Permanent capping of temporary waste slopes: the challenge of declining waste streams

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Permanent capping of temporary waste slopes: The challenge of declining waste streams

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ABSTRACT: With diminishing waste streams many sites now face closure before filling to intended profiles. As a result, slopes which were intended as temporary waste slopes now require permanent capping solutions to be installed. These slopes are often steep and challenging to cap. Various stability and integrity issues arise with solutions including the use of reinforcement within the capping layers. However, on long slopes the total forces are often large and anchorage on benches can be problematic. Tapering the cover soils can achieve a stable solution; however, large soil volumes may be required to achieve a satisfactory resistance to failure.

This paper considers a case study of a 72m high temporary waste slope requiring a permanent capping solution. Interface shear strength is critical on such steep slopes and sampling, testing and interpretation requires careful consideration. A number of shear strength tests were carried out as part of the project and this paper shall consider the designer's concerns around the interpretation of these tests for use in stability analysis. As part of construction of the regulating soil, variable material was delivered to site, some with moisture content higher than specified, thus potentially reducing the strength and introducing a weak layer. This paper considers the challenges in stability risk assessment, data interpretation and future instrumentation requirements at the site.

Keywords: Geosynthetic Interfaces, Landfill Capping, Geomembrane, Geotextile, Restoration

1 INTRODUCTION

With diminishing waste streams to landfill, many sites are reaching a stage of being no longer commercially viable, however, final landforms have not been realised. This poses a number of challenges including, but not limited to:

- Steep "temporary" waste slopes requiring permanent capping solutions as sites can no longer be completed.
- Surface water management; involving capacity below discharge and scour on steep slopes.
- Asset write off: often sites remain in "mothballed" temporary closure to avoid writing off the void as an asset.
- Planning and aesthetic concerns; incomplete sites can be unsightly.
- Environmental risks such as where hydraulic containment was the long term objective and cannot be completed.

This paper shall focus on only the first of these challenges, whereby over steepened internal waste slopes must be capped. The height and/or slope angle of these slopes are often significantly greater than those envisaged during the stability risk assessments carried out at permitting stage. Measures required to cap such steep slopes can include (but are not limited to) the following:

- Regrading of the slope, however, this is often limited by availability of space to regrade the waste. If this requires cell construction, this will be difficult to justify financially with no revenue.

•Selection of high strength (both internal and interface) materials for capping applications. Selection of higher interface friction materials where possible and soils, however, soil selection is often primarily on availability.
•Inclusion of reinforcing. Geosynthetic reinforcement can be included to take up the excess forces that the interface friction and internal strength cannot withstand. Requires interaction with the cover soils to prevent oversliding and can be cost prohibitive on longer slopes.
•Use of a tapered wedge of soils. This involves using a shallower outer slope to the restoration soils than the waste slope. This has three main drawbacks: increased land requirements, increased soil requirements, precludes reopening site in future.

2 CASE STUDY

2.1 *Site*

The site is a deep quarry landfill within the UK with a 72 m high north facing internal temporary waste slope. The site had been subject to a complex filling history with a sequence of over tipping and inert filling over municipal solid waste. The temporary waste slope had a varying slope angle with areas of up to 1(v) in 2.3(h) and was, by necessity, adopted as a final capping slope for a site. A schematic geometry is shown in Figure 1.

