Concrete

Q&A

Vapor Is the Trojan Horse of Moisture in Concrete Slabs

This month's Q&A features a candid discussion of water as it relates to concrete slabs-on-ground. Using a series of answers to commonly asked questions, Scott Tarr, North S.Tarr Concrete Consulting, P.C., Dover, NH, USA, discusses water migration; pH on slab surfaces; efflorescence; vapor retarders/barriers; slab curling; moisture in slabs; concrete exposure to water, sulfates, freezing and thawing, and chlorides; admixtures to stop vapor transmission; and concrete moisture and flooring installation.

Q. *Water tends to accumulate under boxes stored directly on our warehouse floor, and many of the vinyl floor tiles in our office space are loosely seated in a slimy adhesive. Do we have a hydrostatic water pressure issue, or is water being drawn through the concrete by capillary tension?*

A. It's unlikely that these issues are caused by hydrostatic pressure or capillary action. For hydrostatic water pressure to be the cause, the concrete slab would need to be below the water table or nearby ponded water. Further, because concrete is relatively impermeable to liquid water (that's why it's used for pipes, tanks, and dams to contain liquids), hydrostatic pressure would be able to force liquid water through a slab-on-ground only at cracks and joints.

Table 1:
Approximate ages for the capillary pore system of cement paste to become discontinuous (from References 1 to 3). The tabulated 28-day compressive strengths are commonly expected values

w/c	Time for capillaries to close	Approximate compressive strength, psi
0.40	3 days	6000
0.45	7 days	5500
0.50	14 days	5000
0.60	6 months	4000
0.70	1 year	3000
>0.70	impossible	2000

Note: 1000 psi = 6.9 MPa

For capillary action to be the direct cause, the slab would have to be comprised of very poor-quality concrete with a continuous network of small voids in the paste between aggregate particles (capillaries) similar to some fine-grained soils. For concrete with a water-cement ratio (*w/c*) of 0.70 and below, cement hydration eventually closes off capillaries, resulting in discontinuous voids that do not transport liquid water. Table 1 summarizes studies[1-3] showing the effect of *w/c* on the time it takes for cement hydration to make capillaries discontinuous. Also shown in Table 1 are typical 28-day compressive strengths obtained with non-air-entrained mixtures (mixtures with entrained air would have lower strengths). With or without air entrainment, mixtures with *w/c* above 0.70 should not be used when moisture intrusion is a concern, as capillaries created by mixing water will never close.

However, capillary action in the subgrade can certainly be a contributing issue, as surface tension in fine-grained soil can pull liquid water great distances above the water table. A capillary break—a layer of larger, open-graded stone—is thus recommended to break the tension and prevent such transport of liquid water to the underside of a slab-on-ground. Even so, water can continue to migrate to the slab surface if not designed to stop vapor. Just as the Greeks used the Trojan Horse to conceal themselves, "sneak" into the city of Troy, and then emerge to win the Trojan War, water can change phase, invisibly move through the capillary break and the slab in vapor form, and then condense to liquid water. This phase change is important as it can happen in all climates and conditions, and testing has shown that concrete sometimes acts hygroscopically to increase the tendency for moisture to condense.

In your warehouse, condensation can happen beneath relatively impermeable pallets, products, and mats placed directly on the floor, as the stored items trap air, allowing it to contain increasing amounts of water vapor and eventually reach the dew point (the temperature at which a given volume of air at a given atmospheric pressure is saturated with water vapor). Condensation can thus occur at higher ambient temperatures than at exposed slab surfaces. In your office, condensation occurs below the floor tiles largely because the air conditioning system cools the low-permeance flooring material and the nearby concrete to the dew point.

Q. *Does condensed liquid water break down the floor covering adhesives?*

A. Not exactly. While most flooring adhesives are not affected by pure water, many can't withstand solutions with pH values above about 11. Although the condensate that forms beneath a low-permeance floor covering is initially pH neutral, it immediately begins to dissolve soluble materials, including alkali salts, such as potassium-, sodium-, and calcium-hydroxide. These salts are concentrated at a slab surface during concrete placement, as bleed water rises to the surface and the water evaporates. After the slab hardens, these salts are innocuous; however, they produce hydroxide ions when they go into solution in the condensate beneath the tiles, resulting in a solution with a pH above 12. This solution breaks down flooring adhesives.[4] Again, note that the salts were not transported to the slab surface by vapor or liquid water movement through the hardened concrete. They were carried by normal bleed water before concrete setting and hardening.

