In-service structural performance of landfill lining components: instrumentation of a side slope lining system

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ABSTRACT: Data from field scale instrumentation is vital to the validation of numerical modelling techniques. This gives valuable information on landfill lining system performance and allows a better understanding of materials behaviour. This paper highlights the data required in order to validate numerical models, instrumentation techniques that may be used to acquire this data, description of a project conducted at Milegate Extension Landfill Site and measuring instrumentation deployed there.

1 INTRODUCTION

Landfill containment systems are required to prevent unabated transport of contaminants from waste material into the surrounding environment. Containment systems have for some time required assessment in terms of overall stability, however, while there were requirements for Hydrogeological and Landfill Gas Risk Assessment, there had been little emphasis on the requirement to maintain the structural integrity of the lining system throughout its design life. Containment systems must be considered in terms of both stability and integrity, Jones and Dixon (2005) consider stability failure as the ultimate limit state, where large scale movements occur with complete loss of function. Integrity, the serviceability limit state, may involve relatively small scale movements, resulting in overstressing of engineered elements, and hence loss of function. In the context of landfill lining system design, stability of the lining system is the ultimate limit state, and integrity of the lining system is the serviceability limit state.

In traditional geotechnical engineering it would be inconceivable to design and construct a geotechnical system where there are serious implications if it fails and not to monitor the structure and surround to ensure adequate performance. However, in landfill engineering this is the norm. Landfill containment systems are significant and important geotechnical structures the failure of which can have major consequences for the environment. Current designs are complex including soil and geosynthetic structural systems with novel designs particularly for lining steep slopes. However, despite the importance and complexity of these lining systems they are seldom directly monitored during operation to prove adequate structural performance, and hence to confirm the validity of the design assumptions and methodology. For most of the lining systems presently in use there is less than 15 years experience and a dearth of information on their long-term performance even though in many cases they will have to perform their designed functions for many tens of years (*i.e.* until the waste pollution potential is reduced to an acceptable level). This paper details the need for direct monitoring of the lining system components to ensure performance and to validate design assumptions, it describes an ongoing research project to instrument a geosynthetic/soil side slope lining system with the aim of monitoring structural performance of the components during and post waste placement.

2 NEED FOR MONITORING

Assessment of ultimate limit states are commonly carried out using relatively simple limit equilibrium techniques with the aim of achieving appropriate factors of safety. Such design cases include assessment of overall waste mass stability, stability of lining systems and stability of capping layers. There is considerable experience in the use of these analysis techniques and a high level of confidence that if critical conditions are analysed using relevant site specific material properties then the lining system and waste will be stable during the design life of the facility. It is therefore not appropriate in the large majority of cases to require installation of geotechnical instrumentation to monitor for signs of ultimate limit state failures (*i.e.* large scale slippage). The failures that do occur are usually a result of inappropriate or inadequate design, or construction/ operation of the landfill in an unspecified manor (Koerner *el al.* 2000).

Consideration of serviceability limit states is more challenging as these failure modes relate primarily to conditions post waste placement and they are time dependent, relating to waste degradation and creep processes that can continue for many years after cessation of filling and closure of the facility. Waste settlement will occur adjacent to side slope lining systems with the behaviour analogous to negative skin friction in a pile foundation. As the waste settles due to both the weight of successive waste lifts (*i.e.* compression) and subsequent settlement due to degradation and creep, the downwards movement of the waste mass will induce down drag forces on the lining system (Jones *et al.* 2005). These forces must be dissipated to prevent overstressing of geosynthetic barrier layers or loss of function of protection layers.

It has become common practice in the UK to assess integrity of lining components post waste placement by carrying out numerical modelling of the waste/lining system interaction. This is a step change in complexity of analysis. For example, (Fowmes *et al.* 2007) highlight advanced numerical analysis techniques for use in landfill stability and integrity analysis. The numerical models are used to assess strains induced in the lining elements throughout the design life of the landfill and hence to assess structural integrity and performance. This requires that the numerical model represents the staged construction of the lining system and waste placement, and also the long-term waste degradation phase. The models include representations of the subgrade (including engineered support systems such as reinforced earth), geosynthetic and soil liner elements (*e.g.* compacted clay, geomembrane, geotextile protection layer and drainage layer either geosynthetic geocomposites or mineral) and the waste body. A key challenge of this modelling is the need to represent both the short-term compression, and the long-term degradation, behaviour of the waste body. Design cases must take into consideration both the heterogeneous nature of waste and the limited amount of information currently available on its material engineering properties. The combination of the relatively short time period over which landfills have been either designed or "engineered" and the changing composition of waste means that it is difficult to make assumptions regarding characteristic properties of waste materials. Uncertainty regarding waste material engineering properties should be considered in the modelling process. It is clear that numerical models of landfills are highly complex with many assumptions and approximations inherent in the analyses. They also need high quality site specific material properties, which are seldom available. It is common geotechnical practice to validate such models using field monitoring of the geotechnical system performance. It is through collection of a body of field data that confidence in the design process is achieved. Monitoring landfill lining systems with geotechnical instruments would provide the required information to validate the numerical models currently in use but this is presently not incorporated in UK landfills. Without the information provided by such instrumentation it is not possible to have confidence in the long-term performance of current lining systems. It is recommended that since engineering solutions applied to landfill are often novel and do not have the benefit of many years of in-service experience, it is essential that appropriate geotechnical instrumentation and monitoring procedures are applied. Monitoring is of fundamental importance to the continued development of efficient cost effective lining systems that protect the environment.

