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Specifying Concrete Slabs for Floor Coverings

By Howard M. Kanare, CSI, CDT, and Scott M. Tarr, PE

Placing floor coverings on concrete slabs is not a new concept. People have been installing low-permeance floor coverings on concrete for about a century. However, advancements in both the concrete construction and flooring industries over the past 25 years have caused flooring performance to reach critical levels. These problems stem from several sources: the advent of 'fast-track' construction; low volatile organic compound (VOC) adhesives; and a greater awareness of moisture issues, which result in more frequent testing and reveal high-moisture slab situations. While some problems can result from flooring not being installed in accordance with the manufacturer's recommendations, more and more floor covering problems are now related to moisture conditions within the concrete slab and moisture migration.

This article discusses slab details that can help minimize these problems. Additionally, it will look at tests for determining the right conditions for floor-covering installations and

techniques, which can mitigate problems when they occur. It is important to note all concrete specifications should comply with Canadian Standards Association (CSA) A 23.1-04, *Concrete Materials and Methods of Concrete Construction*, and A 23.2-04, *Methods of Test and Standard Practices for Concrete*.

Specifying slab design

In 2003, industry representatives met at the Inter-Industry Working Group on Concrete Floor Issues in Chicago, Illinois, and identified several factors they believe could minimize the risk of moisture-related flooring failures.¹ The group also recommended changes in the way floor slabs are specified.

Vapour retarders

It is now considered an industry standard to locate a vapour retarder directly below the slab to minimize the potential for vapour transmission from the granular base.² This practice is in contrast to that of the past two decades where 'blotters'

Photo courtesy CTLGroup

or 'cushion' layers of compactible fill were often placed above the vapour retarder.

Vapour content beneath a slab is always high due to the natural moisture in sub-grade soils. Where retarders are not installed, vapour below the slab transmits into and through the concrete. That is, moisture in the sub-base material will attempt to reach equilibrium with moisture just above the water table.

Temperature and relative humidity in the pore system of granular materials determines a vapour pressure. Its differential causes vapour to move from the water table to the granular base material immediately below the slab. This high, relative humidity below the slab allows moisture to diffuse into the slab in an attempt to equalize the relative humidity.

The purpose of a vapour retarder sheet is to block this movement and prevent it from transmitting into and through the slab. To be successful, the barrier must be made from a low-permeance, puncture-resistant material, which can withstand chemical breakdown and degradation over time. Since a subslab vapour retarder cannot be replaced without removing the concrete floor slab, it should be installed with consideration that it will be required to function effectively for the life of the building.

Two North American standards for vapour retarders exist: Canadian General Standards Board (CAN/CGSB 51.34-M86), *Vapour Barrier, Polyethylene Sheet, for use in Building Construction*, and the American Standard of Testing Materials International, ASTM E 1745, *Standard Specification for Plastic Water Vapor Retarders used in Contact with Soil or Granular Fill under Concrete*

Slabs. Even though ASTM E 1745 currently requires not more than 0.3 perms, effective vapour retarders should have a perm rating lower than that of the floor covering to be installed.

Polyethylene sheeting with a thickness of 0.25 mm (10 mil) can provide effective protection against vapour transmission. However, it does not meet the ASTM E 1745 requirements for puncture- and tear-resistance. A new generation of high-quality vapour retarders/barriers can provide better reliability at 0.25 to 0.40 mm (10 to 16 mil) thicknesses. Designers should consider the placement details for the vapour retarder at grade beams, walls and footings, column pads, electrical or plumbing penetrations, and construction joints in order to avoid unwanted moisture infiltration. Effective details can be found in the Portland Cement Association's (PCA's) publication, *Concrete Floors and Moisture*.³

Capillary breaks

Another point the design professional should consider is the need for a capillary break layer below the vapour retarder. Certain soils, particularly fine-grained materials, can wick liquid water upward from the water table through narrow spaces between granular particles by means of capillary force.⁴ In such soils, a coarse crushed stone capillary break layer can be installed. These authors recommend that where crushed stone is used as a capillary break layer, a 50-mm (2-in.) choke layer of fine-grained compactable granular fill should be placed before laying the vapour retarder sheets. The purpose of the choke course is to smooth over angular protrusions of the crushed stone and protect the vapour retarder from being punctured during



Serviceable and durable floors begin with carefully crafted specifications, which take into account materials and moisture issues.

concrete placement. A capillary break layer does not reduce moisture vapour transmission, so a vapour retarder or barrier that meets ASTM E 1745 or CAN/CGSB 51.34-M86 is still necessary between the capillary break and the underside of the slab.

