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Technical note

Analysis of geomembrane whale due to liquid flow through composite liner

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ABSTRACT

When defects occur in geomembrane liner (GL), leaking water could infiltrate dry soil below, replace the pore air and may generate geomembrane whale (GW). An analytical solution is proposed in this paper to analyse the geometry and tensile force of axisymmetric GW. Parametric studies are also conducted to identify the influences from key factors and provide predicting charts for practical usage. It is concluded from the parametric studies that the maximum height and tensile force of GW can be achieved when the GW is just about to be submerged by external water. For a given level of external water, the height, width and tensile force of GW versus volume of leaking water curves are bilinear in a log–log graph, with a higher slope before a turning point but a smaller slope after that, whereas gas pressure in GW has reverse trends. It is also observed in this paper that GL with higher tension stiffness has a strong capacity to confine the gas pressure and thus generate lower and wider GW with higher tensile force and internal gas pressure.

1. Introduction

The composite liner provides an ideal impermeable layer for the construction of water reservoirs, city wetlands, wastewater lagoons, solid waste disposals and some other projects that need a waterproof liner. The composite liner is usually constructed using a layer of geomembrane liner (GL) over a compacted clay liner (CCL) or a geosynthetic clay liner (GCL). However, water will leak through GL into the bottom dry soil due to the defect of GL. The defect of GL may arise from manufacturing defects, handling of the geomembrane rolls, on-site placement and seaming, placement of drainage gravel over the liner system, traffic on the liner or the overlying protection layer, placement of the waste in a landfill or cleaning of residue from a leachate lagoon and stress cracking as the geomembrane ages (Rowe, 2012). The water leaking into the dry soil liner will infiltrate the soil and thus replace the pore gas or generate gas due to a microbiological reaction. The gas will then migrate and aggregate underneath the wrinkle or at a high spot below the GL, see step (1) for example in Fig. 1. When sufficient gas aggregates under the GL, gas pressure larger than the hydraulic pressure acts on its top and the GL is lifted from the ground, thus generating a geomembrane whale (GW), as in step (2) in Fig. 1. Although generation of GW will release the gas pressure under GL, it will elongate the GL, making it thinner, increasing the risk of failure and reducing the storage ability of the reservoir. Some in-situ test results have been reported by Cao et al. (2015).

Theoretical calculation methods for the leakage rate, Q (m^3/yr), due to the defect of GL have been proposed by many researchers, e.g., Giroud et al. (1989), Giroud et al. (1992), Giroud and Bonaparte (1989a,b), Giroud (1997), Rowe and Booker (1998), Touze-Foltz et al. (1999), Foose et al. (2001), Cartaud et al. (2005), Rowe and Abdelatty (2012), Rowe (2012) and El-Zein et al. (2012). Generally, the leakage rate of water through the GL is a function of the number and size of holes, permeability of the clay liner, water head difference, interface between the geomembrane liner and clay liner beneath, wrinkles of the constructed geomembrane and properties of the reserved wastewater (Rowe, 2012). As the topic is relatively large and complex, it will not be covered in this paper. The following discussion assumes that the leakage rate of GL, Q (m^3/yr), is known or has been calculated based on the mentioned theoretical calculation methods. Then, the total volume of leaking water, V_1 (m^3), could be calculated as

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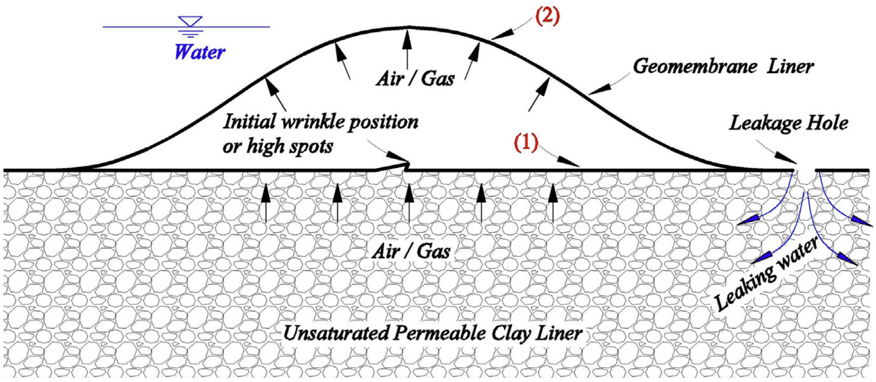

Fig. 1. Generation process of GW due to water leakage through GL for (1) Initial position of GL and (2) Final position of GL (GW).

$$V_1 = Qt \tag{1}$$

where *t* is the time of leakage (*yr*).

