INFLUENCE OF HORIZONTAL WELDED SEAMS ON GEOMEMBRANE TENSION IN A STEEP SIDED LANDFILL LINING SYSTEM

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Abstract: A 1m x 1m x 1m glass fronted test chamber has been constructed at Loughborough University to examine the effect of downdrag forces on the stress, strain and displacement behaviour of vertical landfill lining systems. A geomembrane, fixed at the top, was placed onto a fixed wooden subgrade and overlain by a non-woven geotextile. The lining system was then subjected to downdrag forces from a compressible synthetic waste, to which 75 kPa vertical pressure was applied. A series of geomembranes were tested, some of which contained horizontal fusion and extrusion welded seams. The tests showed an increase in the geomembrane tension, at the point of anchorage, of 8 to 10 % when a fusion seam was present, and 47 % for an extruded seam, compared to the a geomembrane with no welded seam.

Keywords: Geomembrane, geotextile, tensile stress, tensile strain, landfill, landfill liner,

INTRODUCTION

In landfill lining systems, sheets of geomembrane must be joined together by welded seams in order to provide a continuous barrier. In shallow slope lining systems the welded seams usually run from top to bottom of the slope. However, in steep sided lining systems, where construction occurs in lifts, it may be necessary to create horizontal geomembrane seams across the strike of the slope. In the UK, where the slope angle allows, fusion seams would generally be adopted, however, at near vertical slope angles it may be necessary to use extruded welding techniques.

Whilst the behaviour of seams have been considered in terms of leakage through defects (Giroud *et al.,* 1992), strength (Peggs, 1990; Struve and Koerner, 2005), ductility, potential stress cracking (Johnson and Rivette, 1990) and long term tensile behaviour (Berg and Bonaparte, 1993) there is limited information on the influence of seams on interface behaviour.

The initial proposal was to test the influence of seams in direct shear apparatus. However, the inclusion created by the seam would result in forced dilation of the overlying material around the inclusion, which would alter the shear stress at the interface, and the relative size of the inclusion would be large compared to the test area. It was thus decided to carry out laboratory tests in a large scale (1m x 1m x 1m) compression chamber, specifically designed to measure stresses and displacements in vertical landfill lining systems (Fowmes *et al.,* 2008), to asses the influence of welded seams on the displacement of and tensile stresses in geosynthetic lining systems exposed to shear stresses.

LABORATORY TEST DESIGN

Test chamber

The geosynthetics were tested in a bespoke test chamber, shown in Figure 1, designed specifically for testing vertical lining systems that are exposed to downdrag forces. A smooth vertical wooden wall, 1350 mm in height and 1m wide, acted as the subgrade for the geosynthetics, onto which a geomembrane then a geotextile were placed. The lining system forms one side of a 1m x 1m x 1m void which was filled with synthetic waste. Two of the other sides of the test chamber were sheet steel, whilst the final side, adjacent to the lining system was a vertical glass viewing window.

Synthetic waste material

Rubber crumb, with a grain size of 2 – 8 mm, was selected as a synthetic waste material as it represents similar compressive, shear strength and horizontal stress behaviour to municipal solid waste, whilst not displaying the large heterogeneity which can prove extremely problematic in tests of this scale. As the rubber itself does not yield during compression (elastic particle compression and particle reorganisation occurs representing recoverable and non recoverable settlement respectively), the rubber can be reused for additional tests which is extremely important when the test apparatus required $1m^3$ of synthetic waste per test.

