Conceptual Model of Water and Dissolved Salts Movement Through Portland Cement Concrete

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THE PROBLEM

A frequently occurring topic in hydrology is the movement of soil moisture through concrete slabs and into the interior of the structure. The problem is the potential (or lack of) movement of water through Portland cement (PC) concrete slabs that may range in thickness from 3 to 5 inches. Frequently, the source of water generally is underlying groundwater that is naturally occurring, or may be provided by man as irrigation seepage or other factors. These waters have dissolved salts, particularly the sulfate ion, which is occasionally observed on floor surfaces or has damaged floor coverings such as carpet and caused tiles to loosen. When there is moisture transport, the underlying mechanism may be described by the theory of unsaturated flow in porous media.

PC CONCRETE

PC concrete is a man-made stone consisting of aggregate, Portland cement (a limestone powder), and water to initiate the chemical reaction to cause the cement to harden and bind the aggregate together into a solid matrix. Aggregate is usually sand to gravel sizes. Various admixtures are sometimes added to the wet mix to promote desired properties such as early curing or enhanced workability.

Generally, PC concrete will reach about 95 percent of its maximum strength within about 5 days. Concrete is strongest in compression and its compressive strength as well as tensile strength is enhanced by steel reinforcement.

The construction process for installing PC concrete as building slabs and foundations is to truck in ready mixed concrete to the site and pour or pump the concrete into forms to form a pad or slab on compacted soil which may have a thin gravel layer between the slab and soil. Prior to this, plastic sheeting is often laid down to form a barrier to upward water movement after the concrete is cured. Additionally, wire reinforcing screen is often laid down on approximately one inch thick blocks to keep the screen elevated in the mixture. In modern practice, it is common to vibrate the wet concrete to minimize voids.

Sometimes workers can be seen punching holes in the plastic sheeting before the ready mix arrives. This is done for two reasons. One is to allow excess water in the ready mix to drain faster and promote faster setup and curing. The other is that excess water causes what is called "crazy cracks" to form during working and curing, making exposed surfaces somewhat unattractive.

PC CONCRETE AS A POROUS MEDIA

In nature, when a cementing agent, aggregate, water, and time are suitable, an indurated sedimentary stone is formed. Fine uniform silts are called "siltstone" while uniform sands are called "sandstone." When a mixture of sizes ranging to gravel or larger sizes are present the stone is called "conglomerate." PC concrete is basically a man-made conglomerate. Almost all of these stones are a porous media with a finite porosity and hydraulic conductivity. For example, Domenico and Schwartz (1990) indicate that ranges of values for saturated hydraulic conductivity for siltstones, sandstones, and limestone may be from 10^{-11} to 10^{-9} m/s.

During its curing phase, PC concrete has small pores that are caused by entrapped air and water. If the workmen are not careful, some pores can be quite large (cm sized). Some of the pores are interconnected so that the hardened porous concrete has a hydraulic conductivity which may be in the range of those listed for sandstone.

Porous PC concrete will allow unsaturated as well as saturated flow to develop in the presence of a water source. The presence of cracks perpendicular to a water source will inhibit unsaturated flow, and cracks of any orientation will enhance saturated flow.

THE HORIZONTAL PC CONCRETE SLAB

The potential movement of moisture and transport of dissolved minerals through a horizontal PC concrete slab is envisioned as a predominantly one-dimensional process. It is recognized that at the edges of the slab where the building wall footings are, there is potentially a two-dimensional flow and transport process.

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Where there is cracking, saturated flow, if it can develop, is enhanced. However, for saturated flow to develop there must be a hydraulic head such that there is an energy potential greater than atmospheric.

What is more common is to have a water source near the bottom of the slab; i.e., a high perched water table at or below the slab bottom. Another common situation is poorly drained clays may be present and have enough moisture to provide a water source. Water sources may be drainage from landscape irrigation or rainfall infiltration which has moved downslope under the slab. Consequently, unsaturated flow is the dominant process of interest.

A CONCEPTUAL MODEL OF WATER MOVEMENT

A one-dimensional vertical PC concrete column is assumed with vertical upward movement of water and dissolved salts. At the bottom there are moist soils and at the top it is much dryer. *Continuous wetting is assumed;* i.e., the lower boundary condition stays moist and does not dry out. As a result hysteresis is not a factor. **Figure 1** depicts the physical situation. The total hydraulic head (units of length since the gravitational constant has been divided into each term) is denoted by h where $h = z + p$, z is the elevation head and p is the pore pressure head which is less than zero for unsaturated conditions.

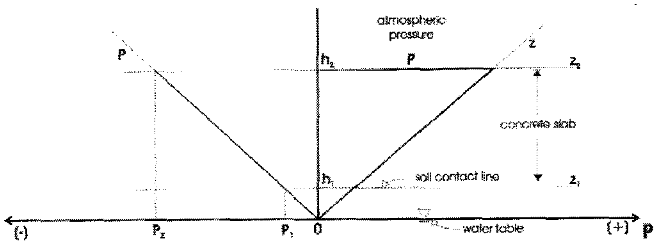

Figure 1. Conceptual System: z=elevation; p=pressure.

For unsaturated conditions p is a function of water content, w (units of vol/vol) as shown in the hypothetical retention curve depicted in **Figure 2**. Numerous measurements, however, have been made on porous media so that there is some general concept of how such a relationship might look for PC concrete. If the top of the column is relatively dry, $p2$ is many atmospheres negative while at the bottom of the column, $p1$ is negative but near zero.

