Vapor Barriers:

Nuisance or Necessity?

By Peter A. Craig

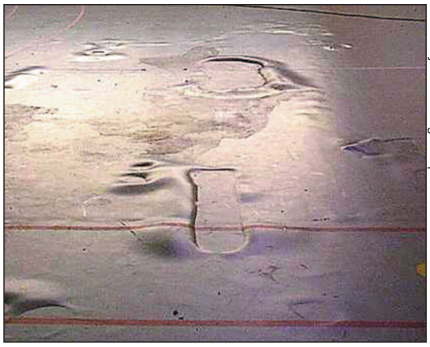
The subject of vapor barriers or retarders beneath concrete slabs on grade has long been controversial. Some justifiably argue that slabs placed in direct contact with a vapor barrier or retarder are more susceptible to curling and other slab problems than those cast on a granular base. They consider a vapor barrier or retarder a downright nuisance.

Others have experienced or witnessed the devastating effect of moisture on modern floor coverings, adhesives, coatings, and a building's environment. They will justifiably argue that a vapor barrier or retarder beneath the slab can be an absolute necessity.

Adding steel reinforcement can reduce curling.

Not surprisingly, reaching consensus on this subject has been difficult. Both sides raise genuine arguments that simply cannot be dismissed. There is, however, a single answer to the title question and it is yes, a vapor barrier can be both a nuisance and a necessity.

To better understand why moisture in concrete slabs has become such a problem, we must examine the sources of slab moisture, how moisture moves, and how it can adversely affect flooring materials, adhesives, and coatings.



Moisture can have a devastating effect on floor coverings, such as this failed gym floor.

Photos by Peter Craig except where noted.

Where does the moisture come from?

Free water within the concrete itself is the first source of moisture that challenges a floor covering or coating.

To produce concrete of a workable consistency, more water is added to the mixture than that which merely satisfies chemical hydration of the cement. After the slab is placed, finished, and cured, some of this additional water-of-convenience must leave the slab in order for the concrete to reach the moisture requirements of the floor covering, adhesive, or coating. Most manufacturers of flooring materials currently require, before the product is installed, that the moisture emission rate from the concrete not exceed 3.0 pounds, or in some cases 5.0 pounds, of water per 1000 square feet in 24 hours.

To understand how challenging it is to comply with these requirements, consider that a 4-inch-thick, 0.50 w/c concrete slab placed at a 4-inch slump can contain between 1600 and 1700 pounds of non-chemically bound water in a 1000-square-foot area.

How quickly moisture is lost from a slab depends on the water-to-cement ratio, density of the concrete finish, ambient conditions above the slab, and moisture below the slab. The following table summarizes the time necessary for laboratory cast, 4-inch-thick concrete samples to reach the commonly required moisture emission limit of 3.0 lbs/1000 sq ft /24 hrs when exposed to 73° F and 50% relative humidity.

This drying study reinforces the benefit of using concrete mixtures with a water-cement ratio not exceeding 0.50 and the need to eliminate or significantly reduce subslab moisture from entering the concrete from below.

Even though the 0.40 and 0.50 w/c samples exposed to water vapor and water in contact did reach a 3-lb rate of moisture loss, they would not remain at this moisture level if the samples were covered with a floor covering or non-breathable coating. The mois-

Where a moisture-sensitive floor covering or coating is planned, plan to take the ground out of play.

ture source below the slab must be taken out of play to avoid the potential for moisture to increase within the slab once it is covered.

The times shown in Table 1 should not be considered to begin until the slab is protected by a watertight roof and the curing period is completed. Re-wetting of the slab by any means will significantly lengthen the drying time. Ambient conditions above the slab also must be conducive to drying for, as one may observe, damp clothes on a damp day don't dry. Regardless of when the drying clock begins, it is important that the underside of the slab be sealed off from moisture below if a new concrete subfloor is to dry to an acceptable level and remain dry thereafter.

