Geosynthetic interface displacements during the construction of a landfill cap

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ABSTRACT: This paper reports the findings of a unique field instrumentation project on a steep, 1(v) in 2.3(h), landfill cap. Displacements and strains were monitored during and post placement of restoration soils above a geosynthetic cap. The relative geosynthetic interface displacements were measured between the Geomembrane (GM) and both an underlying geotextile and an overlying Geocomposite Drainage Layer (GDL). The instrumentation was installed during 2014 and was monitored over a five-month period. The instrumentation comprised two monitoring tables each with six extensometers to measure displacement and relative displacement within the geosynthetic lining system of the landfill cap. The locations of the extensometers were 10, 15 and 20m below the crest of the slope for both the GM and GDL. All of the extensometers cables were installed over the GM and underneath GDL panels. Additionally, six DEMEC strain gauge installations were made, each comprising a set of 4 markers to facilitated four strain measurements at each of the six locations (two measurements across the slope and two measurements along the slope). Displacements were reported in the GM and at the GM - GDL interface that were indicative of post peak conditions, however, it should be noted that the displacements occurred at low confining stresses where displacements induced interface wear is less prevalent.

Keywords: Interface shear, landfill capping, instrumentation, stress path

1 INTRODUCTION

There has long been debate over the use of peak or residual strengths in the design of geosynthetic lining systems (Theil, 2001; Jones et al., 2003; Stark and Chio, 2004), with concerns that the magnitude of *in situ* displacements exceeds the displacement at which peak strengths are mobilised. Laboratory studies (Fowmes et al., 2008), site instrumentation (Zamara et al., 2012) and numerical studies (Sia and Dixon, 2012; Zamara et al., 2014; Fowmes et al. 2007) have all indicated the possibility that post peak displacements may occur in landfill liners, especially when exposed to settling waste masses, however, there is limited information on geosynthetics displacements in capping systems. Following analytical work presented by Fowmes and Zamara (2014) as part of a steep capping project in Warwickshire, UK, the authors undertook site instrumentation in order to measure geosynthetic interface displacements, in particular focusing on movements during the placement of restoration soils above the geosynthetic cap.

This paper reports the geosynthetic interface displacements associated with the geosynthetic materials in the permanent capping on the lower bench of the site. The capping system comprised 3 layers of geosynthetics, with instrumentation concentrated on the Geomembrane (GM) and overlying Geocomposite Drainage Layer (GDL). A second GDL was present beneath the GM which was not investigated as part of this project, as this was already in place prior to the project commencing. The slope under investigation forms the lower of four benches of an 80m high waste slope. The lower slope is ~25m in height with a variable slope angle of up to 1(v) in 2.3(h). The permanent capping system comprises a buttress of restoration soils to aid stability (FCC, 2014) and restoration soils vary in thickness from 1 to 3m in the area of study. Further details of the slope geometry and numerical modelling of the post installation deformations have been reported previously by Fowmes and Zamara (2014).

The instrumentation comprised a series of wire extensometers and DEMEC gauges and was installed by the authors between 11th August 2014 and 22 August 2014 and the monitoring period reported herein ranges from 22 August to 24 November 2014.

2 INSTRUMENATION

The investigation comprised two primary geotechnical monitoring systems and was supported by local surveying on site. The first comprised a series of wire extensometers attached to the GDL and the GM. Two monitoring tables (See Figure 1 and 2) each with six extensometers were installed as part of a monitoring condition within the permit for the site. This was to measure total displacement and relative displacement within the geosynthetic lining system of the landfill capping. The monitoring tables were spaced 10m (two panels of GM) horizontally across the slope from each other. The location of connection points of the extensometers to the geosynthetics were 10, 15 and 20m below the crest of the slope for both the GM and GDL. The extensometer system used 1.5mm steel wire within a 6mm OD nylon tubing to protect the cables from pinching outside of the area of interest. The resilience of the tubing was trialed in a 300mm shear box under 100 kPa, nearly double the maximum representative loadings. The monitoring table was a welded steel structure, fixed to a 100 mm concreted base for stability, with lubricated machined nylon runners, and was the same equipment as previously deployed at Milegate Quarry Extension landfill as reported by Zamara et al. (2012). Tensioning of the wires was carried out using weights hung from the free end of the pulley system.

