Panel discussion: Reactive nature of passive containment barriers

Débat de spécialistes: Caractère réactif des barrières de confinement passives

C. D. Shackelford – *Department of Civil Engineering, Colorado State University, Fort Collins, Colo., USA*

1 INTRODUCTION

Passive containment barriers that consist of an appreciable amount of clayey soil are naturally reactive primarily in two ways. First, the containment liquid may react with the barrier material such that the properties of the barrier material, such as the hydraulic conductivity, are altered. This type of reactivity commonly is referred to as compatibility. Second, the barrier material may react with the principal contaminants (solutes) within the containment liquid such that the migration rate or extent of migration of the contaminants is reduced. This type of reactivity is referred to as attenuation. This discussion focuses on these two types of reactivity with a view towards future considerations.

2 COMPATIBILITY

A significant amount of study has been devoted to the evaluation of compatibility considerations, especially with respect to the effects of different types of permeant liquids on the hydraulic conductivity of clayey soils (Shackelford 1994). However, one aspect of compatibility that has received attention only relatively recently is the so-called "first exposure effect", as illustrated in Fig. 1.

The data in Fig. 1 represent the results of two hydraulic conductivity tests performed on identical specimens of a compacted sand-bentonite mixture containing 16 percent bentonite. The tests were performed in flexible-wall permeameters without back-pressure saturation to minimize the potential for side-wall leakage. Further details of these tests are provided by Shackelford (1994).

Test No. 1 in Fig. 1 represents permeation with water to establish a baseline hydraulic conductivity followed by permeation with a calcium saturated tailings solution. Test No. 2 represents permeation only with the calcium solution. The observed initial decrease in hydraulic conductivity for Test No. 1 is attributed to the swelling of the bentonite, whereas the subsequent increase in hydraulic conductivity is attributed to flocculation of the bentonite particles in the presence of the high concentration of di-valent calcium ions (Ca^{2+}). The significantly higher hydraulic conductivity associated with Test No. 2 is attributed to reduced swelling resulting from immediate flocculation of the bentonite. Similar results also have been reported recently for other sand-bentonite mixtures as well as for the bentonite component of geosynthetic clay liners, or GCLs (see Stern and Shackelford 1998). As a result of the differences in k shown in Fig. 1, Shackelford (1994) concluded that great care must be exercised to ensure that the sequence of permeation in the laboratory mimics the containment sequence in the field; otherwise, significantly unconservative (low) values of k may be measured.

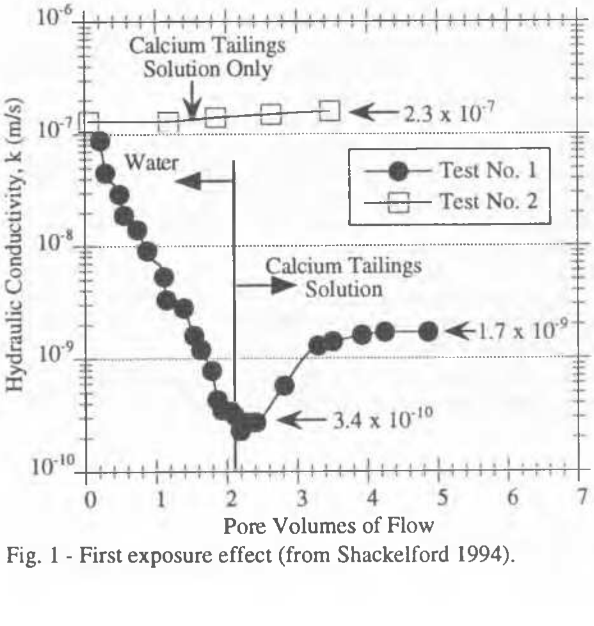

Fig. 1 - First exposure effect (from Shackelford 1994).

Stern and Shackelford (1998) present results that indicate the first exposure effect can be reduced by substituting a relatively inert clay, such as attapulgite clay, for all or a portion of the relatively reactive bentonite in sand-clay mixtures. However, the ability to achieve a relatively low hydraulic conductivity based on permeation with water may be reduced. Thus, the future challenge is to utilize materials that not only provide a low hydraulic conductivity based on permeation with water but also minimize incompatibility and first exposure effects.