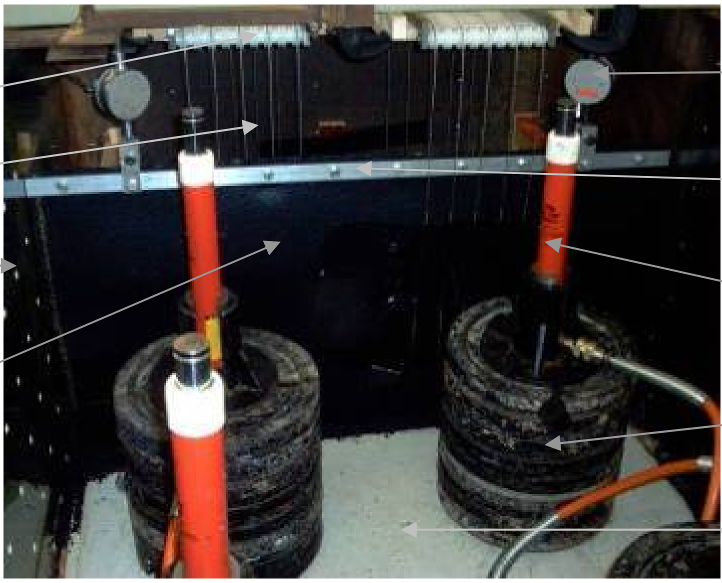

Figure 1. Photograph of laboratory test chamber

Load application

A vertical pressure of 75 kPa was applied to the upper surface of the waste. 5 kPa was from kentledge, including a ridged steel load plate (see Figure 1), and 70 kPa was applied using a hydraulic four point loading system. Vertical compressive strains of approximately 28% were induced. The loading was limited to 80 kPa (75 kPa and 5 kPa self weight) at the base of the chamber due to the glass viewing window in the test chamber.

Geosynthetic materials

A single type of textured LLDPE geomembrane from the same roll was used for all of the tests reported within this paper. The welding of the seams was carried out by the contractor at the site. As the samples were delivered from site, some clay deposits accumulated on the surface of the materials. These were removed using jetted water, as removal of the clay using any abrasive techniques was found to damage the texturing. The geomembrane properties are summarised in Table 1.

Table 1 Geomembrane Properties

	Geomembrane properties
Polymer Type	LLDPE
Resin Density	< 0.926 g/cc
Texturing	Double
Texturing Type	Blown film
Thickness	1 mm
Asperity Height (ave.)	0.25 mm
2% modulus	$4x10^5$ kPa
Break Strength	17.5 kN/m
Break Elongation	400 %

The overlying protection geotextile had a thickness of 3.9 mm.

SEAM INCLUSION

Two tests with seam inclusions have been carried out, one of which contained a horizontal fusion bonded seam and one with a horizontal extruded seam. Cross sections through the extruded and fusion seams can be seen in Figure 2a and Figure 2b respectively. The materials were placed so that the seam would be representative of field orientation; with the upper part of the seam overlapping the lower portion, and the side from which the seaming was carried out facing the geotextile. In each case the seam was located 500 mm from the base of the test (i.e. half way up the height of the undeformed rubber crumb).

(a)  (b) 

Figure 2. (a) a cross section through an extrusion welded seam and (b) a tab from fusion welded seam

Interface shear strength

The interface shear strength between the wooden subgrade geosynthetics and rubber crumb was measured in a direct shear apparatus with a shear area of 300 x 300 mm designed specifically for measuring geosynthetic interface behaviour. The derived interface shear strength behaviour is shown in Figure 3. The peak strength for the geotextile – geomembrane interface is slightly lower than that of the rubber crumb – geotextile interface, however, it is mobilised at smaller displacements. The weakest interface is the wooden subgrade – geomembrane interface, however, the clamped geomembrane restricts movement along this interface, and hence displacement is controlled by the tensile properties of the geomembrane.