Figure 1. Extensometer Measuring Table and Cables

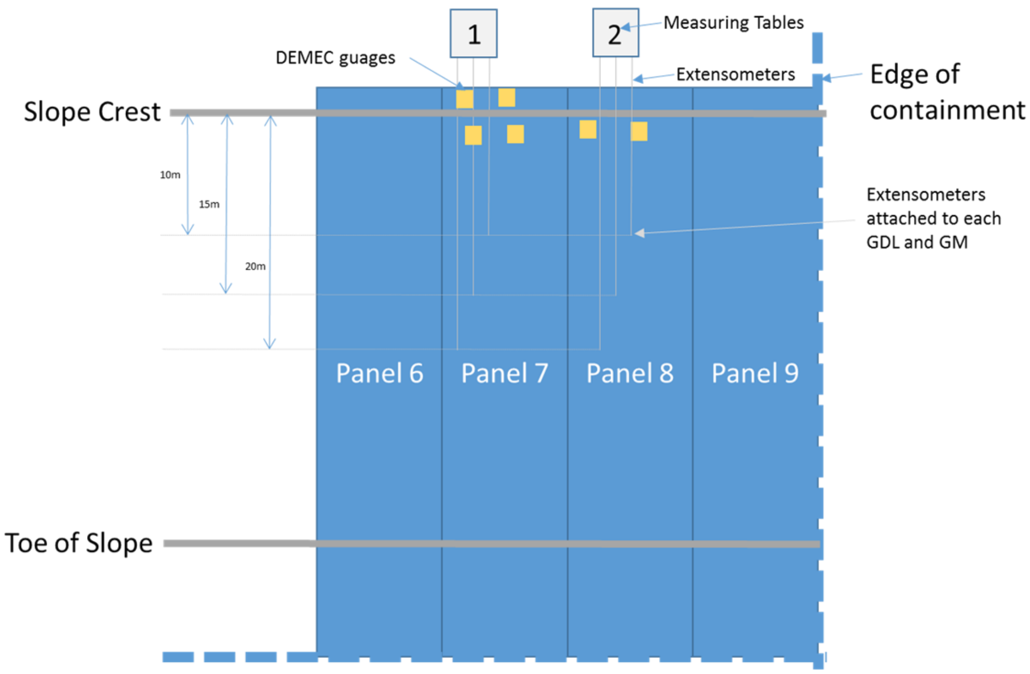

Figure 2. Schematic Location of Instrumentation

Six DEMEC strain gauge installations were made (above and immediately below the slope crest on the GM near to Table 1 and just below the crest near Table 2). Each comprised a set of 4 marker points (See Figure 2 and 3). This facilitated four strain measurements at each of the six locations (two measurements across the slope and two measurements along the slope). Although initial readings were taken on the DEMEC strain gauges, these were erroneously buried during the placement of the first 500mm of soil. Although they were exhumed, no meaningful readings could be taken from these and the remainder of the paper shall concentrate on the extensometer findings.

Figure 3. DEMEC installations

3 MONITORING HISTORY

In order to allow comparison to the results presented later in the paper, Table 1 below presents history of instrumentation installation and cap construction. It should be noted that the entire slope was covered with 500mm deep soil layer within one stage (Table 1, Event Ref 4); this was followed by further soil installation (Table 1, Event Ref 5).

Table 1. History of instrumentation installation and slope cover construction.

Ref No	Date	Action
1	22/08/2014	Installation of Extensometers and Demec Strain Gauges on the GM
2	28/08/2014	Installation of Extensometers and Demec Strain Gauges within GDL
3	02/09/2014	Lower 10m long section of slope covered with soils
4	05/09/2014	Slope covered with 500mm of soil
5	26/09/2014	Stability buttress in place

4 MEASUREMENTS

The measured displacements in the GM are shown in Figure 4, whereby positive values are downslope movements. These represent relative displacements of points on the GM to the underlying subgrade, defined by a reference datum of at the measuring table at the crest of the slope, which for the sake of this plot is assumed to be static. Large displacements (>100mm) were recorded on both tables on 05th September 2014. This corresponded to the placement of the first 500 mm of cover soils. Interestingly these displacements were upslope on Measuring Table 2 and downslope on Measuring Table 1. This can be attributed to placement direction of the bulldozer near to the edge of the geosynthetic area. Table 2 presents final displacements recorded on the 24th of November 2014. As with the values presented in Figure 4, these are absolute displacements based on an assumed fixed datum of the monitoring table.

Table 2. Displacements at the end of the monitoring period.

Location below the crest	Table 1		Table 2	
	GM [mm]	GDL [mm]	GM [mm]	GDL [mm]
10m	165	326	-111	-71
15m	186	320	-129	-61
20m	100	219	-102	-94

