# Design of Slabs that Receive Moisture-Sensitive Floor Coverings

## Part 1: A Design Guide for Architects and Engineers

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Many architects, engineers, floor-covering installers, flooring and adhesive manufacturers, concrete contractors, and concrete producers currently face problems related to moisture-sensitive floor coverings. The problems range from claims for construction-schedule delays caused by slow concrete drying to lawsuits involving indoor air quality.

While many articles and papers have dealt with the floor-moisture issue, few have contained information of direct use to the design professional. Neither ACI 360R-92, "Design of Slabs on Grade,"[1] nor ACI 302.1R-96, "Guide for Concrete Floor and Slab Construction,"[2] contain much guidance on the design of concrete slabs-on-ground to receive moisture-sensitive floor coverings. In response to the potential for moisture problems in slabs-on-ground, ACI Committee 302 recently made a recommendation regarding vapor retarder location.[3]

This two-part article focuses on an integrated approach to the design of concrete slabs-on-ground. It provides basic information that can guide practicing architects and engineers who design slabs that receive moisture-sensitive floor coverings.

### DESIGN PARTICIPANTS

The architect and engineer must communicate to ensure that the Construction Specifications Institute Division 9 specification requirements for floor coverings are compatible with Division 3 requirements for concrete. The engineer can no longer design the slab-on-ground independently of the architect's selection of the floor covering. And the architect can no longer select the floor covering independently of the engineer's choice of concrete materials and construction methods.

Ideally, the design team will also include a flooring consultant, the floor covering manufacturer, or the installer. The team may need input from several floor covering manufacturers to allow for differences in product requirements. Note, for instance, that one or more of the following Division 9 specification sections will have to be addressed by the floor design team:

- Section 09402 EpoxyTerrazzo;
- Section 09621 Fluid-Applied Athletic Flooring;
- Section 09622 Resilient Athletic Flooring;
- Section 09651 Resilient Tile Flooring;
- Section 09652 Sheet Vinyl Floor Coverings;
- Section 09654 Linoleum Floor Coverings;
- Section 09671 Resinous Flooring;
- Section 09677 Static-Control Resilient Floor Covering;
- Section 09680 Carpet;
- Section 09681 Carpet Tile;
- Section 09960 High-Performance Coatings; and
- Section 09963 Elastomeric Coatings.

When preparing specifications for different flooring applications, it's not advisable to rely only on the manufacturers' installation instructions by using catchall phrases such as "Prepare the concrete surface and install flooring in accordance with the manufacturer's instructions." Such instructions can sometimes be confusing, contradictory, or impractical (refer to the sidebar on p. 86). It's not in the design team's best interest to use floor covering and adhesive manufacturers' instructions and recommendations—or even ASTM standards related to floor covering installation—without careful scrutiny. Because some of the floor covering warranty requirements contradict best practices, the design team should get a written approval of their final specifications from the adhesive and floor covering manufacturer.

No single design team member has the ability to ensure a successful slab design without the input and cooperation of the other parties. Reducing the potential for a moisture issue and increasing the ultimate satisfaction of the owner will take a team effort.

## ESTABLISHING DESIGN GOALS

The design team needs to discuss floor covering expectations with the owner's representative. Some owners have already been involved with costly claims or litigation and give strong direction regarding moisture-sensitive floor coverings. Others have yet to experience flooring problems and may need more education and direction.

General goals for the design team include providing a functional concrete slab and maintaining the flooring manufacturer's warranty while staying within the owner's budget.

A functional slab must be strong and durable, with a surface finish and flatness that's compatible with the flooring chosen. The concrete and flooring adhesive interface must maintain the adhesion needed to prevent loose or delaminated coverings, adhesive oozing through floor covering seams, bubbles or blisters in the floor covering, and wet or slippery areas.

Maintaining the flooring manufacturer's warranty generally requires specification requirements related to:

- Proper placement of a vapor retarder or vapor barrier;
- Floor flatness and levelness tolerances;
- Surface texture;
- Repair of surface defects before the flooring is installed;
- Surface preparation for flooring;
- Moisture vapor emission limits or other measures of slab moisture;
- Upper limits on pH of the concrete surface; and
- Adhesive and covering installation.

Staying within the owner's budget requires:

- Compatible Division 9 and Division 3 requirements to minimize the number of change orders;
- Selection of a floor covering that doesn't increase the concrete cost beyond the owner's budget;
- Selection of a floor covering and development of design and construction specifications that minimize the cost of waiting for the concrete to dry to reach the manufacturer's moisture limit;
- Determining the impact on schedule and cost of placing the concrete slab within a water-tight enclosed roof and wall structure; and
- Avoiding increased costs related to delays in schedule caused by slow concrete drying or corrective measures such as desiccant drying or application of vapor-retarding floor coating systems.

