Analyzing Moisture Problems In Concrete Slabs

Use these case histories to learn from others' design and construction mistakes

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Moisture-induced problems with flooring materials installed on concrete slabs on ground continue to plague the construction industry. The result: wasted materials, frayed relationships, voided warranties, lawsuits, and loss of faith in our design and construction professionals. Examining past projects, however, can help us to better anticipate, understand, and avoid these unpleasant situations.

What's Happening?

Problems involving water and water-vapor migration through a concrete slab on ground can affect a variety of flooring materials. Wood, carpeting, vinyl composite tile (VCT), seamless resilient flooring, and coatings such as urethanes and epoxies can experience both aesthetic and functional failures. Wood floors, for example, can "leopard-spot," cup, warp, decay, and buckle. Carpeting distress can include loss of adhesion, bubbling, loose seams, and mold growth. And VCT problems can include staining, curling, and loosening. What trait do all these failures share? Excessive moisture. Unfortunately, there are many sources of excessive moisture, as the following case histories illustrate.

Concrete Mixing Water

Sources of excessive moisture in new concrete slabs include subgrade moisture and mixing water that isn't chemically combined with the cement. This water is lost as a concrete slab and subgrade dry. It can then become trapped—and cause some of the failures mentioned above—when flooring materials are installed too soon after a slab is placed. But how soon is too soon?

Some flooring-material manufacturers require a concrete slab surface to be visibly dry; others require a maximum 3% moisture content or drying periods ranging from 60 to 120 days. The Resilient Floor Covering Institute requires the concrete floor to cure and dry for a minimum of six weeks before a resilient floor covering is installed. A common manufacturer requirement is a maximum moisture emission rate of 3 pounds per 1,000 square feet in 24 hours, as determined by the Rubber Manufacturers Association (RMA) calcium-chloride test procedure.

This latter requirement isn't always easily met. To document the drying process on one Minnesota project in the spring and summer of 1996, moisture-emission testing was performed on new concrete slabs for 15 weeks, starting in April. Using results from RMA test kits to document the

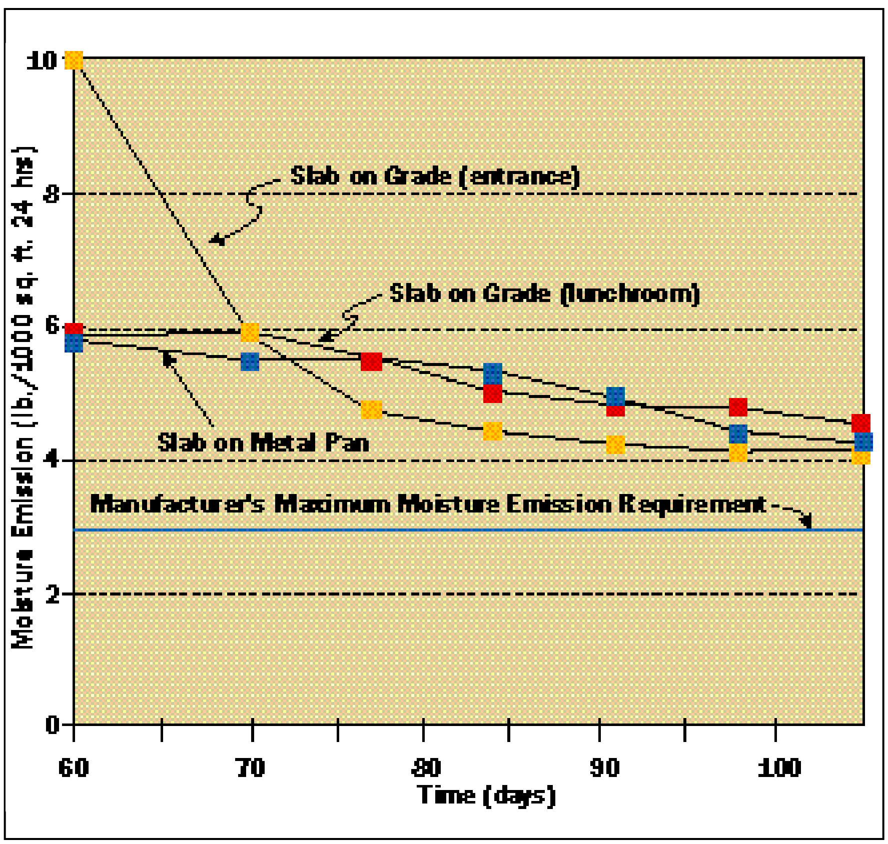


Figure 1. **Variations in moisture emission over time for concrete slabs of differing thickness and cast on differing surfaces.**