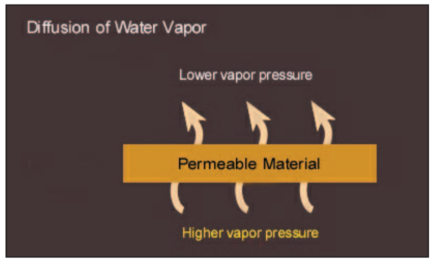
Moisture migration

At some depth below most building sites a natural source of water can be found. Because liquid water is often found beneath a failed flooring system, many people use the term "hydrostatic" to describe the condition. However, for a true hydrostatic condition to develop beneath the floor, the water table would have to be at or above the floor elevation. Such is seldom the case for a slab on grade.

There are two other ways in which water can rise upward through soils and contact a concrete slab on grade. The first method is capillary action. Through the forces of adhesion, surface tension, and cohesion, water can be drawn upward, well above the water table, through very narrow interstitial passageways such as those found in fine soils. An example of capillary action is water rising to a higher elevation within a narrow straw placed into a beaker of water.

Capillary action can be interrupted by a "capillary break" layer of coarse gravel or crushed stone between the slab and the subgrade. However, while a capillary break can be effective in stopping the rise of water in a liquid state, it does not eliminate the potential for moisture to reach the slab in vapor form.

Water changes from a liquid to a vapor as it evaporates. Water as a vapor will move from areas of high vapor



Diffusion of water vapor leads to moisture reaching the slab from below.

From B. Suprenant, "Moisture Movement Through Concrete Slabs," Concrete Construction, Nov. 1997.

Days Drying Time to reach 3.0 lbs/1000 sq ft / 24 hrs			
Water-Cement Ratio	Bottom Sealed	Bottom Exposed to Water Vapor	Bottom In Contact with Water
0.40	46	52	54
0.50	82	144	199
0.60	117	365	>> 365
0.70	130	>> 365	>> 365
0.80	148	>> 365	>> 365
0.90	166	>> 365	>> 365
1.0	190	>> 365	>> 365
4-inch-thick specimen dried at 73° F and 50% relative humidity			

Table 1. Drying time, in days, required to reduce vapor emission to 3.0 pounds per 1000 square feet per 24-hours.

pressure to areas of lower vapor pressure by a natural process called *diffusion*. Diffusion of water vapor occurs in both soils and concrete.

Numerous investigations show that the relative humidity in the base and subgrade material beneath covered slabs will generally test close to 100%. Regardless of the depth of the water table, such high relative humidity is reached beneath slabs on grade even when the moisture content of the base or subgrade material is found to be low when measured by weight loss after oven drying. While capillary action can cause liquid water to rise, diffusion is how water vapor distributes itself above the water table, and, unless restricted from doing so, contacts and enters the slab.

Without effective moisture protection directly beneath the slab, relative humidity near 100% in the environment beneath the slab can contribute to an increase of moisture within the concrete over time.

High moisture levels in the concrete cause soluble alkalis to enter into solution, raising the pH and leading to adhesive breakdown.

The effects

Liquid moisture can cause soluble alkalis within the concrete to enter into solution. When an alkali solution develops at or within the top surface of a slab, pH levels can rise above the 9 to 10 pH limit of most modern adhesives.

High moisture levels beneath a flooring installation can lead to cupping, bulging, or swelling of many flooring materials. It can also lead to total failure or disbondment of the flooring system if moisture-induced high pH levels lead to breakdown or re-emulsification of the adhesive.

In failure investigations, moisture-induced pH levels in the range of 11 to 12 are often found beneath the flooring. If you are to avoid elevated pH levels, adhesive breakdown, and the potential blistering of coating systems, moisture from sources beneath the slab must not be allowed to enter and increase within the concrete once it is covered.

Moisture migration through soils and concrete slabs on grade not only is a problem for the performance of floor covering and coating systems, but also can contribute to indoor air quality issues. At normal building temperatures, only two conditions are necessary to further the development of mold, mildew, and other forms of potentially harmful microbial life when active spores are present. They are moisture and a food source (which includes adhesives, gypsum, and some carpet backing material). Moisture beneath floor coverings or within adhesives or carpets can provide an environment suitable to further microbial development. That in turn may adversely affect indoor air quality. The installation of an effective vapor

