buildup, have led to designers specifying the use of larger gravel, which significantly increases the risk of strains developing well beyond the maximum allowance strain threshold in the geomembrane liner (Peggs, 2005).

While the Norms and Standards specify the need for a protection layer of silty sand of at least 100mm thick between the geomembrane and leachate collection stone to address this issue, in practice designers often opt to substitute this layer with a high mass per m^2 non-woven geotextiles due to relative cost advantages and challenges of installing a earth layer directly on top of a geomembrane liner. Several methods have been developed to assess the puncture resistance and protection efficacy of geotextiles including ASTM D5514 and EN 13719 that have also been adapted overtime based on lessons learnt.

However, both tests being laboratory based, make use either of a controlled placement of stone or a fixed profile for stress contact points. While this is useful to allow for uniformity and repeatability for testing, it is limited in its ability to replicate exact site conditions, including:

- Stone actually used for the formation of the leachate collection layer in construction, in particular the consideration of the shape and angularity of the stone used;
- Handling and placement of stone layers using plant and machinery and loads imparted from this process, and
- Randomized orientation of stone at time of placement.

This paper will attempt to report on a novel method used in South Africa where an adapted ASTM D5514 method is used on trial pads constructed on site, in order to make an assessment of in-situ strain development in the geomembrane when making use of different protection layers including silty sand, and varying grades of protection geotextiles underlying the leachate collection stone layer. The laboratory-based methods are assessed, and their limitations and differences highlighted before explaining the test methodology used on site and how this differs from the laboratory based methods for context. The results of all the tests undertaken (laboratory and site) are then compared. Finally, lessons learnt are highlighted to provide guidance for future designs.

2 Types of Testing for Geomembrane Strain

2.1 Adapted ASTM D5514 in Laboratory - Hornsey & Wishaw Method

In the laboratory, the ASTM D5514-06-cylinder test has been widely used to calculate strain imparted into geomembranes due to gravel contact points and found to be simple to be able to undertake. This standard was updated in 2018, in part due to lessons learnt by Hornsey & Wishaw (2012). In brief, the methodology involves placing candidate geosynthetics in a pressure vessel in contact with the drainage aggregate and loading it to load indicated by the design engineer to be representative of the exposure conditions in practice (see Figure 1). Between the geomembrane and geotextile, a 0.3mm thick aluminum sheet is included and deforms with the geomembrane under load at the contact point sites from the stone. After the test is completed, the aluminum sheet is removed and using a high-resolution laser scanner, the deformation sites are mapped and then assessed in terms of relevant theory to translate the deformations into strain.

Msiza and Lauwrens (2023) reported that one major drawback of the laboratory ASTM D5514 test is that it does not allow for the assessment of the impact of the subgrade material below the geomembrane whether being a CCL or otherwise. In some cases, such as when using a hydrated GCL the stiffness of the base material can significantly affect the strain results comparted to a rigid or hard surface like concrete or cement stabilized material underlying the geomembrane. Other issues such as the effects of wrinkle formation, or mid embankment berms and crest lines that lead to stress concentrations on the geosynthetic barrier are also not accounted for.

In addition, the test can make use of a fixed aggregate profile in absence of leachate stone being provided, which does not account for randomized orientation of stone at time of placement or impacts of handling and placement of the stone during construction.