3 MONITORING OF LINING SYSTEM PERFORMANCE

As discussed above, the aim is to measure structural performance of lining components both during construction and in service so as to validate predicted modes of behaviour and quantify stresses and strains in the components.

Demonstration that values of strain are below design serviceability limit states and that these can be predicted using numerical models, provides evidence for integrity, and hence adequate performance, and validates the design approach.

3.1 *Case study: Miligate Extension Landfill*

The proposed instrumentation at Milegate Extension Landfill (Fig. 1) provides the possibility of conducting a full-scale experiment with known dimensions, loadings and waste placement conditions. This provides an opportunity to obtain valuable information to aid the design of future landfill lining systems and to assess performance of existing systems. This project aims to obtain information on relative displacements of lining elements, tensile behaviour of geosynthetic elements, on loads applied to the liner system during and post waste placement and on temperature below and on the geomembrane liner.

Figure 1. Stages of materials deployment Milegate July 2009: (a) original geotextile liner; (b) uncovered clay layer; (c) geomembrane liner; (d) geotextile protection liner.

Milegate Extension Landfill is located in Yorkshire, UK. The void used for the landfill cell was formed as a result of sand and gravel extraction. The landfill accepts inert and non-hazardous, building, agricultural, commercial and industrial waste. The monitored slope has a side slope of approximately 35 m length, 16 m height and angle of 1v:2.5h (~21.8°). The geosynthetic lining system deployed during the experiment was placed in addition to the existing-clay liner, and therefore is an additional, and hence sacrificial, layer that does not form part of the approved containment system. The combination of materials within the lining system: clay, geomembrane, geotextile was chosen as being common practice in United Kingdom. Geosyntetics and mineral, compacted clay layer are a typical form of creating barrier against leachate and gas contamination.

The instrumented lining system comprised a 2.0 mm double rough HDPE geomembrane strip, 5 m wide, density 0.949 g/cm^3, overlain by a non-woven needle punched protection with Static puncture strength [CBR] of 11 to 14 kN (5 m wide, 35 m length).

The geomembrane was anchored in a 600 mm x 600 mm anchor trench at the top of the slope (Fig. 3d). The geomembrane/geotextile experimental section replaced the existing geocomposite drainage material over a slope width of 5 m (Fig. 2, Fig. 3).

3.2 *Philosophy of instrument design*

All of the instrumentation was planned and design to have a minimum impact on the materials being instrumented. Instrumentation consists of extensometers, fibre optics, Demec gauges and pressure cells (Fig. 2 presents instrumentation locations) that allow information to be obtained on total displacements, differential displacements between lining elements, strains and stresses in geosynthetic elements and applied pressures from the waste. Moreover, temperatures below the geomembrane liner (pressure cells) and on the geomembrane liner (fibre optics temperature gauge) are measured. In addition, observations of waste build up are carried out to relate obtained parameters with height of waste body and filling history.

3.3 *Details of instrumentation installation*

3.3.1 *Pressure cells*

To measure normal stresses imposed on the lining system during and post waste placement, pressure cells were installed. The equipment was installed beneath the geomembrane, at various positions along the slope (Fig. 2). Armoured cables attached to the instruments run to the top of the slope, where readings are taken during site visits.

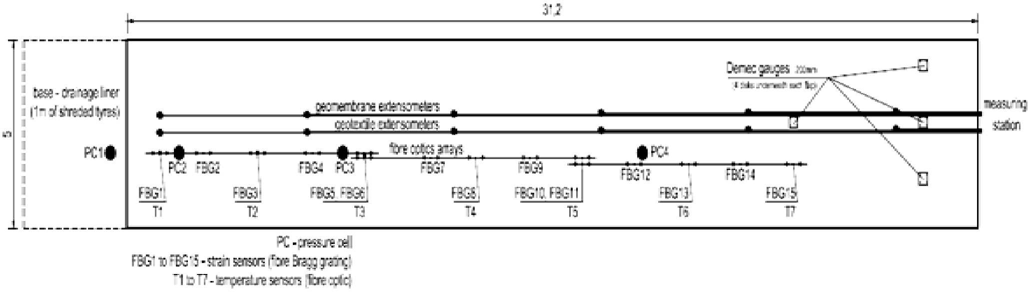

Figure 2. Plan of instrumentation placement - Milegate Extension Landfill.