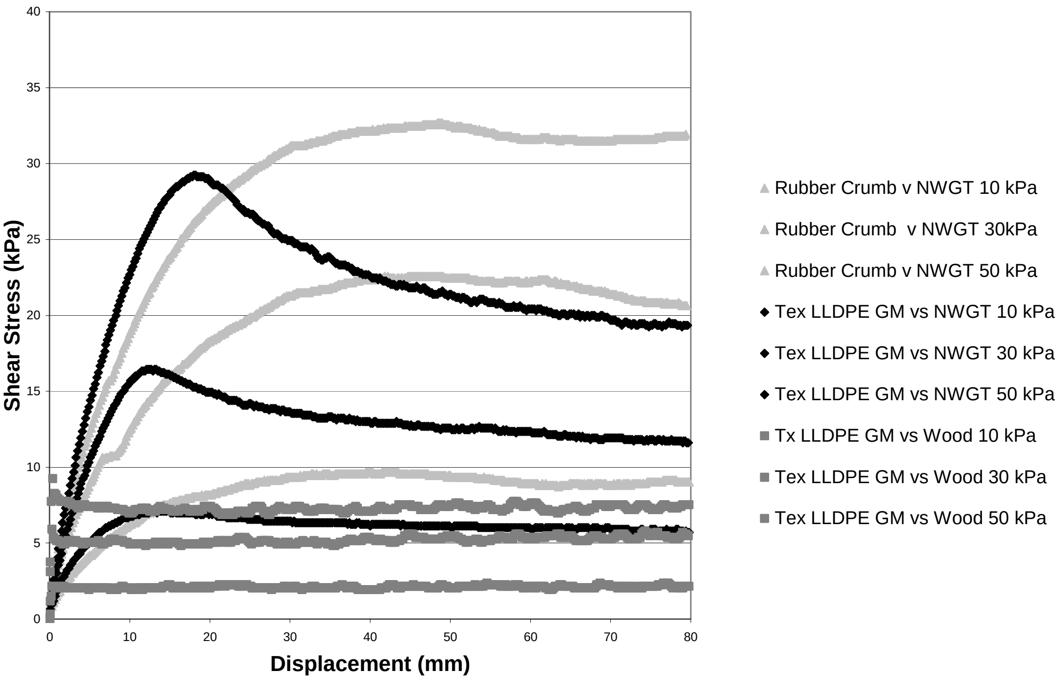

Figure 3. Shear stress vs. displacement curves measured using direct shear tests

INSTRUMENTATION

Synthetic waste settlement

The vertical position of the load plate was measured using a linear MTS Temposonics position sensor. Preliminary tests were carried out with visible markers in the rubber crumb that could be monitored, through the glass window, during compression to ensure that compression was uniform through the vertical profile of the sample. Following the preliminary tests, which showed greater compression in the upper section of the rubber crumb than near the base, the sheet steel and glass walls of the test chamber were lined with a 0.1 mm thick sacrificial plastic sheet to reduce the boundary effects. This resulted in an observed compression in the lower 200 mm of the rubber crumb being equal to 91% of the settlement in the top 200 mm of the rubber crumb, which was considered to be satisfactory.

Geomembrane Displacement

The displacement of both the geomembrane and geotextile were monitored at 200, 400, 600, 800 and 1000 mm above the base of the geosynthetics (measurements are prior to deformation). Wires were attached to the geosynthetics at these points through small holes created in the geosynthetics, whilst it is acknowledged that this would not be appropriate on site; it allowed the wires to be attached with only a small inclusion being formed. The wires were run to the surface via pulley wheels over displacement measuring boards (see Figure 1) and each wire was tensioned using a 0.2 kg static weight. Between attachment with the geosynthetic and upper surface of the test, the wires were isolated inside brass tubing to avoid interaction between the geosynthetic and wire gauges except at the area of interest.

Geomembrane Tension

The geomembrane was anchored at the top using an aluminium flatbar clamp which was attached to a fixed steel frame via two tensile load cells (see Figure 1) allowing the axial force at the top of the geomembrane to be measured. The tensile load cells had a 12 kN limit and 1 N resolution.

RESULTS

Geomembrane force

The axial tensile force at the geomembrane anchorage is shown in Figure 4. For reference, the results are compared to a test with no seam present (Fowmes *et al.,* 2008). This test was selected as it best represents the behaviour of a geomembrane without an included geomembrane seam. The fusion welded seams slightly increase the maximum developed axial force, from 2.36 kN/m with no seam, to 2.57 kN/m and 2.60 kN/m where the seams were present (increases of 9 and 10% respectively). The increase in geomembrane tension only became apparent after 35 kN applied vertical load. This is believed to be a function of the increasing horizontal stress causing the inclusion of the seam to have greater influence.