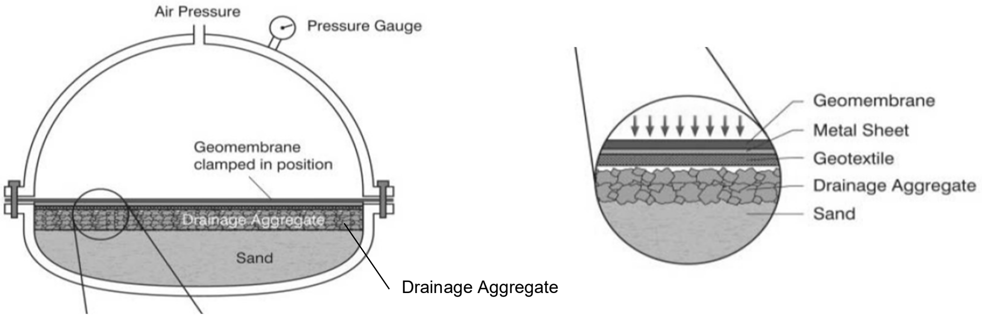

Figure 1. Test Apparatus as per ASTM D5514

Another factor when interpreting the results of the test, is the choice in method of strain analysis. Testing conducted by TRI Australasia for example, using the modified ASTM D5514 method, makes use of the Hornsey & Wishaw method. This method id is advantageous as it measures strain development of the whole surface area of the geomembrane, and therefore leads to accurate assessments of maximum strain development in plane, but not necessarily total strain as contemplated by Tongon et al. (2003). This is also in contrast with the EN 13791 methods, that evaluate incremental strain.

It is important to remember that ASTM being an American Standard, has focused on puncture resistance rather than strain limitations when developing this test method (Hornsey, 2016).

2.2 EN 13719

The test methodology used in EN 13719 is similar to that used in ASTM D5514, except for the fact that the pressure vessel is replaced with a 300mm dia. cylindrical metal tube, and a load is applied axially to the test sample via a loading frame or hydraulic jack (Figure 2). In addition, the aluminum sheet is replaced with a 1.3mm thick lead recording plate. Similarly to ASTM D5514, the test does not account for the stiffness of the underlying layer, rather using a rubber pad as a control beneath the lead sheet and geomembrane, however LFE 2 adapted method prepared in 2016 that addresses this issue.

The key difference between the methods is that EN 13719 focuses on recording incremental strain, and therefore is designed to take readings for every 3mm of movement. In addition, only the 5 worst indentations on the lead sheet are measured, and the worst 3 reported on, which can be subjective.

Figure 2. Test Apparatus as per EN 13719

While both of the above tests are relevant and appropriate when using in design, it is crucial to understand that both tests were developed to meet a certain need and requirement at the time of development, which has led to two different approaches when assessing allowable strain development in geomembranes.

Peggs (2005) notes that in Europe (particularly Germany, who were instrumental in developing geomembrane research in Europe), prior to the development of EN 13719, it was recognized that individual stones could cause a local strain deformation in the top surface of the geomembrane. Peggs et al. (2005) explains that while this would not result in immediate puncturing there was concern that this was significant enough to produce accelerated stress cracking. In Germany, for an HDPE thickness of 2.5 mm (which was the minimum requirement at the time), a 3% bending strain on the underside of the geomembrane is generated by an indentation that imposes an arch strain in the top surface (due to the indenting stone) of about 0.25%.

Hence, in Europe, protection systems are required to limit the localized multiaxial strain due to a stone indentation to 0.25%, along with a 3% limitation in global strain, and this requirement has stayed in place ever since. At the time of this research in Germany, Stress Crack Resistance in HDPE was far less then what is now prescribed in GRI GM 13, and as such there is a general belief such as by Sehrbrock (2002) referenced by Peggs (2005) that 3% limitation was far too conservative if SCR was the only concern. The American ASTM standard has since been developed with this in mind.

In South Africa, strain limitation is pegged at 3% total strain, with the Regulator often suggesting the use of Tongon et. al (2000) approach which combines arc elongation (membrane) and bending stresses as part of the calculation, to give an effective total global strain.

While there is still much debate on this issue, based on prevalent Regulatory views in the South Africa, ASTM D5514 method, combined with the Hornsey & Wishaw strain analysis method or Tongon et. al (2000) method appears to be the most appropriate for our design requirements at this point in time.

2.3 Adapted ASTM D5514 – TANDM Method

The on-site assessment of strain is effectively the same as the ASTM D5514 method as amended by Hornsey & Wishaw except that it is carried out on site, without a pressure vessel or fixed stone profile. The test is typically undertaken on a Trial Pad constructed as per the design requirements and CQA procedures for the designed lining system but can also be undertaken (if planned effectively) within a constructed cell.

During the construction of the trial pad, a 0.3mm thick aluminum sheet is included underneath the geomembrane, before the placement of the protection layer (whether geotextile or silty sand layer) and leachate collection stone. The leachate collection stone is placed using the same plant and methodology as would be used in the construction of cell, and therefore is reflective of actual installation conditions which is the major advantage of the test. In addition, the layers beneath the geomembrane whether a CCL or GCL, are prepared as they would be in the actual construction of the cell. Importantly, the test will also measure strains from any protrusions from the CCL below, if any.