Concrete Properties and Design Details for Slabs Tested For Moisture Emissions with RMA Test Kits			
Location	**Slab-on-Grade (lunchroom)**	**Slab-on-Grade (entrance)**	**Stair**
Slab Thickness (in.)	5	5	2
Description	Concrete slab over 6-inch-thick sand cushion; 8-mil plastic sheet vapor barrier installed 6 inches below slab.		Concrete slab on metal pan provided for stair tread.
Concrete Properties			
Water-Cementitious Materials Ratio	0.52	0.52	0.48
Air Content (%)	2.5	2.5	2.5

moisture-emission rate, we tested three slabs: two are 5 inches thick and placed on-grade with a sand-cushion and vapor-barrier system; one is 2 inches thick and placed on a metal pan in a stairway (see table).

Testing revealed a gradual decrease in the moisture-emission rate over the 15-week monitoring period. At the end of 15 weeks, however, the moisture-emission rate still remained above the 3 pounds per 1,000 square feet per 24 hours maximum value required by the flooring manufacturer. (Refer to Figure 1 for the complete test results.)

The problem: As the building occupation date approached, the owner had to decide whether to install the tile flooring and risk voiding both the manufacturer's and installer's warranty, or delay the installation and risk a bond failure caused by a dirty floor surface. Even though the moisture emission was higher than allowable, the owner had the tile installed. After six months, no flooring distress or evidence of failure had been noticed.

Leaks

Another source of excessive moisture is water from outside sources, such as leaking walls or broken plumbing. These sources can often be difficult and expensive to diagnose, especially in structures with wood floor coverings, where water can travel undetected for long distances below the wood floor. Unsightly test cuts must be made through the floor to explore subsurface conditions, further restricting investigative efforts.

On one project, a high school gym's wood floor experienced recurring buckling, warping, and cupping. The distress occurred each summer during periods when the building was without humidity control.

An investigation revealed inadequate room for wood expansion around the perimeter of the floor, but gave few clues about the moisture source. The sandy subgrade had a very low moisture content. A hot-mopped asphalt membrane was found on top of the concrete slab on grade, but it exhibited no distress. The overall pattern of the buckling suggested a water source along an interior wall.

Further observations of the area revealed possible water entry points at roof level, but no signs of leakage down the wall. Also, drinking fountains in the vicinity showed no apparent leakage. Instead of spending more time and money investigating the problem, the owner elected to install an expansion joint around the floor, increase maintenance efforts, and tolerate the recurring buckling.

Several years later, and somewhat by accident, the water source was determined to be a broken drinking fountain pipe, apparently dislodged when the original structure was built. During normal, intermittent use of the fountain throughout the school year, the

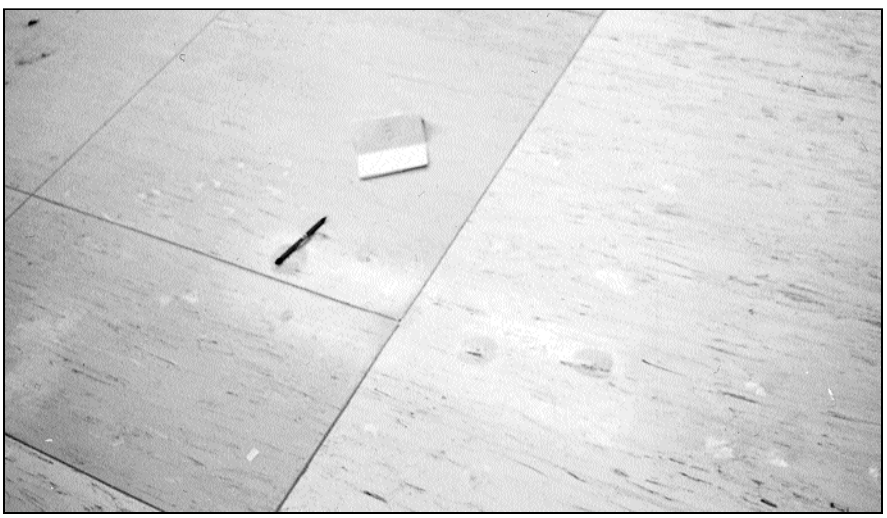


Figure 2. **Blisters in seamless vinyl flooring are commonly caused by moisture emissions in concrete floors. Most blisters in this hospital surgical suite ranged from 1 inch to 4 inches in diameter.**

