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Monitoring of a landfill side slope lining system: Instrument selection, installation and performance

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ABSTRACT

Municipal solid waste landfill barrier systems often comprise a combination of geosynthetics and mineral layers. Throughout the last twenty years there has been extensive research on the interactions between the materials and on performance of the geosynthetics including aspects of durability. This research has resulted in significant advances in the design and specification of landfill lining systems. However, to date there has been limited research carried out on *in situ* landfill lining system behaviour. Measured behaviour from field scale trials and of in service operation can provide valuable information on landfill lining system performance and allow a better understanding of composite material behaviour. Although many numerical modelling programs are applied to evaluate lining system stability and integrity, data to validate these models is currently limited. This paper highlights the data required to validate numerical models and instrumentation techniques that may be used to acquire this information. The paper focuses on geotechnical instrumentation deployed on the side slope lining system at the Milegate Extension Landfill, UK. The instrumented lining system comprises 1.0 m of compacted clay, a 2 mm double textured high density polyethylene geomembrane, a nonwoven geotextile and a sand cover soil layer. Instrument selection and problems associated with acquiring consistent, reliable and valuable data in a field environment are discussed, as are the challenges and problems that occur when preparing a full scale experiment. Sources of uncertainties within readings are highlighted. Additionally, initial results collected during sand veneer layer placement on the slope are presented. These demonstrate acceptable instrument performance over a 2 year period. Measured behaviour highlights the significance of geomembrane strains driven by temperature changes, generation of post peak strengths at interfaces during fill placement on the side slope due to relative displacement at interfaces between components, and mechanisms of stress redistribution in the geomembrane that result in time dependent changes in strain under constant load and temperature conditions.

1. Introduction

Modern landfill engineering in the UK involves detailed analysis of construction and environmental matters in order to meet requirements of the Environmental Agency, European Union regulations and UK legislation. This is to minimise impact on human health and ensure environmental safety. According to the Council Directive 1999/31/EC (1999) official required measures are associated with landfill emissions: leachate volume and composition, surface water composition, gas emission and atmospheric pressures, these are related to waste classification. While advanced systems of design and construction are mandatory according to Landfill (England and Wales) Regulations (Environment Agency, 2002), there is no formal requirement to monitor directly the mechanical performance of the lining system. Monitoring parameters focus on the environmental impact of the liner's performance (*e.g.* groundwater contamination) and reported data in the case of exceeded values may relate to an already damaged liner. Even when monitoring is required as a condition of the license for a particular landfill, data is often not published. Information about lining system performance can be derived from back analysis of large scale landfill failures (Koerner and Soong, 2000; Dixon and Jones, 2003; Muhsiung, 2005) but these cannot provide insight into in-service performance of nominally stable

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facilities. Current practice in landfill design involves applying numerical modelling software and employing complex methods for predicting landfill lining system behaviour to evaluate displacements, strains, and tensile stresses resulting from waste body lining system interaction (Dixon and Jones, 2003). However, there is still little attention given to in-service performance of landfill lining systems and interaction of the materials within a barrier system. Although in-service failure can lead to environmental damage, commonly used design approaches have not been verified through monitoring of liner behaviour during construction, filling and after closure.

To meet requirements for an environmentally safe landfill it is important to maintain the lining system stability (ultimate limit state) and integrity (serviceability limit state) throughout the landfill lifetime. While stability of the landfill involves large scale movements (*e.g.* slope failure), integrity is related to overstressing of liner elements with consequent loss of original functions, according to which the liner was designed (*e.g.* low permeability barrier, protection layer). The key areas for a landfill design engineer are: side slope (steep/shallow) stability/integrity, basal lining system stability/integrity, subgrade behaviour, ground water behaviour, appropriate material selection for the barrier components and waste parameters. It is of high importance to build environmentally safe landfill constructions and to assess adequately the performance of landfill lining systems and in particular, to predict stresses and strains in lining elements resulting from waste placement and settlement. To the Authors' knowledge only a limited number of full scale geotechnical landfill monitoring research projects have been conducted to investigate landfill liner behaviour (Gourc et al. 1997; Bouthot et al. 2003; Nakamura et al. 2006) but a limited number of long term monitoring experiments with back analysis have been reported (Najser et al. 2010; Villard et al. 1999). Although there is an increasing number of laboratory projects investigating lining system behaviour (*e.g.* Gourc et al. 2010; Koerner et al. 1997) and attempts to develop software calibration have been undertaken (Vilard et al., 1999; Fowmes et al. 2008), there is still an urgent need for information on in-service physical performance of barriers. Additionally, much attention has been given to landfill temperature monitoring and assessment of landfill lining system durability depending on liner temperature (*i.e.* Rowe and Sangam, 2002; Rowe et al. 2008; Rowe and Hoor, 2009) and also studies of waste body parameters and mechanical properties have been reported (Fassett et al. 1994; Gotteland et al. 2002; Dixon and Jones, 2005; Stoltz et al. 2010). Nevertheless, limited information exists about geosynthetics liner performance throughout cell operation and after closure.

