Applicability of the equivalent coefficient of permeability in geomembrane lining systems having defects

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ABSTRACT: Several equations for estimating the quantities of leakage through geomembrane lining systems with defects were proposed by Giroud (1989). The amount of seepage through the defects on the geomembranes underlain by low-permeability clay layers was described. When the geomembrane lining systems are modeled in the seepage analysis program for the cases with changing phreatic surfaces, equivalent coefficients of permeability representing leaking geomembrane lining systems are required. This parametric study on the equivalent coefficients of permeability with various thicknesses of lining soils and hydraulic depths shows that the equivalent coefficients of permeability on a representative hydraulic depth can be used for the changing hydraulic head conditions within tolerable errors considering the uncertainties of underlying lining soil.

Keywords: Coefficient of permeability, Geomembrane, Defects, Leakage

1 INTRODUCTION

Geomembrane/clay composite in landfill construction is increasing and leakage problems through the geomembrane/clay system are widely investigated. It was published by Giroud and Bonaparte (1989 a, 1989 b) that seepage quantity is mainly governed by the quality of contact between geomembrane and the underlying low-permeability soil layer and many authors reported factors concerning seepage quantity like overburden soil pressure (Chai and Miura 2003), water pressure above the membranes (Fukuoka 1986). Chai and Miura claimed through large-scale tests that there is interface flow between the geomembrane and the underlying soil layer even in laboratory condition (Chai and Miura 2005). And the authors showed that the leakage rates increase non-linearly with increasing water level.

In analysis cases with constant leakage rates of the geomembrane/clay composite systems, the leakage rate, q from the Giroud's equations may be directly input as "total flux Boundary conditions" in the seepage analysis program such as SEEP/W. But in other analysis cases, the equivalent k value for the geomembrane systems must be input instead. Even though the equivalent k can be calculated from Giroud's equation for the representative water level, the input value of k must be remodified continuously when the water level above the geomembrane changes during the analysis procedure

This paper suggests the use of one equivalent coefficient of permeability, which can be calculated from Giroud's equation, and shows the applicability of it in changing water levels.

2 EQUATIONS ANALYZED FOR PARAMETRIC STUDY

2.1 *Giroud's Equations*

There are almost always spaces between the geomembrane and the soil liner in the geomembrane/clay composite systems, because the geomembrane has wrinkles, the underlying soil surface has irregularities, and there are gaps between soil particles which the geomembrane may bridge over (Giroud et al. 1989).

Giroud and Bonaparte (1989 b) presented the empirical equation as described in Eq.(1) after reviewing the model tests conducted by Fukuoka (1986), Brown et al. (1987), theoretical analysis by Faure (1984), and Giroud (1989 a).

$$Q = C_{qo} a^{0.1} h^{0.9} k_s^{0.74} \tag{1}$$

Where, a = area of hole, k_s = permeability of underlain soil, h = depth of water on top of the geomembrane.

As $a = d^2\pi/4$, Eq.(1) is written as Eq.(2)

$$Q = 0.976 C_{qo} d^{0.2} h^{0.9} k_s^{0.74} \tag{2}$$

The C_{qo} for good contact and poor contact resulted in Eq.(3) and Eq.(4) as follows (Giroud et al. 1989).

$$C_{qo} = 0.21 \tag{3}$$

$$C_{qo} = 1.15 \tag{4}$$

2.2 *Equivalent coefficient of permeability*

When the hydraulic head is larger than the thickness of the underlying soil layer and the head is less than 3.0 m, Giroud (1997) suggested Eq. (2) should be Eq.(5).

$$Q_{4000} = n 0.976 C_{qo} \left[1 + 0.1\left(\frac{h}{t_s}\right)^{0.95}\right] d^{0.2} h^{0.9} k_s^{0.74} \tag{5}$$

Where Q_{4000} = leakage per 4000 m^2 in m^3/s, n = number of holes per 4000 m^2, t_s = thickness of underlying low-permeability soil layer in m as in Figure 1.

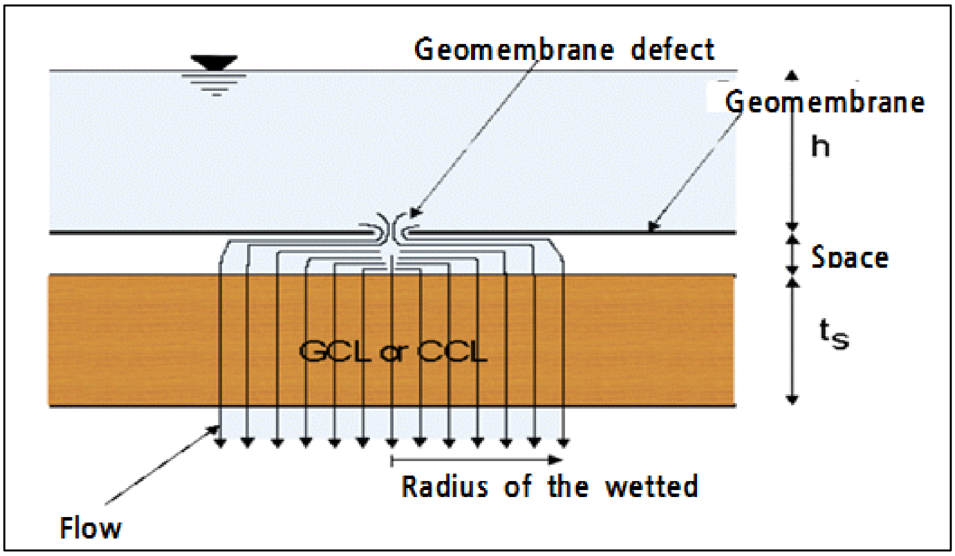

Figure 1. Schematic view of Geomembrane with a hole

Even though above equations are useful for calculating seepage quantities through geomembranes and underlain soil liners i.e. composite liners, they cannot be used directly in the seepage analysis of dams and levees with composite liners. Because constant permeability coefficient, k must be input when the seepage analysis programs are used to calculate the phreatic lines and the seepage quantity of dams as a whole, an equivalent coefficient of permeability values are necessary.