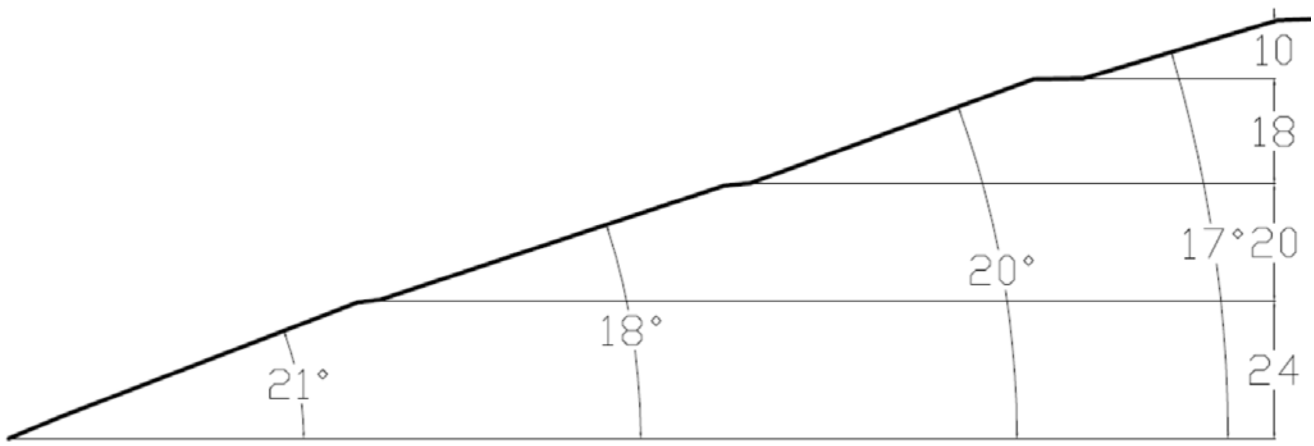

Figure 1. Schematic slope geometry

The operator and regulators of the site had concerns about the historic accumulation of leachate within the waste mass and unacceptable strength utilisation factors were derived from risk assessments of the current waste profile. The site was regularly subject to vandalism and theft; therefore, continued long term pumping to control leachate was both onerous and costly. As a result capping of the slopes was essential to maintain global stability as continued pumping was not a viable long term solution. Due to the scale of the slopes and requirements to maintain areas of active gas collection the capping of the slopes was carried out in the following sequence:

1. An area of the waste mass that was filled to pre-settlement contours was capped to reduce leachate generation.
2. The lower 44m (vertical) of the slope was capped using geosynthetics but without restoration soils due to material availability.
3. The upper 40m (vertical) of the slope was temporary capped without restoration soils.
4. Restoration soils are to be installed to the lower benches of the slope.
5. Restoration soils are to be installed to the upper benches of the slope.
6. The plateau at the top of the slope is to be completed connecting the capped top area (Phase 1) to the slope.

At the time of writing phases 3 and 4 are being completed concurrently. This leaves only an area of the top plateau without at least a geosynthetic layer in place.

2.2 *Materials*

The cap comprised of restoration soils, multi-layered geosynthetic system and soil regulating and restoration layers. The capping system overlaid waste in the following order:

- 300mm regulating layer (in lower two benches, removed from design in upper benches) ;
- Geotextile (increased specification in upper benches to allow for removal of regulating layer);
- 1mm LLDPE geomembrane;
- Geocomposite drainage layer; and
- Min 1m restoration soil layer.

3 SLOPE STABILITY

3.1 *Slope stability analyses*

Consideration of seepage forces within the capping soils is an essential part of the design. The initial design had considered a 1(v) in 3(h) slope, however, detailed geometric analysis suggested localised slope angle of 1(v) in 2.3(h). Due to the steep slopes, mitigation measures as listed in the introduction were considered. Regrading of the slopes was not practicable as there was no void space without cell engineering; whilst this would have been costly it also raised surface waste management problems so was discounted. Whilst the geosynthetics could be specified, restoration soil availability was problematic; therefore, selective sourcing was not possible. Geogrid reinforcement was considered, however, the slope was 72 m in height and 280 m in length thus the residual forces would be in excess of financially viable geogrid solutions and anchorage at the benches was not feasible, thus, a tapered wedge was considered the most viable option. The designers completed a revised stability risk assessment which was carried out using the methods proposed by Zhang et al. (2012).

The initial design considered a low flow capacity geocomposites, facilitating the use of strip drains, however, further calculations by the designer suggested that greater capacity may be required in the lower lifts due to the uncertainty associated with the source of restoration soils. Given the length of the slope the design was revised to consider a tiered geocomposites drainage solution with increasing flow capacity nearer to the base of the slope. This allowed a higher factor of safety against drainage failure whilst allowing a more cost effective solution.

Whilst the geotechnical engineer gave conceptual slope angles, it was emphasized that these were based on estimated interface shear strengths and that the Stability Risk Assessment (SRA) must be revisited following site specific interface shear strength testing.