A loading box of 1m x 1m is prepared within the leachate stone layer, directly overlying the area that contains the aluminum sheet, and then loaded to the design loading of the landfill by jacking against suitable plant on site to provide the necessary kentledge (Figure 3).

Once the test, is complete the aluminum test specimen is removed and scanned using a high-resolution camera or laser scanner to map global strain as per the Hornsey and Wishaw (2012) method, which can then also be translated to total strain as per Tongon et al. (2000) method.

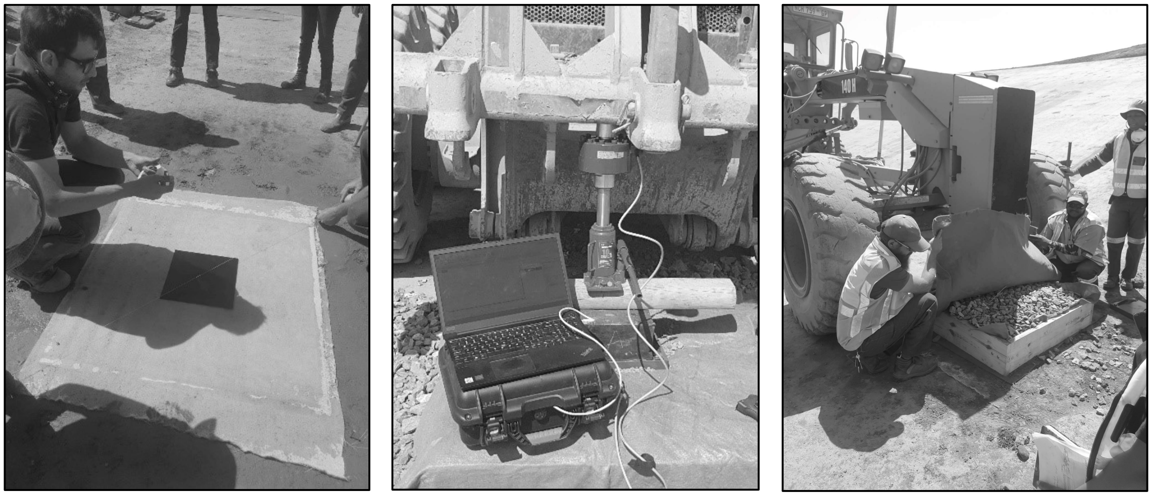

Figure 3. Test Apparatus as per Adapted ASTM D5514 method used by TANDM

3 Results of Testing Using On-Assessment Method

3.1 Test Scenarios & Designs

To date, the author has undertaken a number of on-site assessments of strain using the above method. These have been for lining systems for Class A and Class B landfills. The different lining system, scenarios and loadings associated with the different tests are summarized in Table 1 below. The details of full lining system design are not detailed below, but the key layers as it pertains to localized strain formation due stress contact points has been indicated.

Table 1. Lining Systems, Protection Systems and Loads Used for Numerous on Site Strain Assessment Tests