The design team and owner establish the design criteria for a floor that should, if appropriately constructed, minimize the possibility of moisture-related problems

## MOISTURE AND PH TESTING

Current practice is for the floor covering installer to measure the moisture and pH of the floor and submit the results to the general contractor or construction manager. Too often these test results aren't transmitted to the design team, nor are the tests performed that the design team might have preferred.

The design team should not leave the testing to the floor covering installer. Specifications should require the owner's testing agency to conduct these tests and report them to the floor covering installer, general contractor or construction manager, and the design team. The specifications also should require that each test be conducted in accordance with ASTM standard test methods, or that any deviations from these methods be approved by the design team.

The testing lab performs moisture and pH tests and reports the results, but should not be expected to decide whether the floor covering installer should proceed or must wait. Specifications should be written on the assumption that the floor covering installer knows how and when to proceed, based on the test information. The suggestion that a testing agency be responsible for deciding when a flooring installation can be made is

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# Manufacturer's Warranty Problems

Floor covering and adhesive manufacturers state specific requirements that must be met to maintain their product warranties. Some deal with design issues such as the need for a vapor retarder or vapor barrier. Others relate to surface preparation and subsequent concrete condition—usually moisture vapor emission rate and pH—prior to flooring installation. The design team must consider these requirements when preparing the plans and specifications. Requirements from different manufacturers or their trade associations, however, are sometimes contradictory and also may be impossible to meet, as illustrated by the following examples.

## VAPOR RETARDERS OR VAPOR BARRIERS

Some manufacturers require placing a 6-mil polyethylene sheet as a vapor retarder, directly under the concrete. Others require a 12-mil polyethylene sheet, while still others require that on-grade and below-grade subfloors must be protected against ground moisture with an effective membrane type, moisture barrier, properly installed to prevent moisture migration or water vapor transmission.

*The problem: Proper installation is a key factor. If a layer of granular material is sandwiched between the concrete slab and either a vapor retarder or vapor barrier, floor moisture problems are likely unless the layer is kept dry.*

## CONCRETE FLOOR FINISH

Note the differences in these requirements for floor finish:

- The surface should be finished to a slight texture such as 100 grit abrasive paper;
- The surface should also be finished to a slight texture like shark skin;
- Concrete floor shall be steel troweled to a smooth plane surface, free of score marks, grooves, or depressions; and
- Surface must be smooth.

*The problems: Terms such as "slight texture" or "shark skin" can't be quantified, yet they may be cited as evidence of nonconformance with the manufacturer's requirements. Water evaporates more slowly through a steel-trowel finish. Very dense, hard-troweled surfaces may not dry quickly enough to the required moisture-vapor emission rate.*

## SURFACE PREPARATION

Some instructions require neutralizing the surface with acid then flushing it thoroughly with water. Others recommend removing all contaminants (dust, solvent, scaly paint, wax, oil, grease, asphalt, sealing compounds, and old adhesive) plus curing, hardening, and bond-breaking compounds by mechanical methods such as abrasive blasting. Still others recommend power sanding the surface or power washing it to remove contaminants and roughen the surface.

*The problems: Wetting the surface adds water that must then evaporate before the moisture vapor emission rate will drop below the specified level. Abrading the surface removes the carbonated, lower pH layer and makes it more likely that any subsequent wetting from power washing, acid washing, or the moisture contained in the adhesive will increase the pH, which can cause the flooring adhesive to re-emulsify.*

## MOISTURE LIMITS

Different moisture-limit requirements from manufacturers' instructions are given below; all refer to allowable moisture-vapor emission rates (using the calcium chloride cup test—ASTM F 1869):

- The emission of moisture vapor from the floor should be 3 to 4 lb/1000 $ft^2$/24 h;
- The results should be lower than the upper safe threshold value of 3 lb/1000 $ft^2$/24 h;
- Installations where moisture exceeds 3 lb/1000 $ft^2$/24 h are not warranted;
- Using the calcium chloride test method, moisture emission must not exceed 2.5 lb/1000 $ft^2$/24 h; and
- Warranty does not cover failure due to moisture emission from concrete floor if rate of emission exceeds 3 lb/1000 $ft^2$/24 h at time of installation or at any future time.