When a horizontal extrusion welded seam was included in the test, a significant increase occurred in the measured axial force at the geomembrane anchorage. The maximum value recorded was 3.48 kN/m (an increase of 47 % compared to the sample without a welded seam). The effect of the extruded seam can be seen to increase the measured tension from around 15 kN applied vertical load, which is lower than for the fusion welded seam. As the extrusion weld forms a greater inclusion the effect is seen at lower stresses.

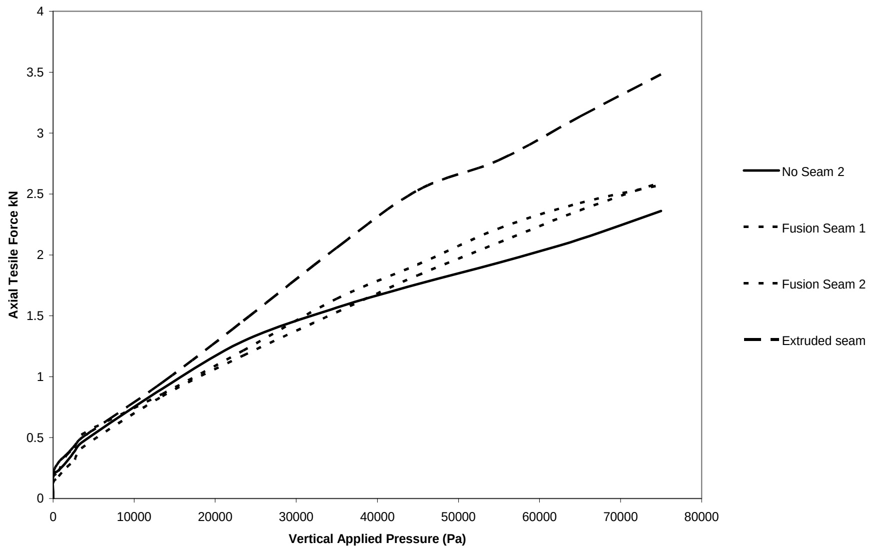

Figure 4. Tension in LLDPE geomembrane with and without welded seams

Influence of seams on geotextile folding

It was noted during exhumation that folding of the geotextile occurred around the location of both the extrusion and fusion welded seam, although this was more pronounced for the extruded seam than for the fusion welded seams. The inclusion of the welded seam is thought to provide a stress concentration that induces the folding in the geotextile, once the fold forms this will in turn provide an inclusion that further increases the fold propagation.

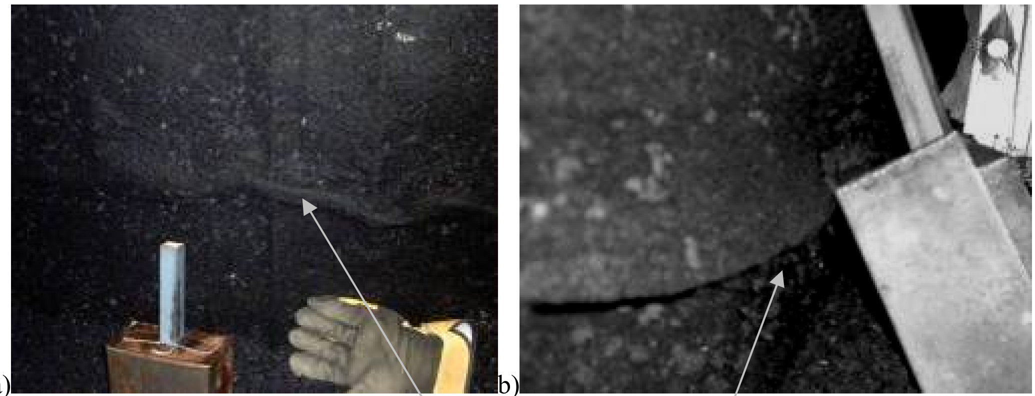

Figure 5. Folding of the geotextile approximately 500 mm above the base of the sample in a) test “Fusion Seam 1” and b) test “Extrusion seam”

It should be noted that

Figure 5 shows the seams photographed following exhumation of the synthetic waste material. Removal of the load applied by the hydraulic jacks resulted in upwards vertical movement of the synthetic waste of approximately 85 mm (≈ 35% of the total compression), and it is likely that the folds were more pronounced before removal of the vertical load and associated elastic recovery in the synthetic waste.

