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Shear strength of geosynthetic composite systems for design of landfill liner and cover slopes

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ABSTRACT

Torsional ring shear tests were performed on composite specimens that simulate the field alignment of municipal solid waste (MSW) landfill liner and cover system components. Simultaneous shearing was provided to each test specimen without forcing failure to occur through a pre-determined plane. Composite liner specimens consisted of a textured geomembrane (GM) underlain by a needle-punched geosynthetic clay liner (GCL) which in turn underlain by a compacted silty clay. Hydrated specimens were sheared at eleven different normal stress levels. Test results revealed that shear strength of the composite liner system can be controlled by different failure modes depending on the magnitude of normal stress and the comparative values of the GCL interface and internal shear strength. Failure following these modes may result in a bilinear or trilinear peak strength envelope and a corresponding stepped residual strength envelope. Composite cover specimens that comprised textured GM placed on unreinforced smooth GM-backed GCL resting on compacted sand were sheared at five different GCL hydration conditions and a normal stress that is usually imposed on MSW landfill cover geosynthetic components. Test results showed that increasing the GCL hydration moves the shearing plane from the GCL smooth GM backing/sand interface to that of the textured GM/hydrated bentonite. Effects of these interactive shear strength behaviors of composite liner and cover system components on the possibility of developing progressive failure in landfill slopes were discussed. Recommendations for designing landfill geosynthetic-lined slopes were subsequently given. Three-dimensional stability analysis of well-documented case history of failed composite system slope was presented to support the introduced results and recommendations.

1. Introduction

Disposal of municipal solid waste (MSW) in engineered landfills has become a common practice. Landfills must be designed and constructed in a way preventing contamination of the surrounding environment. As a result, specially designed liner and cover composite systems should be placed at the base of landfill and over the waste top lift, respectively. Each of these systems usually comprises a multiple hydraulic barrier consists of geomembrane (GM) and geosynthetic clay liner (GCL) sheets. Two types of GCL are commonly used in landfill geosynthetic composite systems: (i) unreinforced GCL that comprises a thin layer of bentonite adhered to a high density polyethylene (HDPE) GM; and (ii) reinforced GCL that comprises geotextile-encapsulated bentonite that is stitch-bonded or needle-punched to connect the backing geotextiles. As shown in Fig. 1, the hydraulic barriers in MSW landfill composite liner systems are typically covered by a leachate collection system and underlain by low permeability soil. In cover systems, barriers are usually placed over compacted sand or gravel with embedded pipes for gas venting and overlain by sand as a drainage layer topped by vegetated soil.

While the hydraulic barriers are instrumental in preventing the infiltration of moisture or leachate to or from the waste, the comprised liner and cover systems must withstand the possibly applied stresses without being affected in its function during and after construction phase. A careful estimation of these stresses as well as strengths of liner and cover systems serves as a basis for safe landfill construction, operation, and closure. Shear stresses that are developed due to placing the geosynthetic composite systems on landfill sloped base and surfaces are of a major concern.

Since the slope failure of hazardous waste landfill unit at Kettleman Hills, California (Mitchell et al., 1990; Seed et al., 1990; Byrne et al., 1992), a significant number of investigations were presented on the interface and internal shear strength behavior of the composite system components (e.g. Swan et al., 1991; Gilbert and Bryne, 1996; Stark et al., 1996; Esterhuizen et al., 2001; Fox and

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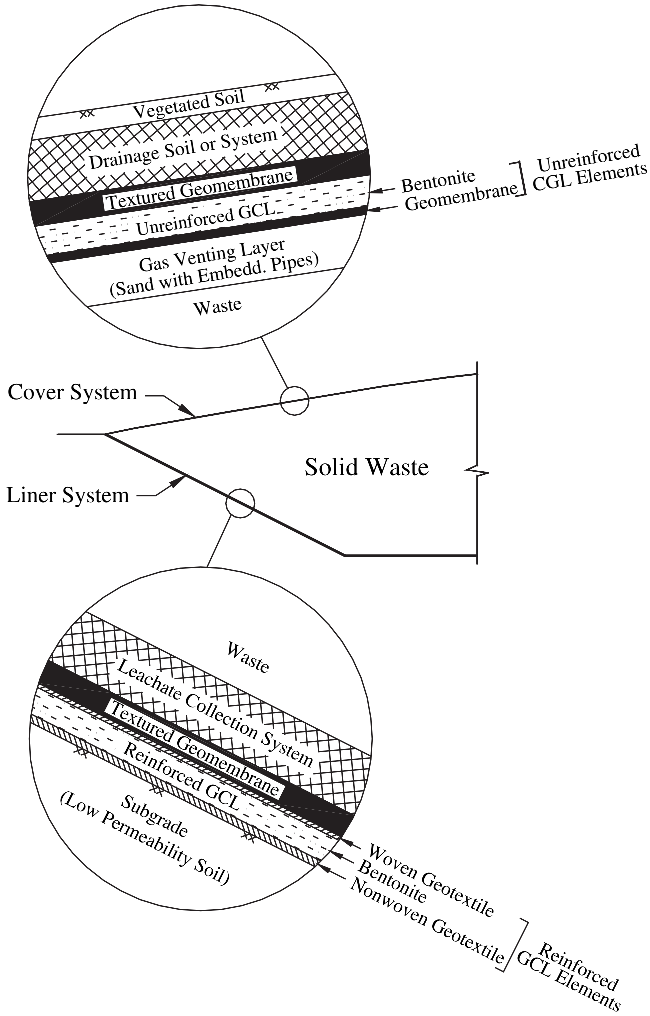

Fig. 1. Typical components of geosynthetic composite liner and cover systems for municipal solid waste landfills.