*The problems: Under some drying conditions, the 3-lb moisture emission rate will never be reached. Under other conditions, the average of several tests may reach 3 lb, but there will still be some tests with values higher than 3 lb. After the flooring has been applied, moisture in the concrete redistributes itself, and if the flooring is removed, the emission rate may be much higher than the 3 lb limit.*

simply an attempt to transfer risk from the installer to the testing agency. If the installer requests guidance on the timing of flooring installation, that request should go to the design team.

## Moisture tests

ASTM E 1907, "Standard Practices for Determining Moisture-Related Acceptability of Concrete Floors to Receive Moisture-Sensitive Finishes," describes eight tests used in the construction industry to determine if unacceptable moisture is present in or is being emitted from concrete slabs. A brief description of each test is as follows:

- Polyethylene Sheet Test: Duct tape an 18 x 18 in. plastic sheet to the concrete surface. After 24 h, visually inspect the underside of the sheet for presence of moisture (dark spots or moisture drops);
- Mat Test: Apply the adhesive and floor covering over a 24 x 24 in. (600 x 600 mm) concrete area. After 72 h, visually inspect and physically remove portions of the mat to determine if moisture is sufficiently low;
- Electrical Resistance Test: Use a proprietary moisture meter to determine the concrete moisture content by measuring the electrical conductivity of concrete between the meter probes;
- Electrical Impedance Test: Use a proprietary meter to determine the concrete moisture content by measuring conductance and capacitance;
- Qualitative Anhydrous Calcium Chloride Test: Pour anhydrous calcium chloride on the concrete floor, and cover and seal a plastic canopy over it; wait 72 h, then remove the canopy and observe calcium chloride for moisture (gets darker or cakes with moisture);
- Quantitative Anhydrous Calcium Chloride Test: Similar to previous test except calcium chloride is weighed, placed in a dish, covered and sealed with the plastic canopy, and then weighed after 72 h to calculate the moisture emission in lb/1000 $ft^2$ in 24 h;
- Primer or Adhesive Strip Test: Place several patches of adhesive or primer (about 24 x 24 in. [600 x 600 mm] in size) on the slab and wait 24 h. If the samples can be peeled from the floor using a putty knife, the slab has unacceptable moisture;
- Relative Humidity or Hygrometer Test: Place a relative humidity measuring device on the concrete slab and install a plastic canopy over it; allow at least 72 h before taking a reading and continue until two consecutive readings taken at 24 h intervals show no change.

The design team should ensure that the moisture test method planned for use is compatible with the manufacturer's moisture requirements. Sometimes the floor covering installer submits results for one test when the flooring manufacturer's limit is based on a different test.

Currently, most floor covering manufacturers require testing for the moisture emission rate by using the quantitative anhydrous calcium chloride test. They set a maximum permissible value, beyond which they won't give a warranty on product performance. When such a limit is set, make sure the specifications require moisture emission testing in accordance with ASTM F 1869, "Standard Test Method for Measuring Moisture Vapor Emission Rate of Concrete Subfloor Using Anhydrous Calcium Chloride." Of particular importance when this test is conducted are the requirements for a) removing curing compounds or sealers before testing; b) maintaining the same temperature and humidity conditions as the final floor covering will be exposed to for 48 h prior to and during the test; and c) measuring at locations uniformly distributed around the slab, with 3 tests for up to 1000 $ft^2$ and an additional test for each 1000 $ft^2$ of floor.

If moisture is present when tested by ASTM D 4263, "Standard Test Method for Indicating Moisture in Concrete by the Plastic Sheet Test," the floor should not receive a moisture-sensitive covering. If no moisture is present, however, the floor may still not be ready. The plastic sheet test can indicate a dry floor even when moisture emission rates as high as 8 lb/1000 $ft^2$/24 h have been measured using the calcium chloride test. The plastic sheet test is useful for indicating moisture variations throughout the floor area and for determining when to use the calcium chloride test. Similarly, use the moisture meter methods for surveying a floor, but not as a basis for a decision on the timing of floor covering installation unless the floor-covering manufacturer requires a moisture content limit.

I specify use of both the calcium chloride and mat tests. The mat test provides additional evidence that the total floor system for the project—adhesive, floor covering, and concrete—is likely to perform satisfactorily. I specify use of the mat test as follows:

- Conduct three trial mat tests throughout the building, with one test near the maximum moisture reading indicated by testing;
- Place a 10 x 10 ft mat using the selected adhesive and floor covering in accordance with the manufacturer's instructions; and
- Perform a visual *and* physical inspection after 1 week instead of the 72 h recommended in ASTM E 1907. A week allows more time for moisture to move from the bottom to the top of the slab, thus producing an in-place moisture condition similar to that experienced by the finished floor covering.