Interface relative shear displacement

The presence of the seams increases the displacement between the geomembrane and the wooden subgrade (Figure 6a). This is in line with the increase in axial tensile force in the geomembrane, as increased tensile force results in extension of the geomembrane, and hence displacement between the geomembrane and subgrade. The geomembrane with the extruded seam showed the greatest extension and hence the greatest relative shear displacement, 15 mm, between the geomembrane and the geotextile. The fusion welded seams show a maximum relative shear displacement of 14 mm at 200 mm above the base, however, this decreases to only 4 mm at 1000 mm, the same as when no seam is present.

The relative shear displacements between the geomembrane and geotextile are shown in Figure 6b. The presence of the extruded seam reduces the displacement between the geomembrane and geotextile to a maximum displacement of 96 mm compared to 144 mm with no seam present. This is believed to be due to the seam providing a rough inclusion, which is high friction and the geotextile must pass around the inclusion, thus reducing the displacement that can occur. A distinct fold in the geotextile formed around the extruded seam altering the displacement profile, increasing above the level of the seam; however, the overall displacement was still less than with no seam. Interestingly when the fusion bonded seams are present, the displacement above the level of the seam (500 mm from the base) were greater; 181 mm and 186 mm compared to the 144 mm with no seam present. However, the displacements below the level seam were less than with no seam present. This is thought to be due to the development of a fold around the level of the seam which caused the greater displacements in the upper region, which was not observed in the sample without a seam, however, greater folding near the base of the sample was seen with no seam present.

The displacements between the geotextile and rubber crumb are shown in Figure 6c. The displacements at this interface are inversely proportional to displacements at the geomembrane - geotextile interface, hence, whilst movements were restricted between the geomembrane with the extruded seam and geotextile, in this test, greater displacements occur between the geotextile and rubber crumb, with a maximum displacement of 188 mm compared to 148 mm with no seam. Where the fusion seams are present, less relative shear displacements occur above the level of the seam, when compared to the no seam sample, and greater displacement occurs beneath the level of the seam.