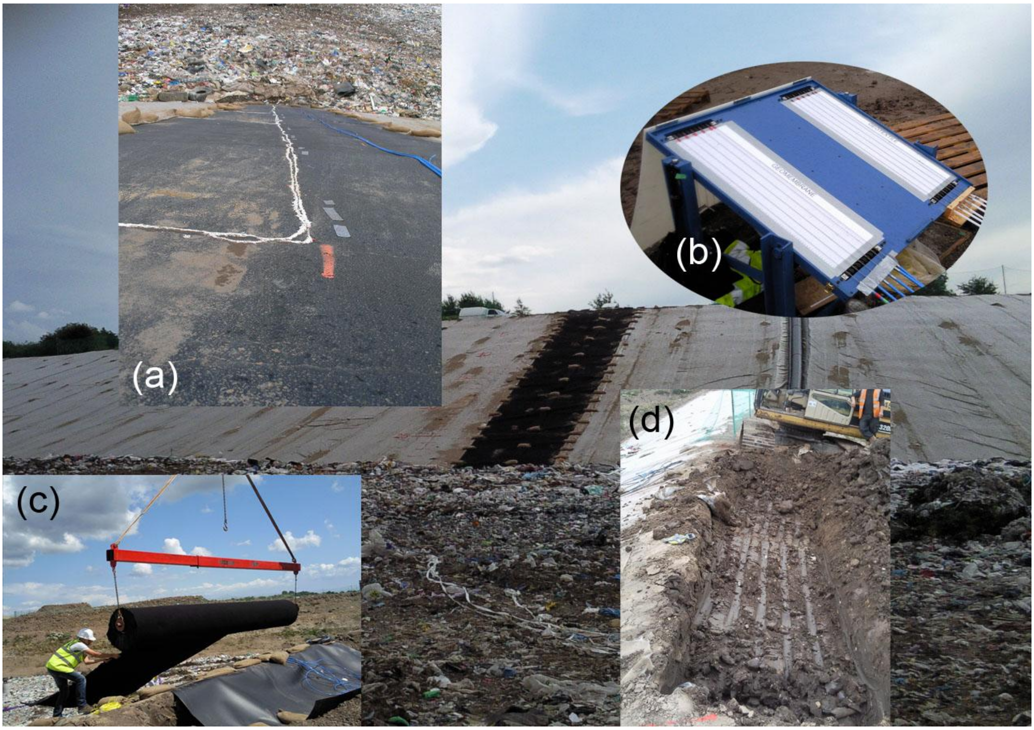

Figure 3. Slope general view: (a) instrumentation on geomembrane; (b) measuring station; (c) geotextile deployment; (d) excavation of anchored trench;

In total 4 vibrating wire pressure cells were installed - 3 along the slope in shallow excavations (see Fig. 4), 1 in the cell base under the one meter thick shredded tyre drainage layer, placed in a plastic bag filled with sand. Pressure cells were installed at distances: 12.3, 23.3 and 29.3m from the slope crest and a distance of 3 m from the left hand panel edge. The second and third pressure cells also contain a thermistor.

Figure 4. Pressure cell before burying (left) and prior to compaction (right).

3.3.2 *Extensometers*

To measure relative movements at various depths between the geomembrane and geotextile, extensometers were installed, 6 on the geomembrane and 6 on the geotextile. Each extensometer consisted of a 1.5 mm diameter steel wire (high tensile strength), with one end attached to the geosynthetic at a desired length along the slope (3m, 8.4m, 13.8m, 19.2m, 24.6m and 30m from the crest). Wire attachments to the geomembrane and geotextile were prepared by drilling (geomembrane) or cutting (geotextile). Two holes measuring approximately 8 mm were cut in the material allowing pulling of the wire through and fastening of the loop. Holes in the geomembrane liner were acceptable in this case because it does not form part of the sites accredited lining system as explained above. The wire extensometers can also provide information on strains in the liner elements between attachment points. The wires run up the slope to the measuring station (Fig. 3b), where they pass through a system of pulleys across a measuring board. Each wire is tensioned by an individual state weight (Fig. 5, Fig. 8). The extensometers method of measurements has been used in previous landfill experimentations by other researchers (*e.g.* Koerner *et.al.,* 1997).