The volume of replaced gas in the GW will be the same as the total volume of leaking water, V_1, if the pore gas in the dry soil is assumed to be fully infiltrated by the leaking water (very low ground water level) and neither the gas generated by the microbiological reaction between leaking water and soil nor the water absorbed by the clay liner in GCL is ignored. After the replaced gas migrates and aggregates underneath the wrinkle or at a high spot, the volume of the replaced gas will change from V_1 to V_2 because the gas pressure changes from gas pressure P_1 in the ground to gas pressure P_2 underneath the GL. The gas removed from the ground to the bottom of the GL will also have temperature changes that will also influence the volume of gas in the two statuses. The aggregated gas follows the ideal gas law, i.e., $PV = nRT$, where the letters denote pressure (Pa), volume (m^3), amount (in moles), ideal gas constant and temperature of the gas in kelvin (K and 0 °C = 273 K), respectively; thus, we have

$$\frac{P_1 V_1}{P_2 V_2} = \frac{T_1}{T_2} \tag{2}$$

where T_1 and T_2 (units in K) are the temperature of gas before and after replacement, respectively.

In this paper, an analytical solution is proposed to analyse the geometry and tensile force along the GW. Parametric studies are also conducted in this paper to identify the influences from the key factors and provide predicting charts for practical usage. The proposed solution is capable of calculating the axisymmetric GW generated in construction projects on dry soil related to landfills, water reservoirs and lagoons for wastewater treatment.

2. Proposed analytical method

2.1. Basic assumptions

In deriving the solutions, the following assumptions need to be made: (1) the GW is an axisymmetric problem; (2) the geomembrane shell is thin, elastic and weightless; (3) the frictions between the geomembrane and soil liner or water are not considered; (4) the soil surface is horizontal and its deformation due to infiltration is not considered; (5) ground water level is very low and thus the same volume of gas is replaced by the same volume of leaking water.

2.2. Theoretical derivations

A 2D analytical model of an axisymmetric GW could be simplified from a 3D model, as shown in Fig. 2(a). The coordinates of the system are set-up with *x* in the horizontal direction and *y* in the vertical direction. The origin of this coordinate is taken as the center of the contact edge with the ground surface. The unit weight of the external water and height are written as γ_w and H_w, respectively. The tensile force along the GW is written as *T*. The height and width of the cross-section of the GW are denoted as *H* and *B*, respectively. An infinitesimal small curve with a length of *ds* at an arbitrary point *S* (*x*, *y*) can be treated as an arc with a radius of *r*, as shown in Fig. 2(b). The angle between the tangential direction at point *S* (*x*, *y*) and the *x*-axis is denoted as θ. Then, two geometrical differential equations relating θ and the *x* and *y* coordinates can be

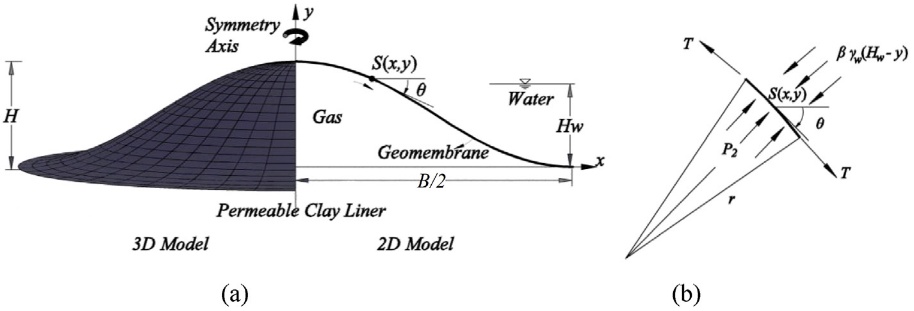

Fig. 2. Simplified analytical model of GW (a) method of simplifying from 3D to 2D model, and (b) free body diagram of an infinitesimal unit.