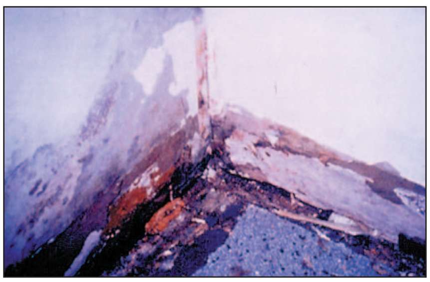
Dry Bulb Temperature °F	Typical vapor pressure range beneath slab (psi) ← Relative Humidity % →					Typical interior vapor pressure range above slab (psi)				
	100	90	80	70	60	50	40	30	20	10
100	0.948	0.854	0.758	0.663	0.569	0.474	0.379	0.284	0.189	0.095
90	.698	.628	.558	.489	.419	.349	.279	.209	.140	.070
80	.506	.455	.405	.357	.303	.253	.202	.152	.101	.051
75	.429	.386	.343	.300	.258	.214	.172	.129	.086	.043
70	.362	.326	.290	.253	.217	.181	.145	.108	.072	.036
65	.305	.274	.244	.213	.183	.152	.122	.091	.061	.030
60	.256	.230	.205	.179	.153	.128	.102	.077	.051	.026
55	.214	.192	.171	.149	.128	.107	.085	.064	.042	.021
50	.178	.160	.142	.124	.107	.089	.071	.053	.036	.018

Adapted from HUD Research Paper #28, Moisture Migration from the Ground.

Vapor pressure (psi) for various temperatures and relative humidity.

The effects of elevated pH levels can be seen in these examples of re-emulsified adhesive, soluble salts, and blistered floor coating.

barrier or retarder directly beneath the concrete can help reduce the amount of moisture available to contribute to such growth within or beneath a flooring system.



Hank Brulfodt

Mold problems affecting indoor air quality can begin with moisture migration through concrete slabs on ground.

Barrier or retarder?

A vapor barrier or retarder is a material designed to block or slow down the transfer of moisture from the ground into a concrete slab. Such materials are typically sheeting materials based on polyethylene or polyolefin technology. For many years all such materials were called *vapor barriers*. However, very few can truly be considered an actual barrier. The term *vapor retarder* is a far more accurate description of most materials used for subslab moisture protection.

How low should the permeance of below-slab moisture protection be? Current ASTM E-1745 class A, B, & C standards allow a vapor retarder material to have a water vapor permeance up to 0.3 perm. When the transmission rate of moisture is tested in accordance with ASTM E 96 Method B, a 0.3-perm material would allow the passage of approximately 18 gallons of water per week in a 50,000 square foot area. Although this may not seem like a great amount of water, and the transmission rate in actual field conditions will typically be lower, even a small amount of moisture allowed to enter the slab over time can significantly affect the moisture content of the slab.

Based on more than 150 flooring investigations, it seems that the performance of low permeance, adhered floor coverings such as sheet vinyl, PVC or urethane-backed carpet tiles, or rubber flooring warrant restricting potential moisture transfer to well below 0.3 perm. Other moisture-sensitive flooring materials, such as linoleum and wood, will also benefit from a greater level of protection.

In short, if the permeance of the material on top of the floor is considerably lower than that of the material protecting it from below, the potential exists for moisture to increase within the slab over time. In such cases it can take months or even years for problems to develop. Considering the extremely high cost of a flooring failure and the difficulty of drying concrete to an acceptable level in the first place, it makes sense to take ground moisture completely out of play.

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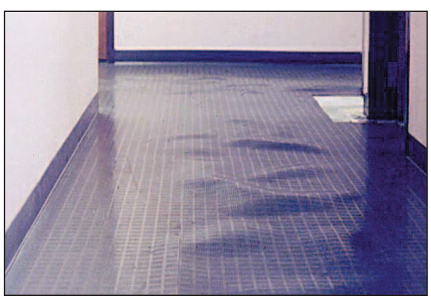
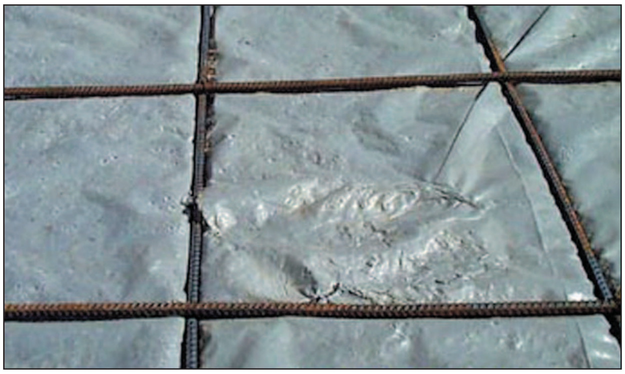