Q. *Are these soluble salts the white deposit we see after a slab surface dries?*

A. Yes. The salts that were concentrated by bleed water during construction and brought into solution by condensed water vapor will result in a white residue after the condensate has dried from the surface of a concrete slab. It's called efflorescence, the same term that applies to deposits that form on a masonry wall after the evaporation of rainwater that has carried soluble salts out of the mortar. Soluble alkali salts are typically left behind after a condensate-damaged flooring system is removed and the slab surface is cleaned and allowed to dry. Salts may also be left behind on uncovered floors after evaporation of condensation that has formed beneath stored items or during a sweating event associated with a rapid increase in ambient relative humidity (RH) over a cool slab. In either case, the salts will appear as a white residue. It is very important to clean these off as soon as possible, as they can be difficult to remove later, and they increase the risk of future sweating.

Q. *If liquid water doesn't move through quality concrete, how can water vapor move through it?*

A. As discussed previously, while concrete is relatively impermeable to liquid water, it is not impermeable to water vapor—a gas. There is a substantial difference between water permeance and water vapor permeance. Likewise, waterproofing and water vapor proofing are not the same. Water vapor passes through concrete but, if the voids at any location within the concrete are at or near the dew point temperature, the vapor condenses to liquid. The dew point is dependent on the RH and temperature of the air in the voids, and the potential for condensation increases with the RH. As vapor naturally moves vertically from the groundwater table to the atmosphere as part of the hydrologic cycle, the rate of transmission decreases, and the RH increases near interfaces with materials with lower permeance. These locations are where condensation is most likely to occur. As an analogy, consider the flow of cars on a turnpike: the traffic speed decreases and the traffic density increases at a tollbooth, and that's where many cars will come to a halt. It is best to reduce the rate of vapor transmission before water vapor reaches the underside of the flooring or stored products, so a vapor retarder with permeance lower than the flooring system is recommended immediately beneath the concrete slab-on-ground.

Q. *Do vapor retarders cause curling of slabs-on-ground?*

A. No, this myth has been entirely debunked. In fact, concrete slabs placed directly on plastic curl less than slabs placed in contact with the ground.[5]

Q. *When a vapor barrier is used under the concrete slab, is moisture no longer a concern?*

A. A vapor barrier is a very good start. When installed directly beneath the slab, plastic sheet materials that meet ASTM E1745[6] can keep moisture in the ground from transmitting through the slab at a rate higher than the flooring system permeance. However, most plastic sheets installed under a concrete slab are considered to be vapor retarders as they are not impermeable to vapor and only serve to reduce the transmission rate to less than 0.1 perms. This can still be greater than the flooring system requires. Fortunately, less permeable materials are available.

ACI 302.1R-15, Section 5.2.3.1,[7] suggests that vapor retarders that effectively reduce the vapor transmission rate to 0.01 perms might be considered vapor "barriers." But even when an effective vapor barrier is used to reduce the vapor transmission rate coming into the concrete slab at a lower rate than the permeance of the flooring system, there may still be available moisture remaining within the concrete.

Before flooring installation, the concrete slab dries from the exposed surface downward, creating a moisture gradient

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through the depth of the slab. The magnitude of this moisture gradient and the drying shrinkage potential of the concrete mixture determines how much curling occurs. The magnitude of the gradient is reduced by vapor retarders, and this reduces curling, but the drying period can be much longer than the construction contract allows.[2] Once the flooring is installed, the moisture redistributes and moisture from the deeper portion of the slab rehydrates the drier upper region.

It is important to verify that the moisture condition of the slab is acceptable to the flooring manufacturers (flooring material, adhesive, primer, and others). If not, topical moisture vapor mitigation systems are available that have a permeance of 0.1 perm or less (ASTM F3010[8]).

Q. *Do we need to protect concrete slabs against exposure to liquid water from the ground?*

A. It is always advisable to drain runoff water away from foundations and use open-graded stone as a capillary break, if needed, to avoid underside exposure to liquid water. Capillary break layers should also be capped with fine material to reduce the frictional restraint on the slab or minimize the risk of puncturing the vapor retarder. Some water, such as seawater, contains high levels of sulfates that can attack and deteriorate concrete. Some soils also contain sulfates, so it is important to design slabs-on-ground for such exposure conditions, if necessary.