3.2 *Shear Box Tests*

In order to ensure optimal design, sufficient stability and integrity of the lining system, a number of geosynthetic interface tests in a direct shear box were carried out. The results of the interface testing are presented in Table 1. The results highlighted the interface at the top of the geomembrane would be the most likely to slip. Also of concern were the residual values, which were significantly below the required values should post peak displacements be mobilized during placement of restoration soils.

3.3 *Health and Safety*

Construction on long steep slopes can pose specific challenges. For this case study there were the following specific concerns:

- Access of plant to the slope to facilitate deployment of the geosynthetics.
- Reinstatement of gas collection and leachate extraction infrastructure, particularly prior to installation of restoration soils.
- Global stability of the slope due to elevated leachate levels.
- Access was limited to specific routes, primarily along the benches on the slope profile.

Figure 2 shows deployment of the geosynthetics from the first bench. Use of small scale excavators and hand digging was required to find the tie-ins to side containment and roped access was used to allow welding personnel to work safely on the steeper areas of the slope.

Table 1. Mean shear strength test results for geosynthetic-geosynthetic and geosynthetic soil interfaces

<table>
<tr><th>Interface</th><th>Conditions</th><th>Peak friction angle (°)</th><th>Peak Adhesion (kPa)</th><th>Residual friction angle (°)</th><th>Residual Adhesion</th></tr>
<tr><td>Restoration soil / Geocomposite Drain</td><td></td><td>37.1</td><td>0.17</td><td>36.68</td><td rowspan="8">Assumed to be zero</td></tr>
<tr><td>Geocomposite Drain / Existing Geomembrane</td><td></td><td>21.2</td><td>0.8</td><td>11.06</td></tr>
<tr><td>Geocomposite Drain / Existing Geotextile</td><td>submerged</td><td>30.6</td><td>1.8</td><td>22.02</td></tr>
<tr><td>Geocomposite Drain / Existing Geotextile</td><td>submerged</td><td>24.7</td><td>3.8</td><td>20.02</td></tr>
<tr><td>Geocomposite Drain / Existing Geotextile</td><td>submerged</td><td>27.4</td><td>4.2</td><td>14.93</td></tr>
<tr><td>Existing Geotextile /Existing Geomembrane</td><td></td><td>25.5</td><td>0</td><td>11.92</td></tr>
<tr><td>Regulating Layer / Geotextile</td><td>dry</td><td>34</td><td>2</td><td>37.44</td></tr>
<tr><td>Regulating Layer / Geotextile</td><td>submerged</td><td>30</td><td>10</td><td>44.32</td></tr>
</table>

Figure 2. Deployment of geosynthetics on steep slopes

Given the phased nature of the construction, gas infrastructure reinstatement was required prior to the cover soil placement. Figure 3 shows the slope following geosynthetic installation. The smooth geosynthetic surface and steep slopes posed significant challenges for temporary reinstatement of gas infrastructure particularly as plant could not be deployed in order to protect the geosynthetics.

Figure 3. Planarity of case study slopes

3.4 *Planarity of the Slope*

One of the challenges on modelling any veneer slopes in a stability risk assessment is selection of a representative geometry to include in the model. Whereas with a cell construction the slopes tend to be engineered to specified gradients, capping slopes are a function of an often irregular profile, further exacerbated by heterogeneous settlement. Figure 3 highlights issues with the planarity of the case study site.

The original design stability risk assessment for the case study site had considered the slope stability of the entire slope top to bottom using limit equilibrium analyses after (Jones and Dixon, 1998). The assumption had been that in taking into account the full slope height, localized steepened areas would be acceptable. However, a series of sensitivity analyses were carried out and these showed that over a vertical height of 10 m, the passive wedge offered little support, therefore, the difference between a 10m height and an 72 m height slope had much less influence than changing the slope angle locally over a 10 m height. Clearly very local irregularities, in the order of <2m height, are beyond the scope of most SRA's, however, a significant section of the slopes was found to be at 1(v) in 2.3(h).