In the past, selecting an extremely low permeance material was costly. Today below-slab moisture protection is commercially available to as low as 0.01 perm with little if any premium to that of conventional materials of far greater permanence.

Additional research is needed to establish exactly where new permeance levels should be set and if a quantifiable delineation between a barrier and retarder can and should be established. Until such work is complete, designers, engineers, specifiers, and users are encouraged to select below-slab moisture protection with permeance levels well below current industry standards. The purpose of a vapor barrier or retarder beneath a concrete slab is to stop below-slab moisture from entering the slab and becoming a problem. Again, the best way to accomplish this is by selecting below-slab moisture protection of extremely low permeance.

In addition to permeance

While permeance is most important in evaluating a vapor barrier or retarder, the ability of the material to



A thicker vapor barrier is required where there will be equipment traffic or with angular base materials. Note the example of torn 6-mil poly.

withstand construction activity is also important. A punctured, torn, or incomplete vapor retarder provides an open avenue for moisture to enter the slab from below (Ref. 1).

Currently the American Concrete Institute's "Guide for Concrete Floor and Slab Construction" (ACI 302) recommends that the thickness of the vapor retarder be not less than 10 mils. Puncture studies of 6-, 8-, 10-, and 20-mil vapor retarder materials conducted by Suprenant and Malisch (Ref. 2) demonstrated that 10 mils is the absolute minimum thickness that should be considered, and that a thicker material may be necessary over more angular base materials. Many have observed the benefit of using materials with a minimum thickness of 15 mils when ready-mix trucks or laser screeds drive directly on the vapor retarder.

Concrete's role

In general, concrete permeability increases with an increase in the water-to-cement ratio. Concrete with a water-to-cement ratio below 0.50 is often considered to be watertight. But even watertight concrete is not impermeable to the passage of moisture.

Some think that low water-cement ratio concrete can by itself satisfy the floor covering industry's moisture emission requirements. After sufficient drying, this can appear to be true. However once the floor is covered, moisture within the slab will redistribute itself such that if the flooring were removed and the moisture emission rate re-tested, a higher emission rate would be observed. In addition, without adequate subslab moisture protection, the total moisture within the slab will increase over time. Also, without continuous moisture protection directly below the slab, sawed contraction joints and random cracks provide open passageways for moisture to rise through the slab.

Certainly concrete slabs to receive floor coverings or coatings will benefit from a reasonably low water-cement ratio. However, to omit an effective vapor barrier or retarder beneath the slab, and depend solely upon the concrete to provide protection from moisture migration, places the flooring installation at serious risk. Omitting an effective vapor barrier or retarder may also result in liability for a flooring failure, since the use of a vapor barrier or retarder is a published requirement in guidelines from the floor covering industry and many flooring manufacturers.

Where to place the vapor retarder

Until 2001, published guidelines from the American Concrete Institute (ACI) led slab designers and specifiers to place a 4-inch layer of granular fill atop a required vapor retarder. This detail has been successful on many projects, but has caused problems on others.

In April 2001, ACI published an update on vapor retarder location in *Concrete International*. The update informs the reader of instances where fill courses above the vapor retarder have taken on water from rainfall, curing, or sawcutting and may have subsequently contributed to flooring problems. As a result, the flow chart shown here was developed and will be published in the next revision of ACI 302.

A vapor retarder placed under granular fill may trap rainwater, leading to such moisture problems as were later seen with this tile floor.

The debate over vapor barriers or retarders will not be resolved overnight. With the cost of floor coverings over concrete subfloors now estimated at more than a billion dollars a year in the United States, far greater attention must be given to the issue of moisture within and below concrete slabs on grade.