Test No.	Subgrade	Geomembrane Thickness (mm)	Protection Medium & Thickness (mm)	Leachate Stone Size Range (mm)	Applied Load (kPa)
Test 1	Hydrated 4500 g/m^2 GCL	1.5mm Mono TXT	1500 g/m^2 NW	300mm Thick 20-63mm	225
Test 2	Hydrated 4500 g/m^2 GCL	1.5mm Mono TXT	1200 g/m^2 NW	300mm Thick 20-63mm	225
Test 3	Hydrated 4500 g/m^2 GCL	1.5mm Mono TXT	150mm Silty Sand	300mm Thick 20-63mm	225
Test 4	Hydrated 4500 g/m^2 GCL	1.5mm Mono TXT	1200 g/m^2 NW	300mm Thick 28-53mm	600
Test 5	Hydrated 4500 g/m^2 GCL	1.5mm Mono TXT	1500 g/m^2 NW	300mm Thick 28-53mm	600
Test 6	Hydrated 4500 g/m^2 GCL	1.5mm Mono TXT	1200 g/m^2 NW	150mm Thick 12-19mm	600
Test 7	Hydrated 4500 g/m^2 GCL	1.5mm Mono TXT	1500 g/m^2 NW	150mm Thick 12-19mm	600
Test 8	200mm Compacted Clay Liner	1.5mm Mono TXT	150mm Silty Sand	150mm Thick 38-53mm	500
Test 9	200mm Compacted Clay Liner	2mm Double TXT	150mm Silty Sand	150mm Thick 38-53mm	500
Test 10	5mm Thick Cuspated Core Drain	2mm Smooth GMB	470 g/m2 GTX + 300mm Silty Sand	150mm Thick 38-53mm	370
Test 11	150mm Clean River Sand	1.5mm Double TXT	--	6mm Cuspated Core Drain (S1)	440
Test 12	150mm Clean River Sand	1.5mm Double TXT	--	6mm Cuspated Core Drain (S2)	440

The testing that has been undertaken has been specific to the needs of the specific lining system that was designed in each case, and the prevalent concern for localized strain formation on the geomembrane. The testing undertaken has not been limited to only the use of varying grades of protection geotextiles to protect the geotextile for leachate drainage stone under varying loads, but also silty sand protection layers. In addition, some of the tests has varied the particle size range of the leachate drainage stone from the standard 38-53mm to 12-19mm in some applications and geomembrane thickness and texturing has also varied. Subgrade has also varied between the use of hydrated GCLs, to CCL's as well as clean river sand used as a leak detection layer in double composite liner Class A design.

Some unique testing has also been undertaken to assess the potential for localized strain formation in geomembrane that directly overlies or is underlain by a cuspated core drain where there was concern that contact points from the cusps may induce concentrated stress on the geomembrane.

3.2 Test Results

The results of testing of the 12 test scenarios indicated in Table 1, are presented in Table 2. From the results, strains measured varied between 0.00 to 9.68%. Where laboratory testing was undertaken prior to on-site assessment, these strain values are indicated, and vary between 0.00 to 7.25%. Once the on-site test assessments were found to be reliable, and accepted by the Regulator, laboratory assessments were ceased due to logistical and economic challenges in sending samples overseas for testing. In addition, no EN 13719 was undertaken by the author for comparison purposes at time of design, but even if such assessment was undertaken, it would be difficult to compare if not translated to a total strain value to allow for effective comparison.

For all tests, other than Test 4, the protection method employed as part of the design for the respective load and drainage layer was found to be adequate to limit total strains due to gravel contacts to less than 3%, assuming no other strains are expected in the geomembrane. It must be kept in mind that, expected strains due to downdrag, differential settlement or at stress concentration points such as crest points at mid embankment benches would still need to be calculated and added to the below results before assessing whether total strain is less than 3% limit. In the designs referenced in Table 1 and Table 2, the geomembrane was designed to have 0% strain due to the forementioned strain development mechanisms, and therefore the below values are directly comparable to the 3% limit.

Table 2. Results of On-Site Strain Assessment for different design scenarios

	IN FIELD ASSESSMENT		**LABORATORY ASSESSMENT**	
Test No.	Hornsey & Wishaw (2012) (%)	Tongon et al. (2000) (%)	ASTM D5514 (%)	EN 13719 (%)
Test 1	1.71	--	5.35	--
Test 2	1.59	--	7.25	--
Test 3	0.00	--	0.00	--
Test 4	9.68	--	--	--
Test 5	1.77	--	--	--
Test 6	0.47	--	--	--
Test 7	0.54	--	--	--
Test 8	0.85	0.80	--	--
Test 9	0.90	0.77	--	--
Test 10	0.60	0.40	--	--
Test 11	1.48	1.15	--	--
Test 12	1.48	1.25	--	--

3.3 Analysis

To date, not enough data has been generated to allow for effective comparison and trend analysis where there are distinct independent variables and where all other variables are controlled and similar, however initial trends and themes can be identified within the results of testing undertaken indicated in Table 2.