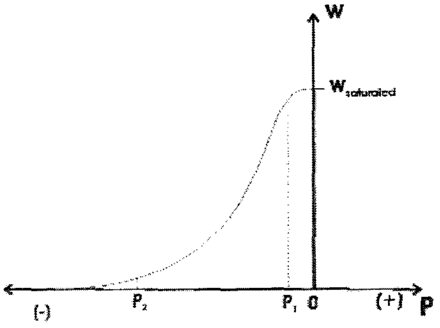

Figure 2. *Conceptual Relationship Between Water Content (w) and Pore Pressure (P) for an Unsaturated Soil Media.*

Consequently, there is a very large gradient upward; i.e.

$$\textbf{grad } h = (h2 - h1)/(z2 - z1) \quad (1)$$

Guymon (1994) discusses the origin of the forces that make up p.

To determine the moisture flux, v, upward, Darcy's law is used; i.e.

$$v = -\,\mathbf{K}(w).\textbf{grad } h \quad (2)$$

where $\mathbf{K}(w)$ is the hydraulic conductivity which is a function of water content or pore water pressure, i. e., $\mathbf{K}(p)$ (Guymon,1994). For most fine grained soils the hydraulic conductivity function changes considerably (over log-cycles) with changes in water content, w.

A complete model applicable to the situation conceptualized here is given by Guymon (1994):

$$\bullet(\mathbf{K}(p)\bullet h/\bullet z)/\bullet z = (\bullet w/\bullet p)\,(\bullet h/\bullet t) \quad (3)$$

Boundary conditions are discussed above. Initial conditions would be a *uniform* but small water content throughout the column. (An application of this conceptual model including phase change is found in Kim and Heydinger, 2002).

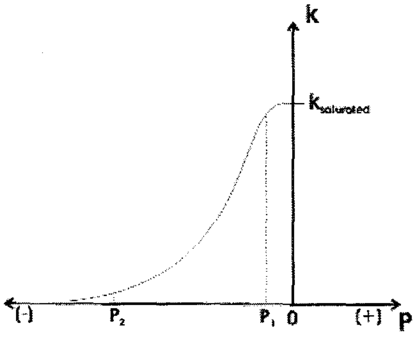

Figure 3. Conceptual Relationship of Hydraulic Conductivity (k) to Pore Pressure (P) for an Unsaturated Soil Media.

Figure 4 shows the wetting process in the one-dimensional PC concrete column. *Upward moving wetting fronts are a result of a* wet condition at the bottom of the column and drier conditions at the column top. Very strong upward pressure gradients dominate the process. After a long time, moisture flux is in equilibrium and quasi-steady-state is achieved and Equation 3 reduces to Equation 2. Moisture is continuously supplied by the underlying soil, is transported through the column, and exits the surface as evaporation where it may condense in floor coverings. This is similar perhaps to a desert situation where there may be a water table below the surface. It is well known in Boy Scout lore that a desert survival technique is to place a sheet of plastic or tarp over the surface and arrange it so its underside will drain into a container. During the night groundwater moisture collects on the bottom side of the covering and drains into the container.

To make a very rough calculation of how much moisture might be transported, assume a vertical PC concrete column 10 cm tall. At the bottom assume $p1$ equal zero and assume at the top $p2$ equal -1,000 to -10,000 cm of water. Assume the log-averaged hydraulic conductivity is 10^{-11} to 10^{-13} m/s. From Equation 2, the hypothetical velocity flux ranges from about 0.01 mm/day to 10 mm/day.

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Conceptual Model - *continued from Page 6*

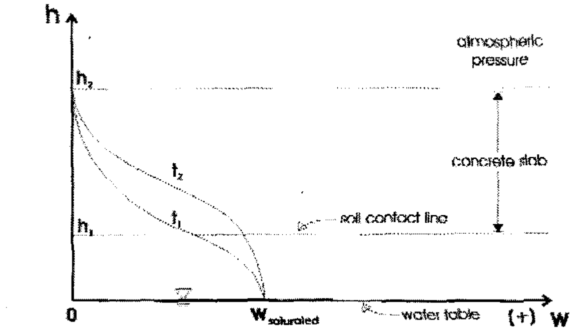

Figure 4. Conceptual Wetting Curves through a Concrete Slab for Various Times $t_2 > t_1$.

A CONCEPTUAL MODEL OF DISSOLVED SALT TRANSPORT

An underlying soil water is envisioned that has dissolved salts but the solution is dilute. We are particularly interested in the sulfate ion which apparently is a major component of salts deposited on floor surfaces. How does the sulfate get there?

The dissolved sulfate is being transported with the upward moving water. It is well known that sulfate in dilute solutions is miscible with water and that it does not react with most porous media (Hillel, 1980a,b). Consequently, the appropriate mass transport model is (Guymon, 1994):

$$\bullet C/\bullet t + v_s \bullet C/\bullet z = \bullet(D\bullet C/\bullet z)/\bullet z \qquad (4)$$

where C is the concentration, t is time, z is the vertical coordinate, v_s is the seepage velocity (v/w), and $\mathbf{D}$ is the dispersion coefficient. At the bottom of the column the sulfate transport boundary condition is approximated by some constant concentration. The appropriate top boundary condition is open to question. If it were $\bullet C/\bullet z = 0$, we could obtain an analytical solution to Equation 4. For an initial condition, one might assume the sulfate to be a uniform concentration of zero. The solution is not sensitive to the initial condition over a long time period.

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