FLOW AND TRANSPORT THROUGH CONCRETE

Fluid flow and mass transport through a concrete vault are two of the most important factors influencing concrete degradation rates and the ability of the concrete to assist with isolation of the waste. Over time as a concrete vault ages, the properties of the concrete and its ability to assist with isolation of the waste will change. Portions of the concrete will crumble and become more permeable. Eventually cracks will penetrate the concrete slabs, leading to preferential pathways through the barrier. This section reviews some of the aspects of flow and transport through concrete that are relevant to understanding the mathematical models for concrete degradation. The performance implications of the degradation phenomena will be treated in more detail in a future document.

Fluid Flow Through Matrix

The rate of water percolation through a waste isolation system is one of the most important measures of performance. Initial matrix permeability of cement paste is influenced strongly by water-to-cement ratio (WCR) with its influence upon capillary porosity (Powers, 1958 and 1960). Evaluation of fluid flow is complicated by location of the low-level waste (LLW) facilities in the unsaturated zone.

Flow through the unsaturated zone can be described using the Richard's equation (Hillel, 1971).

$$\frac{\partial\theta}{\partial t} = \frac{\partial}{\partial x}\left(K(\psi)\frac{\partial\psi}{\partial x}\right) + \frac{\partial}{\partial z}\left(K(\psi)\left(\frac{\partial\psi}{\partial z} - 1\right)\right) \qquad (1)$$

where

- ψ = pressure head (cm)
- θ = volumetric water content
- K = hydraulic conductivity (cm/s).

Concrete differs from other components of the vault system (e.g., soils) in that typical pore sizes in concrete are very small. Typical soils can be dried to near the residual saturation at soil tensions of a few bars (Wosten and van Genuchten, 1988), while removal of water from cement or concrete requires tensions of hundreds to thousands of bars (Daian, 1988). For example, concrete can maintain 85% saturation at tensions of 9 bars (Daian, 1988). The small pore sizes are especially characteristic of low WCR concretes used for concrete barriers. In subsurface environments, the small pores in the concrete successively remove water from the surrounding materials leading to saturation of the concrete matrix. The concrete matrix remains near saturation even when the surrounding soils are quite dry.

The hydraulic conductivity of gel pores is approximately 7×10^{-16} m/s (Powers, 1958). The permeability of the cement paste is a function of capillary porosity. Capillary porosity in turn is dependent upon the WCR and degree of hydration. Typical cement paste has a permeability of 20 to 100 times the minimum (Powers, 1958). In general, the hydraulic conductivity of concrete with a low WCR should be less than 10^{-13} m/s.

Fluid Flow Through Cracks

Approach. Even in relatively minor amounts, cracking can lead to orders of magnitude increases in saturated hydraulic conductivity of concrete. If the concrete is one of the more significant barriers to flow through the system, the increase in hydraulic conductivity can lead to proportional increases in water percolation through the system.

Location of the LLW facilities in the unsaturated zone greatly complicates the role of cracks in influencing performance of concrete barriers. In unsaturated environments, water remains in a state of tension created by capillary action (absorption) and adsorption. Because cracks are large relative to the pore size of the matrix, they have a limited ability to hold water in tension. In other words, under unsaturated conditions cracks will drain quickly. The drained cracks not only no longer contribute to flow but may also serve as barriers to flow (Wang and Narasimhan, 1985). Depending upon the degree of saturation, cracks may range from orders of magnitude increases in flow rate to significant decreases in flow relative to an uncracked specimen. The ability of cracks to hold water (and thereby contribute to flow) as a function of pressure head is illustrated in Figure 1.

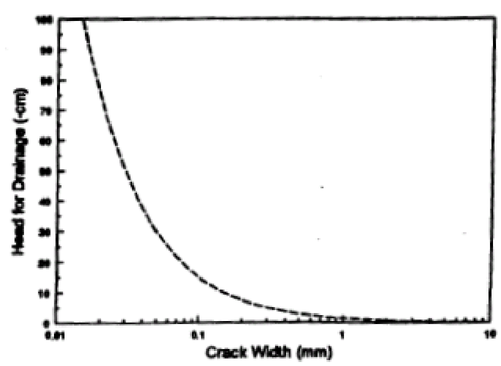

Figure 1. Suction head for crack drainage under partially saturated conditions.