ACI 318-19[9] and ACI 301-20[10] provide durability requirements for concrete mixtures exposed to sulfates (Exposure Category S), such as reducing the *w/c* or using Type V cement. Recently, the idea of isolating the concrete from water-soluble sulfates was suggested as an equally effective, or perhaps more effective, method of protection.[11,12] An underside vapor barrier can serve to isolate the concrete from sulfates, thus creating the minimum Exposure Class S0. Sulfates are water-soluble and are transported by liquid water but are not transported by water vapor, so they do not penetrate effective vapor barriers.

Q. *Is isolation possible for other exposure categories listed in ACI 318-19 and ACI 301-20?*

A. Slabs exposed to cyclic freezing and thawing (Exposure Category F) are typically outside, subjected to rain/snow/sleet as a source of moisture, so vapor retarders aren't generally beneficial or recommended for these applications. However, vapor retarders are always included as part of interior freezer slab designs for the purpose of limiting the exposure to moisture and corresponding ice crystal growth within the subfloor insulation and concrete. Vapor retarders can also help with the other exposure categories.

For exposure to water (Exposure Category W), vapor retarders keep moisture out of the slab and allow them to dry, limiting the moisture available for alkali-aggregate reactivity such as alkali-silica reaction (ASR). Likewise, for exposure to chlorides (Exposure Category C), vapor retarders decrease the moisture necessary for the corrosion of embedded steel reinforcement. As quality concrete does not allow water-soluble chloride ions to be transported from the soil or irrigation water to embedded steel with proper concrete cover, the chloride ion limits in ACI 318-19 and ACI 301-20 apply to chlorides contributed from concrete materials, not from the environment surrounding the concrete. However, as effective vapor retarders prevent the concrete from being rehydrated after the initial drying period, they reduce the exposure class to C0 and permit a higher maximum water-soluble chloride ion content in the concrete mixture. This can be very helpful when certain admixtures, such as accelerators, are needed.

Q. *What about admixtures that stop vapor transmission?*

A. To be as effective as vapor retarders or topical moisture mitigation systems, integral admixtures that claim to stop vapor transmission must reduce the water vapor transmission rate (WVTR) of concrete to 0.1 perms or less.[13] Ideally, though, as with vapor barriers discussed previously, the WVTR should be reduced to less than that of the flooring system. This means the admixture must reduce the WVTR of concrete by several orders of magnitude, depending on the concrete mixture. The effectiveness of the admixture can be demonstrated by testing the permeance of the concrete mixture (ASTM E96/E96M[14]) without the admixture and repeating the test on a sample of the same concrete mixture with the admixture. Of course, care must be taken to adjust the batch water to compensate for the amount of admixture.

Q. *So, how do we know the concrete is dry enough to install glued-down flooring?*

A. It's not as simple as looking or touching the concrete slab surface to determine if it is wet or even basing a decision on the amount of drying time, as ambient and exposure conditions vary. Like the Trojan Horse analogy, invisible vapor (a gas) "sneaks" into the concrete and, when the conditions are right, the process of condensation and solution formation occur. And as stated in Reference 4, the solution to floor covering failures is avoiding this solution.

Along with having a vapor barrier, manufacturers of moisture-sensitive adhesive and flooring establish moisture limitations to determine if the drying time and exposure were sufficient to reduce the moisture within the concrete and secure the product warranties. As the critical moisture is not visible, moisture testing typically involves using RH sensors installed in drilled holes (ASTM F2170[15]) or domed calcium chloride kits (ASTM F1869[16]) as required by the manufacturers. The manufacturers may also set a limit on pH but remember, while it is the high pH of the solution that causes the breakdown, pH does not exist without liquid water. To run a pH test currently, distilled water must be added to the slab surface to create a solution. As discussed previously, if water is supplied to dry concrete, an alkali solution will form. However, if there isn't enough moisture within the concrete to redistribute to the surface and form a solution after flooring installation, the soluble alkali salts cannot contribute to a high pH.

In Closing

Moisture is the same compound (H_2O) whether it's in liquid (water), gaseous (vapor), or solid (ice) form. As a liquid, it is an essential ingredient in concrete, necessary to hydrate and cure the cementitious portion for a minimum period after placement. But after the concrete mixture is batched, placed, and cured to achieve the properties needed, it is generally preferred to remove moisture from the concrete and prevent it from returning.

Moisture loss and corresponding shrinkage can create a variety of issues in concrete slabs-on-ground, including cracking and curling. And vapor intrusion, along with phase changes to a liquid and solid, can also cause problems in capillary pores. As the people of Troy learned when they allowed the Trojan Horse to enter, it is important to predict the risk of exposure to a potential hazard. In this case, we must anticipate moisture movement into, within, or leaving concrete slabs and protect against it in our design and construction details.

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