With an irregular capping profile, it becomes part of the engineering judgment as to what scale to consider locally steepened slopes over. This highlights the importance of using limit equilibrium tools to assist the designer not as a "black box" to do the design for the designer. The designer must be familiar with not only the parametric requirements, but also the formulation of the equations in order to make a valid judgment.

4 SPECIFICATION AND PROCUREMENTS

Procurement of geosynthetics, as with most engineered commodities is carried out via a specification on the key relevant engineering properties. This can become problematic with geosynthetic interfaces as the nature of the material surface is specified on asperity height alone, however, this can, in some cases, bear limited resemblance to the shear strength generated. There are a number of contractual ways to address such a challenge, one being to specify the interface shear strengths required, however, this can become difficult when procurement timescales are short and especially due to the heterogeneity of the cover soils as dealt with in the next section. Use of conservative values, that on the balance of probability will be achieved by the likely geosynthetics sources, can alleviate some issues, however, the designer, client and contractor must be aware that there is a possibility of lower strengths and have mitigation measures in place.

In the case study adopted, the restoration soils were to be placed in a tapered wedge formation, the angle of the wedge and potentially reinforcement within the wedge could be added depending on the findings of interface shear strength testing. This allowed the geosynthetic components to be placed and tested with the soils, prior to placement of the soil wedge.

5 RESTORATION SOIL

5.1 *Soil Heterogeneity and Condition*

Interface shear strength involving geosynthetic – soil interfaces are sensitive to the *in situ* strength and moisture content and the soil constituency. Regulating and restoration soils are typically derived from a variety of sources and can be heterogeneous, both in terms of composition and moisture content. Representative sampling for direct shear testing can be challenging.

The restoration soils were placed wetter than anticipated, and due to the north facing internal slope, within a quarry, the slope received very little sunlight, therefore, when the restoration soils got wet, there was limited chance of drying prior to deployment of the geosynthetics. Figure 4 shows the field deployment of the regulating layer. In order to quantify this, twenty moisture-density core samples were taken in twenty locations in order to statistically profile the slope and select a representative worst case for shear box testing. The tests for the regulating layer geotextile interface were then conditioned to this moisture content as part of the shear box tests for the lower interface. Additionally six CD Triaxial strength tests were specified to facilitate an assessment of the long term behaviour of the regulating layer behavior.

Figure 4. Regulating layer deployment on the steep capping slope

6 NUMERICAL ANALYSES

Due to the challenges listed above, the process of construction has been delayed in order to acquire more information on interface properties. A number of direct shear box tests have been carried out, to add confidence in the design, as stability risk assessment based on Zhang et al.(2012) with initial tests results were indicating a rupture failure on the top geosynthetic. As a result of these tests it was decided by the designer in consultation with the regulatory body to conduct more detailed stability and integrity assessment of the capping system. Further assessment was carried out using the explicit finite difference modelling code, FLAC (Itasca 2013) to investigate possible scenarios of geosynthetic materials and interface interactions, however, due to the commercial timescales for the analysis, strain dependent interface behaviour was not fully defined and whilst post peak displacements were predicted, the magnitude of interface movements and presence of geosynthetic tension could not be accurately predicted. The modelling mesh used in the analyses is shown in Figure 5 and the outputs in terms of strains in the geomembrane are presented in Figure 6.

As a result of the FLAC modelling and uncertainties in the input values and limitations of the modelling which could be achieved in the commercially available timescales, the decision was made to monitor the actual behaviour of the materials and interfaces in-between to ensure that no significant strains develop within geosynthetics and that no increased materials displacement occurs. Details of this instrumentation are given in the future work section.