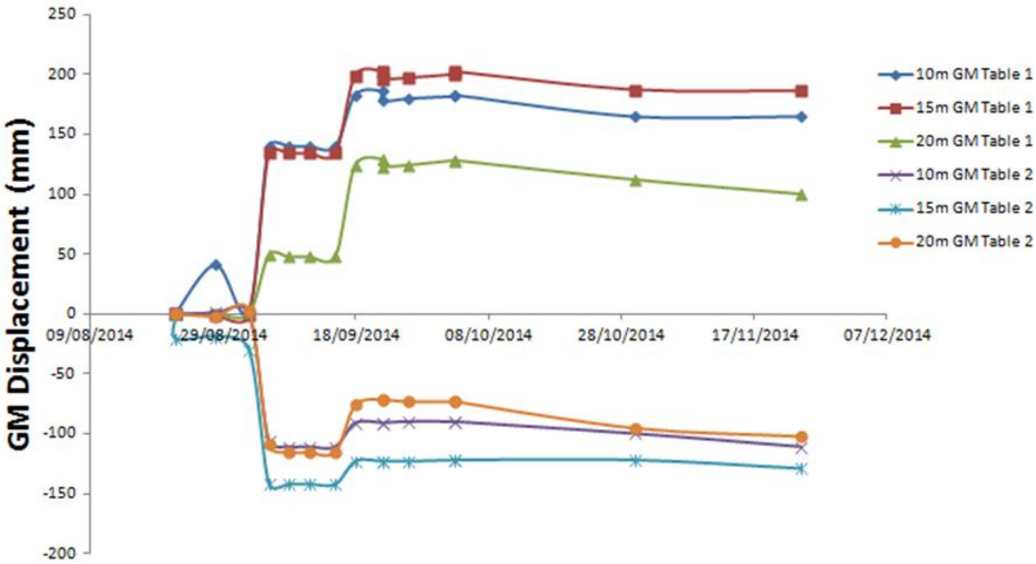

Figure 4. Displacement of the Geomembrane

Additional movements can be seen on both measuring tables on 26th September 2014 as a result of the second soil layer being placed. In this case all of the movements were downslope, despite an upslope placement of soils using a bulldozer. Although displacements were smaller than for the first soil layer, downslope displacements of up to 81mm were reported.

Figure 5 presents the relative displacement between the GDL and GM. As with the GM displacements, two events dominate the time displacement chart. Firstly, relative movement of over 100mm are recorded during placement of the first 500mm of soil. These relative displacements are positive and show the GDL moving downslope relative to the GM. The second event shows relative movements of up to 23mm during the placement of the second soil layer.

Approximate strain development calculation can be carried out based on the extensometers monitoring data. Final strains developed within the Geosynthetics are summarized in Table 3. This provides only indicative information on the geosynthetics tensile condition, as local displacements might be affecting the reading that would not be representative for all of the sections. In simple terms the lower monitored sections (middle on the slope) of the Geosynthetics undergo compression. The top section is generally in tension, except for the GM Measuring Table 2, which indicates compression. This is in partial agreement with the numerical modelling by Fowmes and Zamara (2014) which predicted areas in vicinity of the crest are expected to develop tensile strains, while lower sections of the slope undergo compression. The measured barrier layer GM tensile strains do not exceed 0.54%, while GDL strains undergoes compression, only one location indicates tensile strains of 0.2% on the Measuring Table 2.

Table 3. Final strains, as per readings undertaken on the 26th of November 2014 negative indicates contraction).

Location below the crest	Table 1		Table 2	
	GM [%}	Upper GDL [%]	GM [%]	Upper GDL [%]
10-15m	0.42	-0.12	-0.36	0.2
15-20m	-1.72	-2.02	0.54	-0.66