The aim of an ongoing study conducted by the Authors is to validate design approaches. This paper reports an investigation of the mechanical performance of a multilayered landfill lining system (Fig. 1) at various stages of landfill development (*i.e.* barrier response to applied pressures in relation to waste placement during subsequent stages of cell filling, waste compaction and liner performance after cell closure due to waste settlement). This paper describes the challenges associated with design of a landfill lining monitoring system. It reports the research conducted at Milegate Extension Landfill in East Yorkshire, UK (Fig. 2), where a section of landfill slope has been monitored using geotechnical instrumentation to measure stresses imposed on the liner, displacements within and between the lining elements, strains within the liner elements, and also temperature of the clay surface and geosynthetics. This provides an opportunity to obtain valuable information to aid the design of future landfill lining systems and to assess performance of existing systems. Problems associated with waste barrier interactions, interface properties and mechanisms involved in certain material/interface behaviour are also investigated. The project started in July 2009. Instrumentation consists of pressure cells (PC), extensometers, fibre optics (FO) and Demec strain gauges. In addition, site slope surveys were conducted using laser scanning. To date, response of the lining system to placement of three soil veneer layers and 9 m thickness of waste body has been recorded.

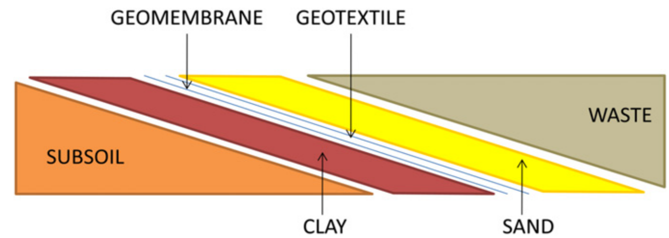

Fig. 1. Schematic view – Milegate landfill multilayered side slope lining system.

1.1. Context of the research

Construction of landfill barriers typically involves placement of geosynthetic materials over a mineral layer, which is often compacted clay. Further, landfill construction often comprises a mineral drainage layer and subsequent placement of waste layers. In the last 15 years there has been significant improvement in understanding of landfill lining systems. Numerical modelling codes have been developed with specific functions for analysing landfill site geotechnical problems (Fowmes et al. 2008; Villard et al. 1999) including staged placement of municipal solid waste, mobilized shear strength of the geosynthetic lining system interfaces (strain softening and progressive failure), tensile stresses in geosynthetics elements and representation of waste behaviour (Zhang, 2007; Machado et al. 2002). Construction stages result in deformation of components and hence shear stresses developed between and within materials and consequently formation of tensile stresses in the geosynthetic elements. The importance of several factors has been established and these should be considered when designing landfill lining system. They include consideration of progressive failure through strain softening of interfaces between geosynthetics and geosynthetics/soil materials, staged placement of the waste body, consideration of tensile stresses in geosynthetics, and assessment of waste properties such as unit weight, stiffness and strength, and their change due to ageing, deformation and settlement. An important challenge is the selection of peak or residual interface shear strength parameters for use in limit equilibrium stability analyses of multi-layered lining systems. The importance of accurate prediction/design of engineering aspects of landfill behaviour is self evident.

Previous studies undertaken to investigate landfill liner behaviour have been based on back analysis of monitored slopes (Villard et al. 1999), laboratory results (Fowmes et al. 2008), landfills failures (*e.g.* extensive numerical and laboratory analysis of Kettlemen Hill failure - Seed et al. 1990; Byrne et al. 1992; Mitchell et al. 1990; Chang et al. 1999) and parametric studies partially based on global databases (Kodikara, 2000; Sia, 2007). However, a validated approach taking into consideration the full complex nature of the landfill lining systems is still unattainable, and research is required to achieve a better understanding of the material behaviour and interaction mechanisms incorporated in models, to remove conservatism in the design process and to assure confidence and optimal construction geometry.

Recently, a number of laboratory investigations have been carried out using centrifuges (*i.e.* size reduced models with increased model weight, which simulates *in situ* stress conditions).