In Darcy's law, seepage quantity, q can be expressed as Eq.(6)

$$q = ki = k\frac{\Delta H}{L} \tag{6}$$

As ΔH is considered to be lost through clay liner, Eq. (6) can be as Eq. (7)

$$q = k\frac{h+t_s}{t_s} \tag{7}$$

If the seepage quantity q is given, k is expressed as Eq. (8)

$$k = \frac{q}{\left(\frac{h+t_s}{t_s}\right)} \tag{8}$$

If terms which are not related with non-linearity of k can be expressed into c as follows

$$c = n0.976C_{qo}d^{0.2}k_s^{0.74}/4{,}000 \tag{9}$$

Using Eq. (9), Equation (5) can be rewritten as Eq.(10)

$$q = c\left[1 + 0.1\left(\frac{h}{t_s}\right)^{0.95}\right]h^{0.9} \tag{10}$$

Suggested equivalent coefficient of permeability which can be used in seepage program is as Eq.(11)

$$k = c\left[1 + 0.1\left(\frac{h}{t_s}\right)^{0.95}\right]h^{0.9}/\left(\frac{h+t_s}{t_s}\right) \tag{11}$$

The suggested equivalent coefficient of permeability of the composite liners varies non-linearly if hydraulic head of the composite varies, in contrast to the ordinary soil layers of which the permeability does not vary with the hydraulic head.

The following Table 1 shows an example of parametric study for the equivalent coefficients of permeability for the various hydraulic heads, ranging from 0.3 m to 20.0 m. It was assumed that the number of holes for 4000 m^2 = 1, C_{qo} = 0.21, the diameter of the hole = 3.5 mm, and the permeability of underlying soil= $1x10^{-7}$ m/s. The equivalent coefficient of permeability increases only 1.33 times from $1.2x10^{-9}$ m/s to $1.6x10^{-9}$ m/s when the hydraulic head increases 2 times from 1.0 m to 2.0 m. And it increases 1.6 times from $3.6x10^{-9}$ m/s to $5.7x\ 10^{-9}$ m/s when the hydraulic head increases 2 times from 10.0 m to 20.0 m.

Table 1. Estimated equivalent coefficient of permeability with respect to the hydraulic head and the thickness of soil layer

Thickness of low permeability soil layer, t_s (m)	Hydraulic head (m)								remark
	h=0.3	h=1.0	h=2.0	h=3.0	h=4.0	h=5.0	h=10.0	h=20.0	
0.3	0.75	**1.2**	**1.6**	1.9	2.1	2.4	**3.6**	**5.7**	k (x10^{-9} m/s)
0.6	0.96	1.8	2.3	2.7	3.0	3.2	4.5	6.6	
1.0	1.1	2.2	3.0	3.5	3.9	4.2	5.5	7.8	
1.4	1.2	2.5	3.6	4.2	4.7	5.0	6.5	8.8	

Figure 2 shows that in the high hydraulic heads above 5.0 m, the hydraulic heads increase of 2 times the result in an almost constant permeability increase of 1.6 times, especially when the thickness of low permeability soil is 0.3 m.

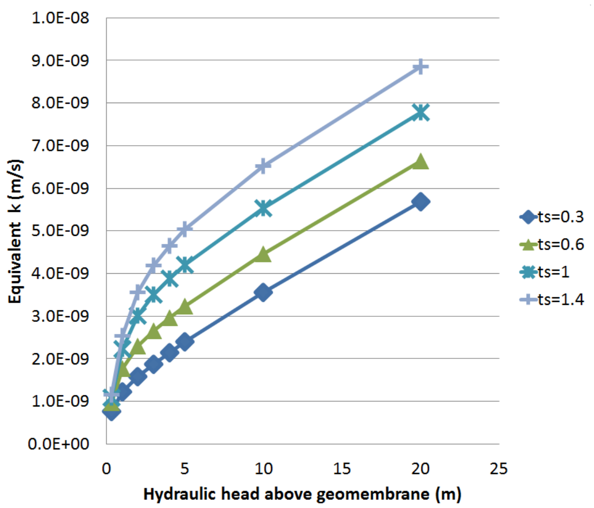

Figure 2. Trend of calculated equivalent k with hydraulic heads and thicknesses of low permeability soil liners.

Considering the fact that in actual construction site with the same underlying low permeable soil, permeability of clay may vary more than 50~100 times with the compaction degree, the constant equivalent coefficient of permeability by Eq. (10) can be used in the seepage analysis program, even though k varies with the hydraulic head in a composite liner system (Daniel 1993).

3 CONCLUSIONS

The equivalent coefficient of permeability was derived from Giroud's leakage quantity equation for the various hydraulic heads. And the effects of the hydraulic heads and the thickness of the underlying soil layer on the equivalent coefficient of permeability were studied.

It is found that as the hydraulic heads increase by 2 times, the equivalent permeability increases only by 1.6 times in hydraulic heads above 5.0 m. So, it is concluded that the use of equivalent coefficients of permeability for a representative water depth is reasonably accurate for the seepage analysis with changing water heads, considering the fact that the variation of the permeability of the underlying soil usually vary 50~100 times with varying compaction degree even in the same clay.

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