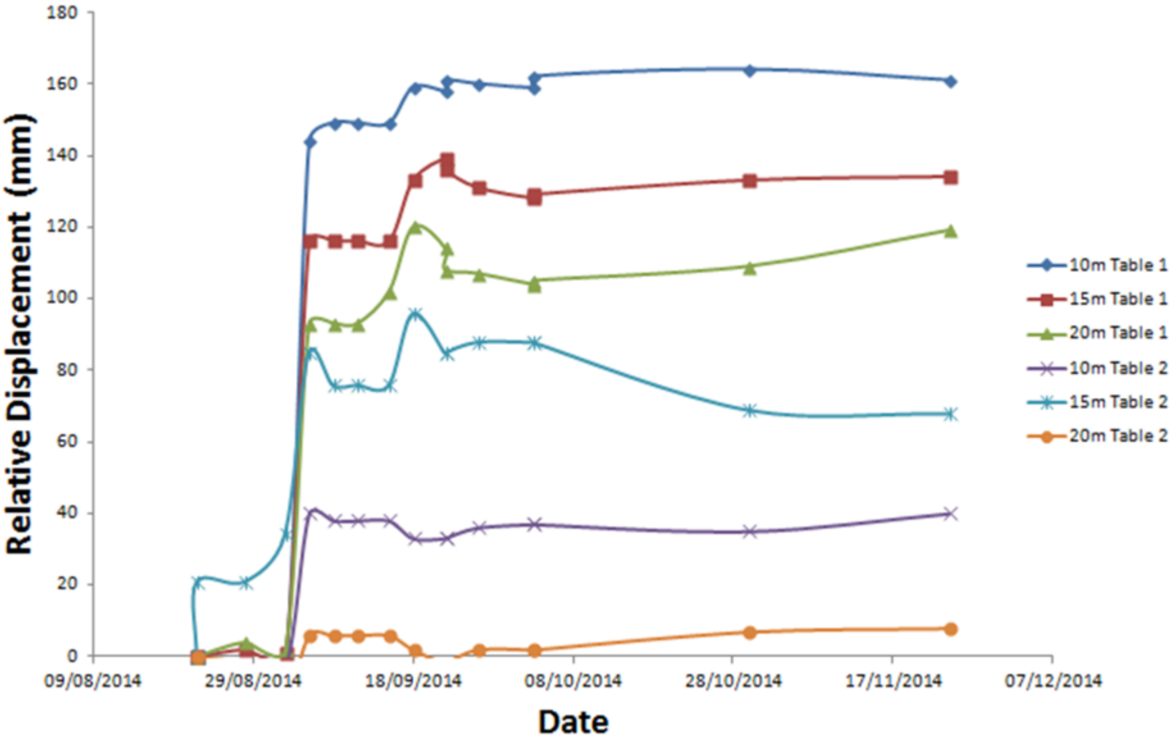

Figure 5 Relative Displacement of the GDL and GM

5 INTERFACE STRESS PATHS

The most prominent observation from the results presented above is the magnitude of the recoded displacements. Figure 6 presents the measured shear stress displacement curves using a 300mmx300mm direct shear apparatus (DSA) for the GM - GDL interface for 10, 20 and 50 kPa normal stresses. The peak shear strength is mobilized at below 6mm, however, the recoded field relative displacements were up to ~160mm, twice that in a typical geosynthetic DSA test.

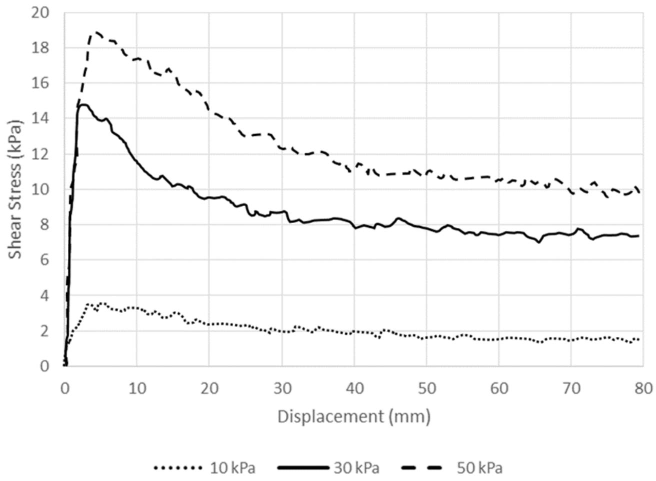

Figure 6 Shear box test results for GM GDL Interface

The largest initial displacements occurred during the placement of the first 500 mm of soils on the slope, therefore, the stress range at this level was between 0 and 10 kPa. With further displacements of 10s of millimetres occurring during the second phase of soil placement with a stress range of 10-60 kPa. The displacement magnitudes were in excess of what was expected by the authors prior to the study, and what is not clear from these results is the exact stress paths (full displacement-stress history) experienced by the interfaces during placement of the soils. Unlike in a typical DSA test, normal stress, displacement and shear stress are all changing during the tests, therefore, it is not simply a question of what displacement has occurred, but also at what normal stress and most importantly what physical affect this has had on the interface.

A limitation of this study was that continuous monitoring was not available for the extensometers during placement of the fill. This, along with detailed survey records for the soil placement would have allowed a more detailed assessment of the stress path to be determined. Additional further work from this study included the detailed assessment of the development of wear at geosynthetic interfaces, focusing on the physical changes at the interfaces, rather than simply assessing if the displacement is "post peak". Initial outputs from a doctoral research project addressing this were presented by Zaharescu et al (2015), who showed that interface wear is a key parameter where changing normal stresses occur. Despite large displacements at low normal stresses, if the interface wear is low, full peak strength can be mobilized at higher normal stresses, thus not impacting on the long term performance of the containment system.

6 CONCLUSIONS

Displacements were reported in the GM and at the GM-GDL interface that could be indicative of post peak conditions. However, it should be noted that the displacements occurred at low confining stresses where displacement induced interface wear is less prevalent.

For future monitoring installations, greater control on the filling process is required to allow readings to be taken at more regular intervals, and detailed observations on the filling methodology. The above data is unique and presents first of this kind monitoring data carried out on a landfill capping system. Therefore, the conclusions at this stage are limited and comparison with any other existing data is not possible. It should be highlighted that further instrumentation of this kind would enhance findings of this project and increase understanding of the geosynthetics performance on the landfill capping systems.

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