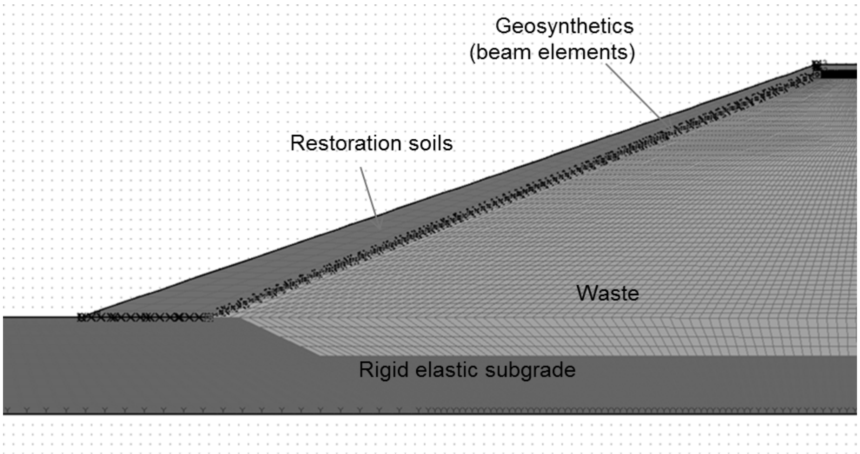

Figure 5. FLAC modelling mesh lower bench (see fig 1)

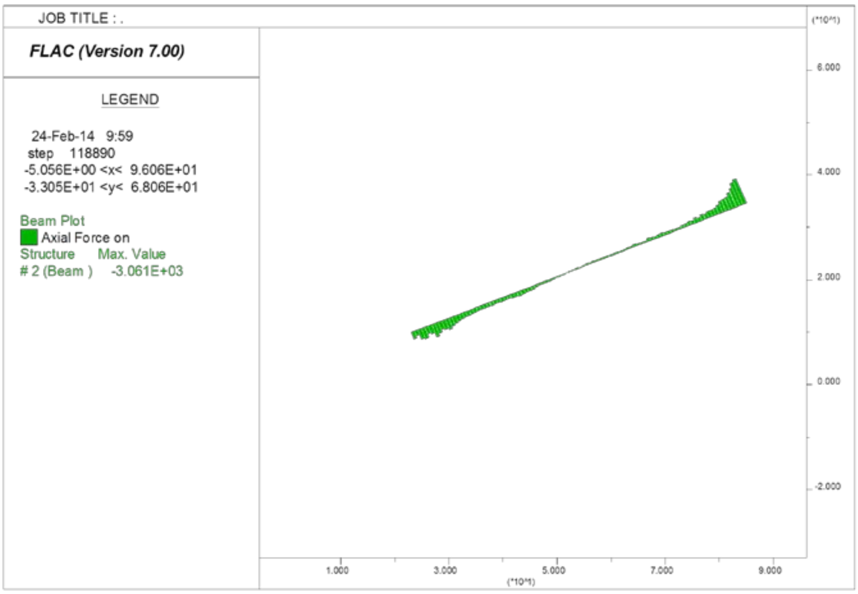

Figure 6. FLAC generated prediction of geomembrane axial strains (maximum tension at crest of slope, 3.06 kN/m)

7 FUTURE WORK

To progress the project in a timely fashion it has been agreed that instrumentation will be placed on the slope to measure the *in situ* performance of the slopes. The proposed instrumentation will include Demec strain gauges and extensometers as deployed by Zamara *et al.* (2012). The FLAC modelling indicates maximum tensile strains near the crest of the slope, and this is in line with finding of Fowmes *et al.* (2005 and 2008). Therefore, the Demec gauges will be placed 1m below the crest of the slope and the extensometer system shall target the top 5 m of the slope to assess strains within the capping system.

8 SUMMARY

Early closure of landfill sites can result in the adoption of steep temporary waste slopes as permanent final capping profiles. These slopes present many challenges and are often steep and higher than the anticipated capping slopes considered in stability risk assessments at permitting stage.

A case study has been presented demonstrating the challenges of capping large steep waste flanks. Acquisition of restoration soils is challenging and the soils can be variable and of mixed consistency. This raises further challenges when selecting reliable input parameters for the Stability Risk Assessment. Moreover, waste slopes, by their nature are irregular, and consideration of the planarity of the slope is important when assessing the conservatism of calculation methodologies.

Limit equilibrium analyses were carried out for the slope using parallel veneers and tapered wedge solutions. Whilst stable solutions could be achieved, preliminary numerical modelling highlighted the potential for post peak interface displacements, which when using post peak strength in the analysis resulted in unacceptable strength utilization factors. Given the lack of *in situ* geotechnical information relating to capping system performance, it is proposed to instrument the capping system to assess geosynthetic displacements and strain during and post restoration soil placement.

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