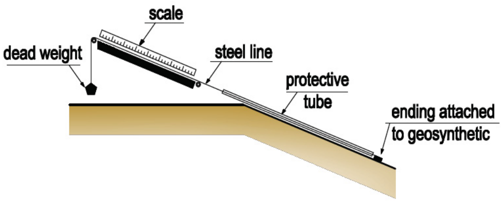

Figure 5. Extensometer - schematic view.

3.3.3 *Fibre optic*

To measure strains in the geomembrane, fibre optic instrumentation was employed. This aspect of the project is in collaboration with the Cranfield University Photonics Group. Six arrays of fibre optics sensors were deployed at various positions along the slope (Fig. 2). Three strings with 5 strain sensors each and three strings with 2 temperature sensors each were installed (see Fig. 6). In total, optic fibres sensors covered 25 m slope length with a temperature sensor at every second strain gauge. Strain gauges were placed from the bottom at every second meter of the slope. Fibre optic cables were attached to the geomembrane at various depths (as shown on Fig. 2).

Fibre Bragg grating sensors are located at intervals along the geomembrane enabling the strain over 0.5 m long gauge lengths to be measured. To allow correct measurements of strains, the geomembrane surface had to be prepared – texture removed to obtain a smooth surface for optic fibre sensor attachment with dust and dirt removed. Both the geomembrane and fibre optic covering are low energy surfaces, therefore, a structural plastic adhesive was used to attach fibres to the geosynthetic.

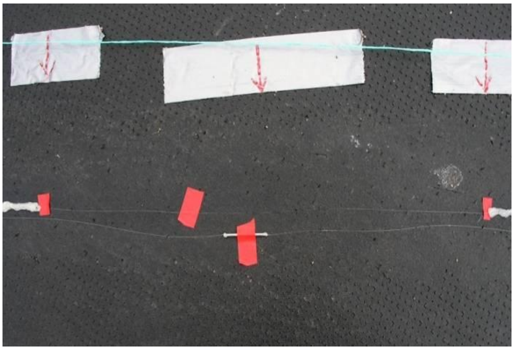

Figure 6. Fibre optics - strain and temperature sensors.

3.3.4 *Demec gauges*

In order to measure strains in the geomembrane at the crest of the slope, DEMEC strain gauges were installed. Four small flaps were cut to place discs on the geomembrane – three along the crest and one lower at the high of the first fibre optic temperature sensor. This is in order to obtain information on temperature influence on Demec gauge readings. Under each flap four discs were placed in a square shape with 200 mm side lengths (Fig. 7). The reading instrument consists of an invar steel bar with two conical-shaped points, one fixed at one end of the beam and the other pivoting. The readings are taken with gauge point stainless steel discs, attached to the geomembrane. Movement between the steel discs is obtained by a change in dial gauge reading. Measurements are taken manually during site visits. The strain readings will be converted to tensile stress using a tensile stress vs. strain relationship obtained from a laboratory wide width tensile testing programme.

Figure 7. Demec strain gauges.

3.4 *Monitoring strategy and experimental program*

Installation of the instrumentation took place at the end of July 2009 with subsequent readings being taken every second week. It is planned to monitor the instruments over several years during and following waste placement. Measured behaviour of the geosynthetics will be analysed, then compared with numerical modelling predictions to consider the implications for design.

In addition it is planned to conduct an experiment on veneer soil cover stability. A half meter thick sand layer will be placed on the instrumented slope in stages (*i.e.* prior to waste placement). It is planned to take readings, from all instruments deployed in the slope following placement of each 2 meters layer of soil cover up the slope. Soil coverage will be placed on the slope in direction from toe to the top.

4 SUMMARY

Numerical modelling is often used to assess the performance of landfill lining systems, and in particular to predict stresses in lining elements resulting from waste settlement. However, there is currently very little site information on liner structural performance during and post waste placement to enable calibration of these numerical models. The instrumentation at Milegate Extension Landfill gives the opportunity to conduct a full-scale experiment with known dimensions, loadings and waste placement conditions. This research project aims to obtain information on relative displacements of lining elements, tensile behaviour of geosynthetic elements and on loads applied to the liner system during and post waste placement. The data obtained will enable validation of numerical models and will increase confidence and less conservatism in current design practice.

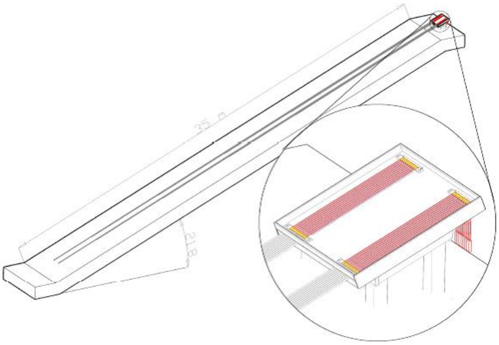

Figure 8. Measuring station general view

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