Stark, 2004; Zornberg et al., 2005; Bergado et al., 2006; Müller et al., 2008; McCartney et al., 2009). Several laboratory testing techniques have been introduced to study the peak and post-peak shear strength behavior of these components. Most of these techniques utilize either the standard or large direct shear box in which shear failure is forced – regardless of the normal stress level – to occur through a single interface or surface that is placed along the gap between the upper and lower halves. Similarly, torsional ring shear device is frequently used to study geosynthetics strength behavior through shearing only two components against each other or a GCL specimen internally.

A study of interactive shear strength behavior of landfill liner system components as well as that of cover system components is presented in this paper. This was done using a laboratory testing set up that provides simultaneous shearing for specimens of these components without forcing the shear failure to occur through a pre-determined plane. The effects of this behavior at different normal stress levels and hydration conditions on the stability analyses and the possibility of progressive failure of landfill slopes are discussed. A three-dimensional (3D) analysis of well-documented case history of a failed geosynthetic composite cover slope is presented to confirm the study results. The interfaces and internal shear strengths of liner and cover systems components are project specific and product dependent. Therefore, the discussion of the test results and their applications focused on analyzing the shear behavior rather than determining the specific shear strength values required for the design of landfill liner or cover systems.

2. Specimen preparation and testing procedure

Specimens that represent typical MSW landfill liner and cover geosynthetic composite systems were tested using a modified Bromhead torsional ring shear apparatus. The apparatus utilizes an annular specimen with an inside and outside diameter of 40 and 100 mm, respectively (Eid and Stark, 1997). For each test, a 1.5 mm (60 mil) thick textured HDPE GM was glued to the top platen. The textured GM was manufactured by Gundle Lining Systems, Inc. of Houston, USA. The specimen container that could accommodate a 10-mm-deep specimen was filled with compacted soil. Drainage is provided by annular bronze porous stone secured to the bottom of specimen container. After soil compaction, the specimen container is installed in the ring shear apparatus.

To assemble a representative composite specimen, the soil surface was overlain by an annular GCL specimen which in turn overlain by the top platen with a secured textured GM (Fig. 2). The bentonite typically used in this GCL is Wyoming bentonite with a liquid limit and plasticity index of 300–450 and 260–390, respectively (Mesri, 1969; Mesri and Olson, 1970). Aligned marks were put on the textured GM, the GCL woven and nonwoven geotextiles, and the bottom platen before shearing the composite liner specimens, as well as on the textured GM, the GCL GM backing, and the bottom platen before shearing the composite cover specimens. Shifting between such marks during and after shearing helped in locating the shear failure surfaces.

All specimens were sheared at a displacement rate of 0.015 mm/min. Based on the data presented by Eid et al. (1999), using such

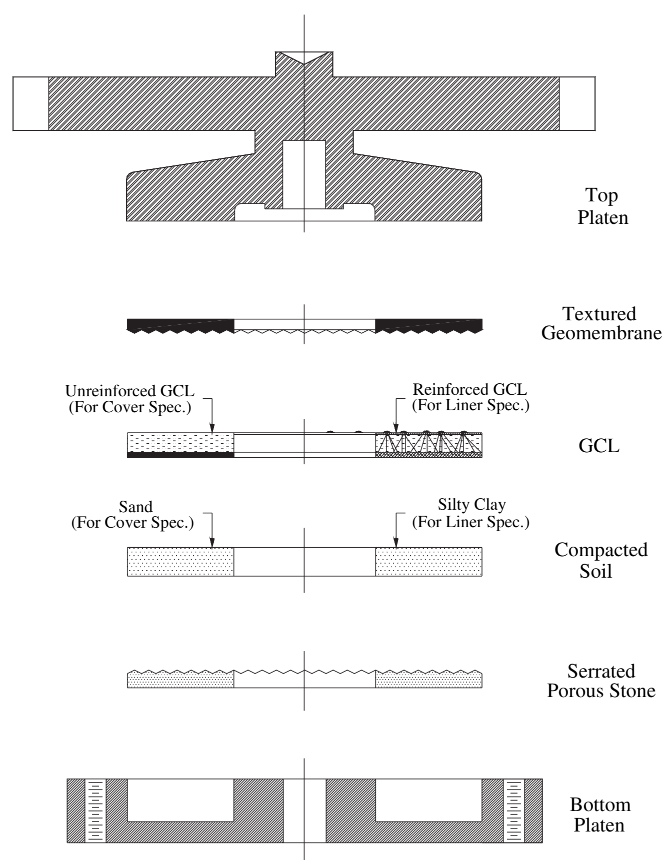

Fig. 2. Schematic of torsional ring shear specimen container and composite specimens used in testing.