Special thanks to Herman G. Protze, Dennis Pinelle, and Ned Lyon for their review and comments. ■

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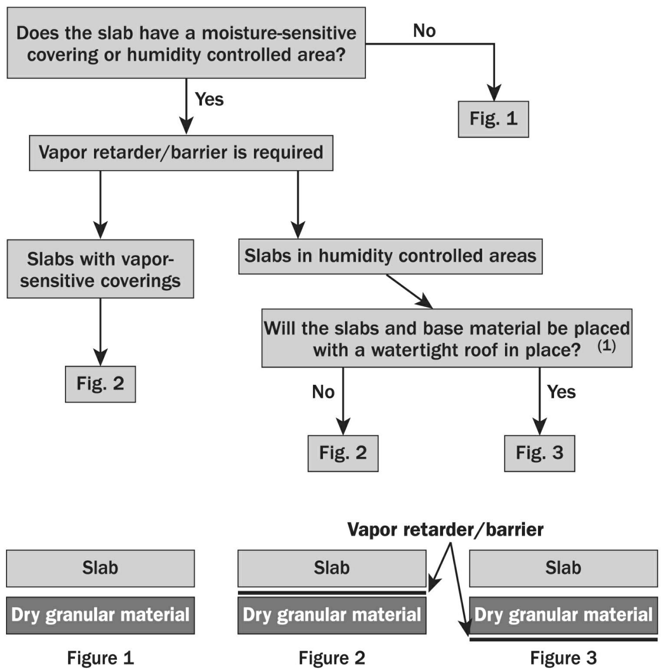
References

1. B. Suprenant & W. Malisch, "Don't Puncture the Vapor Retarder," CONCRETE CONSTRUCTION, Dec. 1998.

2. B. Suprenant & W. Malisch, "Examining Puncture Resistance," CONCRETE CONSTRUCTION, July 2000.

For more information on low-perm vapor barriers **circle 1** on the Reader Service Card.

Flow Chart for Location of Vapor Retarder/Barrier



(1) If granular material is subject to future moisture infiltration, use Fig. 2
(2) If Fig. 2 is used, reduced joint spacing, low shrinkage mixture design, or other measures to minimize slab curl will likely be required.

ACI's flow chart for determining the location of the vapor retarder or barrier.

Overcoming moisture problems

Although each project should be considered individually, the following recommendations have proved helpful in understanding and overcoming moisture-related problems with concrete slabs-on-grade:

1. An effective, low permeance vapor barrier or retarder is necessary to protect many modern floor coverings, adhesives, coatings, and building environments, and to conform with published guidelines from the floor covering industry.

2. Whenever possible, a capillary break should be included as a subslab component. A capillary break will not, however, prohibit moisture from reaching the slab in vapor form.

3. A water-cement ratio between 0.45 and 0.50 is a practical range that considers workability as well as reduced drying time. Lower water-cement ratios may be used to further hasten drying times, but special considerations should be given to placement size, workability, and curing. Pozzolonic materials such as fly ash or ground granulated blast furnace slag added to the concrete mixture may help in reducing soluble alkali content within the slab.

4. For most floor covering or coating applications, the vapor barrier or retarder should be placed directly beneath the slab. Additional slab design considerations such as continuous reinforcement may be needed to offset the potential increase in curling stresses with the slab.

5. For moisture- or alkali-sensitive flooring applications, including sheet vinyl, rubber, PVC or urethane-backed carpet tile, wood, or linoleum, consider the benefit of vapor retarder materials of extremely low permeance (0.01 perm or lower).

6. Homogeneous vapor retarder materials should be not less than 15 mils thick when they will receive direct traffic from ready-mix trucks, concrete buggies, or laser screeds.

7. There is only one opportunity to select the level of below-slab moisture protection, and that is before the slab is placed.

8. To help minimize the drying time of the slab and surface preparation costs, consider moisture-retaining, 7-day cover curing methods rather than membrane or chemical curing compounds, which may adversely affect adhesive bond and require removal before installing the flooring material.

9. It is difficult enough to sufficiently dry free-water from within the slab without exposing it to additional moisture from below.

10. Take the ground out of play!