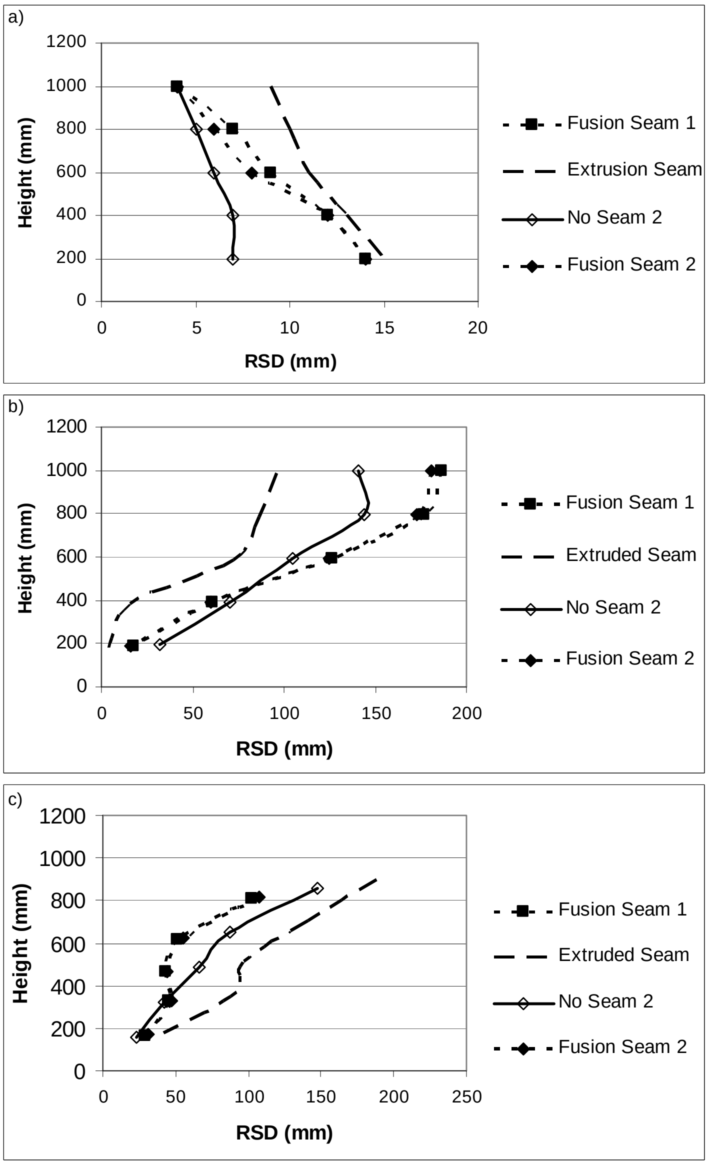

Figure 6. Relative shear displacement between the (a) Wooden subgrade – geomembrane (b) geomembrane – geotextile and (c) geotextile – rubber crumb interfaces**.**

DISCUSSION

The laboratory testing carried out in this paper is not intended to directly represent behaviour of a landfill lining system; it was instead designed to represent the interaction of lining system components when exposed to downdrag forces, and hence generate post peak shear strength interface displacements experienced in side slope landfill lining systems. It must be acknowledged that real world landfill lining systems generally have a drainage layer between the protection geotextile and the waste, thus altering the stress transfer into the geomembrane. The laboratory box was designed for validating of a numerical model against measured behaviour (Fowmes *et al.,* 2008)

The effects of a fusion bonded seam is shown to have caused a small increase in the geomembrane tension, although the magnitude of this increase is only 10% in the worst case, therefore, designers should be mindful of this and allow for the potential stress increases in their factors of safety. The presence of an extrusion welded seam, when subjected to down drag forces, has been shown to cause an increase of 47% transferred stress into the geomembrane. The authors would suggest that designers should be careful when calculating geomembrane tension, as values which ignore seams will be unconservative.

Although many sites do not require the need for horizontal seams, complex geometries may develop, particularly around corners in the lining system, which require seams in a non-vertical orientation. Seaming techniques should not only maintain the strength of continuous barrier requirements of the geomembrane, but also, where possible, not provide a significant inclusion which will act to concentrate stress into the geomembrane layer.

The geomembrane, including the seam must still act as a continuous barrier layer, and hence the seam must offer sufficient strength and not provide a preferential flow path through the barrier. Geomembrane seam performance should be tested using appropriate methods and CQA procedures carried out to ensure seam quality. Whilst this paper focuses on the additional stress induced in the geomembrane by the presence of the seam, the stress concentration directly at, and adjacent to the seam, should be considered in terms of accelerated stress cracking and creep.

CONCLUSIONS

When post peak shear strength displacements were generated between a geotextile and geomembrane, the relative shear displacements in a multilayered lining system were further complicated by the presence of seams. Extruded seams formed a rough inclusion that acted to prevent interface displacements, whilst the presence of both extruded and fusion welded seams was shown to induce folding in the overlying geotextile that altered displacement behaviour within the system. Hence, horizontal seams in geomembranes were shown to increase the measured axial force at the point of anchorage. Extrusion welded seams resulted in 47 % increase in measured tensile force; whilst fusion welded seams resulted in an increase of between 9 and 10 %. It is recommended that the increased transfer of stress into the geomembrane, and subsequent increased strain, due to the presence of the horizontal seams, should be accounted for in design.

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