drain water flowing through this broken pipe was easily absorbed by the sandy soil. However, in the summer when basketball teams practiced in the gym, the fountain faucet was blocked to run continuously and provide a supply of cold water to the players. That's when the drain-water flow was more than the subgrade could absorb, and water rose above the slab to cause the wood flooring problems.

Water-Vapor Pressure

On several large projects, the behavior of flooring materials indicates that the forces exerted by water-vapor transmission can be quite large. One such project was a hospital surgical suite. It received an application of 3⁄16-inch-thick seamless vinyl flooring bonded to a concrete slab on grade with an epoxy adhesive provided by the flooring manufacturer. The bond was so tenacious that it was virtually impossible to pry the flooring from the slab after numerous blisters developed in the flooring and required investigation. The blisters appeared about one year after construction, and they grew larger over time (Figure 2). The blisters ranged from ¼ inch to 15 inches in diameter and were as much as ¾ inch high, creating a tripping hazard for the facility's surgeons and surgical attendants. Other portions of the surgical suite were covered with ceramic tile, which was in excellent condition and showed no loss of bond or distress.

The floor slab was placed on cohesive soils without a vapor barrier or sand cushion. Soil borings indicated the water table was 8 to 13 feet below grade and that the site soils were moist, cohesive materials with a moisture content ranging from 7% to 32.4%. RMA test kits indicated emissions ranging from 7 to 13 pounds per 1,000 square feet in 24 hours.

Core samples revealed that the 3⁄16-inch-thick vinyl flooring was permanently deformed at the blisters. The coring also revealed bond failure of the epoxy adhesive at the blisters, though the flooring was firmly bonded to the area around the blisters and could not be pried from the slab.

Based on the appearance of the failed bond at the blisters, it was apparent that the setting and curing of the epoxy adhesive were unaffected by water-vapor pressure. But the fact that the blisters continued to grow indicated that vapor pressures were large enough to permanently deform the flooring and exceed the epoxy-adhesive bond to the concrete and tile. The culprits: the surgical suite's air-conditioning units and the subgrade soils' high moisture contents. The vapor pressure differential was large enough to develop the high pressures that led to deformation of the floor covering.