From the data in Table 2, the following observations are highlighted:

1) When aggregate size range is reduced, or controlled, the lower the total strain imparted into the geomembrane. It is clear when comparing Test 4 and 6, and Test 5 and 7 results, that strain has reduced significantly when using smaller stone particle sizes when all other conditions are the same.
2) The higher the design load or pressure, the higher the strain that can be expected to be imparted into the geomembrane, although the data suggests that the load is less important than the protection mechanism used and stone particle size adopted.

3) In general, the greater the thickness or mass per m^2 of protection geotextile employed, the greater the protection efficacy. Whether it is the mass, thickness, puncture resistance or other property of the non-woven geotextile that governs this relationship is not clear from the data however, and this warrants further investigation.
4) The silty sand protection layer (when particle size is controlled), was by far the most effective method at protecting the underlying geomembrane from the imparted stresses from contact points.
5) Having a GCL subgrade compared to a CCL subgrade directly beneath the geomembrane liner, generally led to lower strain development in the geomembrane when all other variables remained the same, and when Test 3 is adjusted for loading difference. Whether this is due to stress imparted from particles contained with the CCL or that the relatively firmer CCL surface compared to the hydrated GCL cushion is unclear.
6) Cuspated Core Drains when in direct contact with a geomembrane liner can induce localized strains, of between 1-1.5% up to loads of 440 kPa.

Comparing the difference between Test 1 and Test 2 vs. Test 4 and Test 5, which other than the higher load are effectively under the same conditions, and yet do not explain the massive difference between difference in test values respectively. A key observation from assessing the stone and geomembrane surface of these respective test samples, was that specifications of the leachate stone gave little restriction or guidance on the shape and angularity of the drainage stone. The sharpness or orientation of gravel particle was found to be the key difference between these tests, and it has clearly had a significant impact on the imparted stress and localized strain on the geomembrane when comparing Test 4 and Test 2

3.4 Lessons Learnt

Based on the testing undertaken to date, and some of the observations outlined in Section 3.3, the following lessons have been applied to designs at conceptual and preliminary stage to assist in ensuring that localized strain formation is limited:

1) If possible, use a slightly thicker but smaller aggregate particle range for the leachate drainage layer. The author proposes 200mm thick 28-40mm stone size to provide equivalent drainage potential while significantly reducing the risk of strain development, however this decision may be influenced by other factors such as providing sufficient confining pressure to GCL for example.
2) Specifications on leachate drainage stone should describe appropriate crushing and screening methodologies, and/or provide limitations on shape and angularity of the drainage aggregate to reduce the risk of concentrated contact points.
3) Ensure that when using a Cuspated Core Drains as a leak detection layer and when in direct contact with a geomembrane liner, that the imparted strain due to contact points is accounted for.
4) Ensure that an on-site Trial Pad and Strain Assessment is included within the scope of works during construction stage, in order to have evidence of proven performance of the lining system designed in terms of strain limitation.

4 Conclusion

This paper reviewed the current testing methods and strain analysis tools available to calculate and account for strain development in geomembrane liners due to stress contact points from drainage layers such as drainage aggregate or cuspated drains. An on-site strain assessment method based on an adapted ASTM D5514 using the Hornsey & Wishaw (2012) method was presented. Test results from 12 different testing regimes using this method were presented, with observations from the testing indicating a strain development of between 0 and 9.38% depending on the loading conditions, subgrade formation, protection mechanisms and drainage medium employed.

Key observations and trends identified included strain generally increasing with drainage aggregate size, and increasing load applied. In addition, the greater the thickness or mass per m^2 of protection geotextile used, the lower the strain development, with the use of silty sand protection layers being found to reduce strain development even further. Subgrade type was found to play a role in strain development, with firmer CCL surfaces producing higher strains then a cushion of a hydrated GCL. Cuspated core drains were also found to impart localized strain in the geomembrane when used in direct contact with a geomembrane. Lessons learnt which have been applied to concept and preliminary designs include using 200mm thick 28-40mm stone aggregate rather then 38-53mm stone to reduce risk of strain development, ensuring specifications for leachate drainage stone address crushing processes and provide limitations on shape and angularity, and ensure trial pad and on-site strain assessment is included as part of the scope of the works.

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