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Analytical modelling of gas leakage rate through a geosynthetic clay liner–geomembrane composite liner due to a circular defect in the geomembrane

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Abstract

An analytical model was developed to predict gas leakage rate through a GM/GCL composite liner with a circular defect in the geomembrane. The predictions of the proposed analytical model were found to be in good agreement with experimental results for specimens with moisture content higher than the so-called critical moisture content. However, at moisture contents lower than the critical moisture content, the model predictions seem to overestimate the experimental results. This deficiency was attributed to the change in the gas flow pattern at lower moisture content, which appears to be controlled by the ratio between the gas permeability of the GCL and the gas permeability of the interface zone between the GCL and the geomembrane.

Keywords: Analytical modelling; Defects; Gas flow; Geomembrane; GCL; Leakage

1. Introduction

Composite liners consisting of a geomembrane (GM) overlying a low permeable material such as a geosynthetic clay liner (GCL) are commonly used in waste containment facilities and have been subject to considerable recent research (e.g. Bergado et al., 2006; Dickinson and Brachman, 2006; Bouazza and Vangpaisal, 2006, 2007a; Bouazza et al., 2006, 2007; Touze-Foltz et al., 2006; Vukelic et al., 2007; Meer and Benson, 2007; Nye and Fox, 2007). Nowadays, they are frequently used in landfill cover systems unless another type of cover can be constructed that has equivalent hydrologic performance. Landfill covers must serve three primary functions: (a) isolate the waste from the surrounding environment, (b) control egress of gases (e.g., egress of decomposition gases from municipal solid waste), and (c) limit percolation of water into the underlying waste. Obviously, control of percolation and movement of gas is a very important function. Also, when a cover controls percolation effectively, the waste is isolated as well and gas movement is controlled. The primary focus of this paper is on the effectiveness of a composite barrier composed of a geomembrane and GCL in limiting egress of gas into the atmosphere.

The geomembrane component of a composite barrier is essentially impervious to gas flow when devoid of holes or defects. However, gas transport through geomembranes can happen through small holes or defects in the geomembranes. Defects in the geomembrane can occur even with carefully controlled manufacture and damages can be found even in sites where strict construction quality control (CQC) and construction quality assurance (CQA) programs have been put in place (Bouazza et al., 2002). A comprehensive body of experimental and theoretical work on liquid leakage rate through composite liners with defects in the geomembrane is available in literature (Rowe, 1998; Touze-Foltz et al., 1999; Rowe and Booker, 2000; Foose et al., 2001; Touze-Foltz and Giroud, 2003, 2005; Cartaud et al., 2005a, b; Chai et al., 2005; Giroud and

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Nomenclature

K_g	cross plane gas permeability of the GCL
K_{pg}	in-plane gas permeability of the interface zone
L	GCL thickness
M_r	radial gas mass flow through the interface zone
M_s	cross plane mass flow of gas through the GCL
P	gas pressure
P_0	gas pressure at the defect point
P_1	gas pressure under the GM/GCL composite
P_{R_e}	gas pressure at $r = R_e$
Q	the total leakage rate ($Q_d + Q_r$)
Q_d	gas flow through the GCL directly below the defect
Q_r	radial gas flow through the interface between the geomembrane and the GCL
Q_s	cross plane gas flow rate through the GCL
r	radius distance measured from defect centre
r_0	circular defect radius
R_e	affected radius
s	thickness of interface zone
γ	gas unit weight
ρ	gas density at pressure P
θ	gas transmissivity through the interface zone
ρ_0	gas density at pressure P_0

Touze-Foltz, 2005; Touze-Foltz and Barroso, 2006; Barroso et al., 2006; Saidi et al., 2006, 2007). However, very limited studies on gas flow rate through geomembrane defect in a composite barrier system are available in literature. Recently, Bouazza and Vangpaisal (2006) reported the results of an experimental investigation on gas leakage rate through a GM/GCL composite liner, where the GCL was partially hydrated and the GM contained a circular defect. The test results showed that gas leakage rate through a GM/GCL composite was affected by differential gas pressure across the composite liner, the moisture content of GCL, contact conditions, and defect diameter. It was also found that gas leakage rate increased as the differential gas pressure increased, and decreased as GCL moisture content increased.

The objective of this paper is to present an analytical model capable of predicting gas leakage rate through a GCL–GM composite liner due to a circular defect in the geomembrane.

2. Problem configurations

A schematic diagram of a GM/GCL composite cover containing a defect in the geomembrane is shown in Fig. 1. A geomembrane containing a circular defect of radius r_0 is underlain by a partially saturated GCL. The GCL consists of a bentonite layer sandwiched between two geotextile layers. Spacing s is the thickness of the transmissive zone of the interface between the geomembrane and the bentonite component of the GCL. For a GCL containing geotextile, the transmissive zone of the interface between the geomembrane and the GCL consists of the space between the geomembrane and the geotextile component of the GCL, and the transmissive space in the geotextile component. The transmissive zone provides a pathway for gas to flow laterally to the defect. Flow in the transmissive zone is called interface flow. The transmissive zone is assumed to be uniform and can be characterised by its gas transmissivity θ.

Gas flow through a defect in the geomembrane of a GM/GCL composite cover consists of flow through the underlying GCL and radial flow in the interface to the circular defect in the geomembrane. Gas flows radially in the interface from the points where there is no change in the gas pressure ($\mathrm{d}P/\mathrm{d}r = 0.0$) to the centre of the defect. The interface flow is assumed to be axisymmetric to the defect. The distance between these points and the centre of defect is referred to as the affected radius R_e.

Gas pressure under the GM/GCL composite is assumed to be constant at pressure P_1, as shown in Fig. 1a. When gas flows through the GCL with thickness L, the gas pressure drops from P_1 to P_0 (at the defect point); consequently, the differential gas pressure across the GCL is equal to $P_1 - P_0$. It is assumed that no pressure is lost when gas flows through the geomembrane defect; therefore, the pressure of gas above the defect is equal to the gas pressure in the interface directly under the defect, P_0. This implies that the thickness of the geomembrane can be neglected.

The gas pressure in the interface directly under the defect is assumed to be constant at P_0 and there is no gas accumulation above the defect. However, the gas pressure within the interface at distance $r > r_0$ from the defect centre is higher than P_0 due to the accumulation of gas, which flows through the GCL within the affected area. The actual shape of the curve of the gas pressure acting under the geomembrane is a function of the radius r measured from the centre of the geomembrane defect (Fig. 1b). Therefore, the gas pressure in the interface is the lowest at pressure P_0 at the defect ($r \leqslant r_0$) and increases to pressure P_{R_e} at $r = R_e$. The pressure P_{R_e} is assumed to be constant, and converges to pressure P_1 if the pressure drop across the GCL is very low. It is assumed that no gas interface flow is occurring where $r > R_e$.

For simplicity of the analysis, the following assumptions are also made:

- Steady-state flow conditions prevail in the flow system.
- There is only one circular defect in the geomembrane of the GM/GCL composite cover under consideration and there is no wrinkle in the geomembrane.