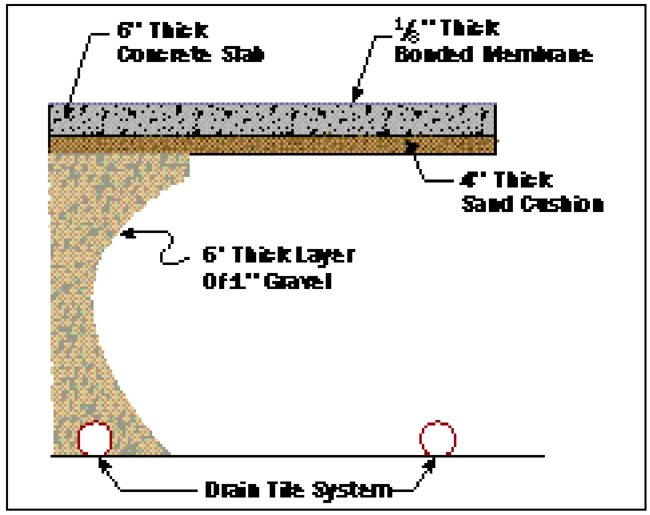


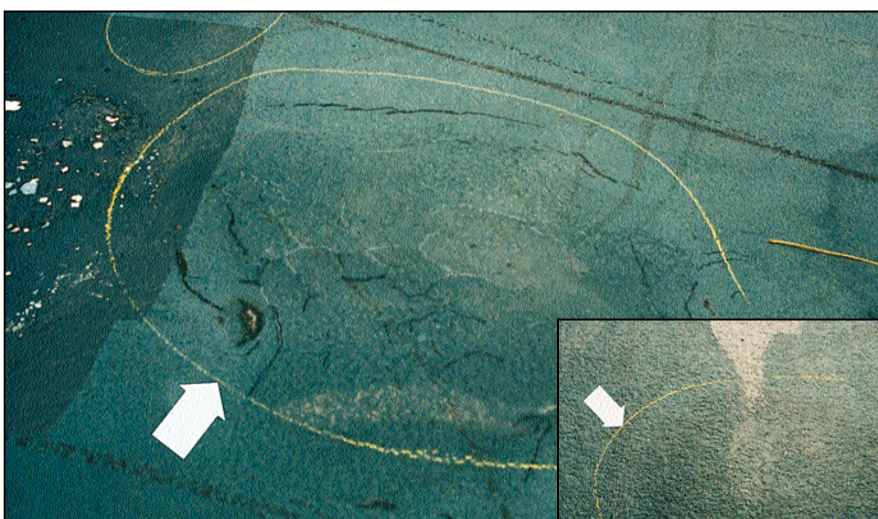
Figure 4. **Swimming pool floor construction details.**

A review of the flooring manufacturer's literature revealed that a below-grade vapor barrier with a sand cushion was required on all slab-on-grade installations. On this project, a sand cushion was specified, but not a vapor barrier. Had both been installed, the risk of failure on this project could have been greatly minimized.

Exterior Installations

Exterior installations of slabs on grade can also experience coating failures. When the exposure conditions are just right, a damp—not wet—subgrade is all that's needed to cause blistering of a concrete slab coating. This was demonstrated on a recent project where the slab was placed on an engineered drainage system consisting of a relatively dry sand cushion and gravel subgrade.

After draining an outdoor



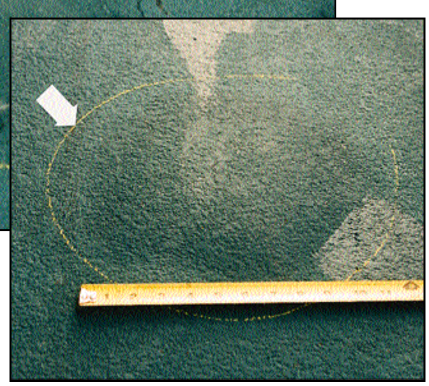


Figure 3. **A typical blistered area of a swimming pool coating was 15 inches in diameter (top). Overnight, blisters collapsed and receded in diameter while visible moisture in the blisters appeared to dissipate (right).**

pool for routine cleaning and maintenance, the owner noticed that the pool's bonded membrane blistered on sunny days. Moisture bled from the blisters during the day; overnight, the blisters collapsed and visible moisture in the blisters appeared to dissipate (Figure 3). When the pool was empty, the blistering gradually increased, but did not appear to worsen when the pool was filled with water.

As Figure 4 indicates, the pool floor construction consisted of a 6-inch-thick reinforced-concrete slab on grade, a 4-inch-thick sand cushion, and a single-size 1-inch-diameter rounded-gravel layer to a depth 6 feet below the pool slab. Drain tile was present at the bottom of the gravel layer.

Moisture emissions through the slab were measured with RMA moisture kits, and cores were drilled to observe the moisture condition of the soils below the slab. Emission rates ranging from 15 to 30 pounds per 1,000 square feet per 24 hours were documented. Normally, the test duration is 60 to 72 hours, but on this project testing was performed over 24 hours due to the large amount of moisture accumulating in the desiccant. During the day the desiccant would nearly dissolve, indicating very high moisture emission from the slab. Overnight, however, this same desiccant would lose moisture and become semidry. Coring revealed that the 4-inch-thick sand layer and the gravel layer below the slab were only slightly damp. When the gravel was removed from the core hole, the gravel surface quickly dried.

Even though no free water was present in the subgrade, large amounts of water vapor were moving from the gravel layer and sand cushion and through the concrete slab. The warming of the slab surface during the day and the high internal humidity in the slab and subgrade created vapor pressures high enough to blister the coating. What caused the apparent overnight disappearance of the moisture in blisters wasn't determined. What is known is that drain tiles and capillary breaks didn't prevent this failure, even though the design approach may have appeared sound when the pool was built.

Failures, not successes, often teach us most about which design and construction processes work best. Although analysis of these failures is not always pleasant for the designer or owner, it's always instructive.

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