3 ATTENUATION

Although most low-permeability soil barriers have some intrinsic attenuation capacity, the concept of designing passive barriers with an enhanced attenuation capacity recently has gained momentum. For example, the use of additive barrier materials, such as zeolites, high carbon fly ash, organically modified clays, and tire chips, has been proposed to enhance the attenuation capacity of waste containment liners (e.g., Evans et al. 1990, Thornton et al. 1993, Lo et al. 1994, Gray 1995, Allerton et al. 1996, Park et al. 1996, 1997, Evans and Prince 1997).

For example, c(L,t) in Fig. 2 resulting from diffusion with

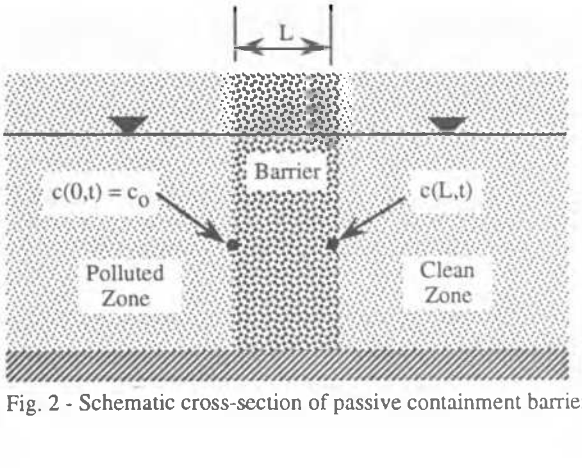

Fig. 2 - Schematic cross-section of passive containment barrier.

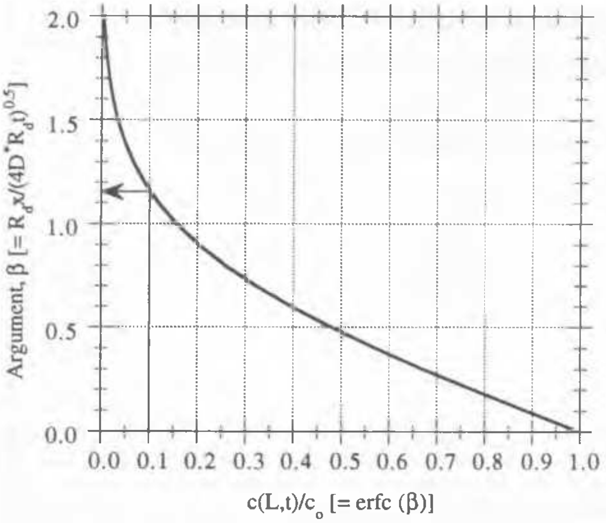

Fig. 3 - Analytical solution for diffusion-controlled scenario.

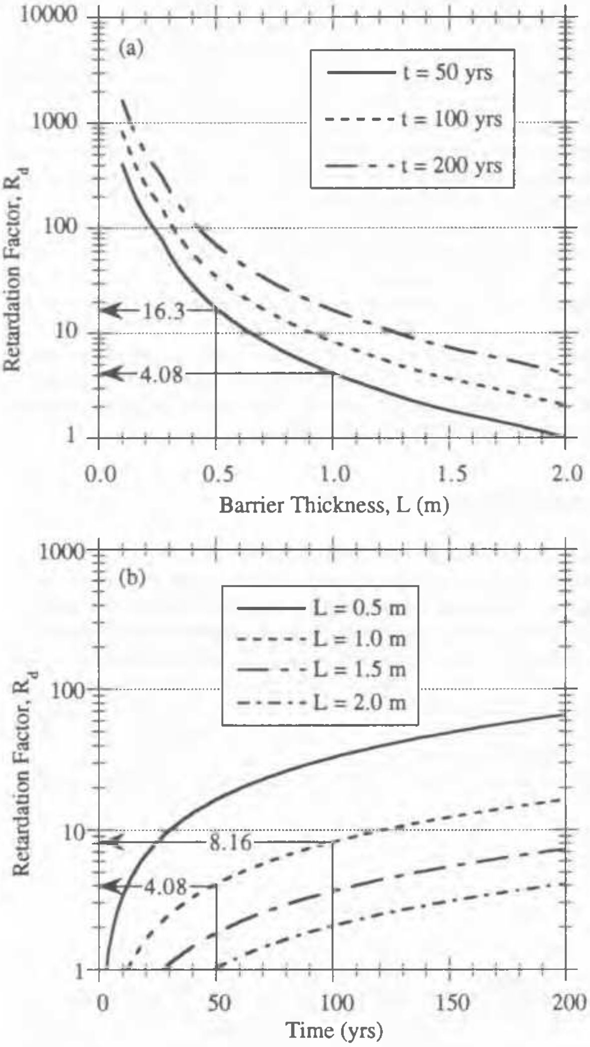

Fig. 4 - Retardation factor (a) as a function of thickness, L, for a given containment time, t, and (b) as a function of containment time for a given thickness for the case of pure diffusion.