## Tests for pH

Testing for pH is typically accomplished by placing a few drops of water on the concrete surface, waiting a given time interval, and then dipping pH paper into the water. The paper is removed immediately and the color is compared to a chart to determine the pH reading. The readings, however, are very sensitive to the amount of time the water is in contact with the concrete.

Don't specify ASTM D 4262, "Standard Test Method for pH of Chemically Cleaned or Etched Concrete Surfaces." This method doesn't require a specified waiting time before the pH is measured. Specify pH testing in accordance with ASTM F 710, "Standard Practice for Preparing Concrete Floors to Receive Resilient Flooring," or incorporate the following into the specification:

"A pH test shall be taken at every location and at each time a moisture test is performed. To perform a pH test, place several drops of distilled water on a clean concrete surface, forming a puddle of about 1 in. (25 mm) diameter. Wait 60 ± 5 seconds after the puddle has formed, then dip the pH paper into the water. Remove immediately, and compare the paper color to that on the chart to determine the pH reading. Report the pH reading with each moisture test result."

## MOISTURE MOVEMENT AFTER TESTING

Many of the moisture tests mentioned previously measure moisture at or near the surface of the concrete. After an impervious floor covering is applied, however, the moisture content near the surface is likely to change as uncombined water deeper in the slab moves nearer to the surface. Figure 1 was developed by Swedish researchers and illustrates this shift in moisture distribution as measured by relative humidity probes.[4]

This behavior presents two problems:

- Measurement of moisture at the surface may give no indication of how much moisture is present throughout the entire slab thickness; and
- Because the moisture distribution changes, moisture emission rates also change and may increase to a level high enough to cause a flooring failure or air quality problems.

The first problem can be solved by measuring moisture with relative humidity probes placed at varying depths in the concrete slab. ASTM F 2170-02, "Standard Method for Determining Relative Humidity in Concrete Floor Slabs Using In-Situ Probes," describes the equipment and testing methods needed for this determination. Until the method is more widely used in the U.S., and the desired test results specified in terms of internal relative humidity, however, design professionals will still have to deal with requirements based on other moisture measuring methods.

The solution to the second problem is even more complex. It requires controlling both internal and external sources of concrete moisture, and setting limits that will ensure proper performance of the flooring. These topics will be addressed in the second part of this article.

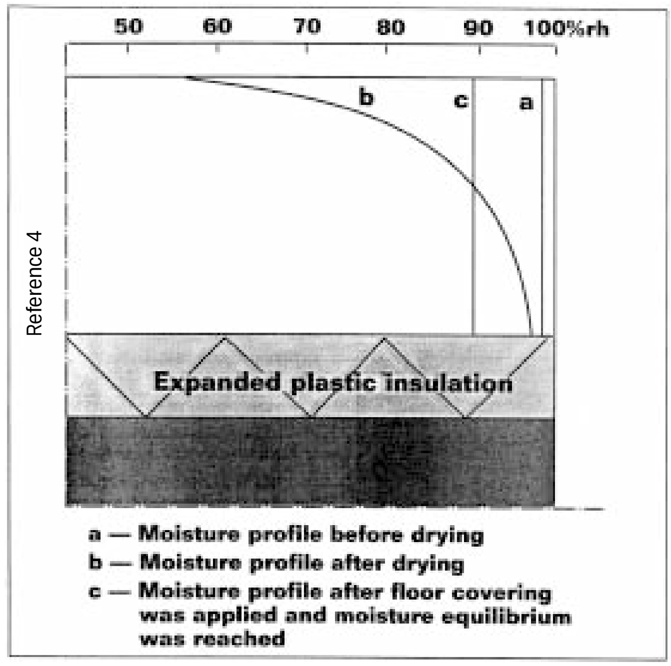


Fig. 1: Effect of an impervious floor covering on moisture distribution. Before drying, relative humidity was about 98% throughout the concrete slab. After drying from the top only, relative humidity was about 50%. After the impervious floor covering was applied, relative humidity rose again to about 90%

## References


1. ACI Committee 360, "Design of Slabs on Grade (ACI 360R-92)," American Concrete Institute, Farmington Hills, MI, 1992 (reapproved 1997), 57 pp.

2. ACI Committee 302, "Guide for Concrete Floor and Slab Construction (ACI 302.1R-96)," American Concrete Institute, Farmington Hills, MI, 1996, 65 pp.

3. "Vapor Retarder Location," *Concrete International*, Apr. 2001, V. 23, No. 4, pp. 72-73.

4. Hedenblad, G., *Drying of Construction Water in Concrete*, Swedish Council for Building Research, Stockholm, p. 12.



Selected for reader interest by the editors.



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