reaction for the case of a constant source concentration, c_o, can be evaluated using the following analytical model:

$$\frac{c(L,t)}{c_o} = \text{erfc}(\beta) \tag{1}$$

where erfc is the complementary error function, and the argument, β, is given as follows:

$$\beta = \frac{R_d L}{2\sqrt{D^* R_d t}} \tag{2}$$

where L is the thickness of the barrier, D^* is the effective diffusion coefficient, and R_d is the retardation factor for linear, instantaneous, and reversible sorption. Equation 1 is plotted in Fig. 3.

Based on Eqs. 1 and 2, the required attenuation capacity as represented by R_d may be calculated for given values of β {i.e., $c(L,t)/c_o$)}, D^*, L, and t. For example, for $c(L,t)/c_o = 0.10$, $\beta \approx 1.136$, and assuming $D^* = 5 \times 10^{-10}$ m²/s (e.g., Shackelford and Daniel 1991), the required L for a given containment time, t, or the required t for a given L are illustrated in Fig. 4.

As illustrated in Fig. 4, L can be halved by increasing the retardation factor (i.e., attenuation capacity) by 4X for a given t or, conversely, t can be doubled for a barrier with a given L by doubling R_d of the barrier material. Thus, the potential benefits of utilizing the reactive nature of passive containment barriers, particularly for long-term containment, are illustrated.

REFERENCES

Allerton, D. K. et al. (1996). Waste containment barrier enhancement with zeolite. *Tailings and Mine Waste '96*, Balkema, 255-264.

Evans, J. C., Sambasivam, Y., and Zarlinski, S. (1990). Attenuating materials for composite liners. *Waste Containment Systems: Construction, Regulation, and Performance*, R. Bonaparte, Ed., ASCE, 246-263.

Evans, J. C. and Prince, M. J. (1997). Additive effectiveness in minerally-enhanced slurry walls. *In Situ Remediation of the Geoenvironment*, J. C. Evans, Ed., ASCE, 181-196.

Gray, D. H. (1995). Containment strategies for landfill wastes. *Geoenviron. 2000*, Y. B. Acar and D. E. Daniel, Eds., ASCE, 484-498.

Lo, I. M.-C., Liljestrand, H. M., and Daniel, D. E. (1994). Hydraulic conductivity and adsorption parameters for pollutant transport through montmorillonite clay liner materials. *Hydraulic Conductivity and Waste Contaminant Transport in Soil, ASTM STP 1142*, D. E. Daniel and S. J. Trautwein, Eds., ASTM, 422-438.

Park, J. K., Kim, J. Y., and Edil, T. B. (1996). Mitigation of organic compound movement in landfills by shredded tires. *Water Environ. Res.*, 68(1):4-10.

Park, J. K., Kim, J. Y., Madsen, C. D., and Edil, T. B. (1997). Retardation of volatile organic compound movement by a soil-bentonite slurry cutoff wall amended with ground tires. *Water Environ. Res.*, 69(5):1022-1031.

Shackelford, C. D. (1988). Diffusion as a transport process in fine-grained barrier materials. *Geotech. News*, 6(2):24-27.

Shackelford, C. D. (1990). Transit-time design of earthen barriers. *Engrg. Geol.*, 29:79-94.

Shackelford, C. D. (1994). Waste-soil interactions that alter hydraulic conductivity. *Hydraulic Conductivity and Waste Contaminant Transport in Soil, ASTM STP 1142*, D. E. Daniel and S. J. Trautwein, Eds., ASTM, 111-168.

Shackelford, C. D. and Daniel, D. E. (1991). Diffusion in saturated soil: I. Background. *J. of Geotech. Engrg.*, ASCE, 117(3):

Stern, R. T. and Shackelford, C. D. (1998). Permeation of sand-clay mixtures with calcium chloride solutions. *J. of Geotech. and Geoenviron. Engrg.*, ASCE, in press.

Thornton, S. F. et al. (1993). The role of attenuation in landfill liners. *Proc., Fourth Inter. Landfill Symp.*, Sardinia, 407-416.