Concrete mix design

The concrete mix design generally should be optimized for performance based on available batch materials. To optimize the concrete mixture, it is necessary to understand the difference between the water-cement ratio (w/c) and the total water and cement content. A low w/c can result in higher strength, but this is not necessarily the most important characteristic of concrete floors. While floors require a certain minimum strength to perform adequately, a concrete floor's shrinkage potential has far more influence on its performance. It can also add to the risk of random cracking, joint and crack widening, and warping, all of which can have significant influence on the performance of floor coverings. A reduction in the risk of cracking is an obvious benefit.

Warping is the upward deformation of slab edges due to the moisture differential through the depth of the slab (*i.e.* drier at the surface and wetter at the bottom). Warping causes joints and cracks to widen at the slab surface, creating a v-shaped configuration. It is common to re-straighten slab surfaces either by grinding high areas or filling low spots with a levelling compound. When floor coverings with low permeability are installed, however, the moisture gradient through the depth of the slab tends to equilibrate. The floor covering creates a sealed system, followed by moisture migrating from the lower region to equalize with the drier upper region. As the moisture gradient equalizes, the warped edges relax downward. If the slab surface has been re-profiled, this relaxation causes a depression in the slab surface. This, in turn, compresses the floor covering and can cause it to buckle and de-bond over the joint or crack.⁵ These problems can be prevented by minimizing the shrinkage potential of the concrete mixture.

Decreasing the w/c does not necessarily decrease the shrinkage potential of concrete. The w/c can be decreased by reducing the water content of the mix. However, when a specification requires a low w/c, it is more often achieved by adding more cement. Doing so increases the paste content and likewise, the shrinkage potential. Therefore, it is often preferable to minimize the total paste content (cement and water) and allow for a moderate w/c rather than a very low w/c.

On the other hand, a lower w/c has several advantages over high w/c, including decreased permeability of the hardened cement paste and free water content. Achieving low permeability is most important when the slab lacks an effective vapour retarder, but it can also be helpful if the concrete is not under a roof cover. High permeability allows quicker drying in a closed system (with no source of additional moisture). However, where there is potential for topside moisture (*e.g.* rain and high-ambient humidity), a high-permeability cement paste will absorb moisture just as readily. If the slab can be kept dry, then total design mix water is of greater concern than w/c.

Cement paste needs a w/c of approximately 0.28 to hydrate the cement. However, this ratio results in a stiff paste, requiring more water be added for workability and finishability. This is called 'water of convenience.' The more of it, the longer the drying period and the higher the shrinkage potential. Therefore, a balance between total paste content and w/c is best. Many designers allow a maximum w/c of 0.50 and limit the cement content of the mix to 297 kg/m³ (500 lb/yd³). Lower cement contents are possible when the top size of the coarse aggregate is maximized. Maximum size aggregate (MSA) of 25 to 30 mm (1 to 1.25 in.) is preferable for a 100-mm (4-in.) floor slab. However, these authors find 20 mm (0.8 in.) MSA is most commonly used.

Curing

It is important to consider concrete curing methods during the design process. Moist curing is neither desirable nor necessary since this can cause water to infiltrate cracks and joints and accumulate, causing problems later. Curing compounds typically do not bond well to flooring adhesives and are not recommended. Instead, a moisture-retaining curing cover is advisable, where an absorbent material is saturated and placed flat on the slab. If held flat on the slab, effective covers should retain enough moisture so that little water is required for three days. If the construction schedule requires other trades to work on the slab during the curing period, a disposable paper cure cover should be used, allowing chalk lines and local cutting for slab access where necessary.

If curing compounds are used, they must be removed before the floor covering is installed. The most effective method of removal is light shotblasting. Although curing compounds may be less expensive than cover curing, once the cost of proper removal is taken into account, this method may become more economical.



One approach to remediating high-moisture floors is the application of a topical moisture suppression system. Various products are available to specifiers, who should carefully research product claims and service histories.

Specifying testing

The designer should specify the particular testing required to determine when the slab has reached an acceptable moisture condition. The following are some options.

Calcium chloride test

The most popular method of testing moisture condition in concrete floor slabs is the calcium chloride test, as per ASTM F 1869, *Standard Test Method for Measuring Moisture Vapor Emission Rate of Concrete Subfloor using Anhydrous Calcium Chloride*. This test measures the moisture vapour emission rate (MVER) from the slab surface in micrograms/second/m² (lb/1000 ft²/24 hours). Most floor covering and adhesive manufacturers have established MVER limits required prior to installation. Typical limits include 280 micrograms/second/m² (5 lb/1000 ft²/24 hr) for materials such as vinyl composition tile (VCT), felt-backed resilient sheet flooring, or porous-backed carpet, and 170 micrograms/second/m² (3 lb/1000 ft²/24 hr) for solid vinyl sheet flooring, vinyl-backed carpet, and non-porous-backed carpet. However, this test must be performed when HVAC units are operating and ambient conditions in the building are at operational levels for at least 48 hours. Keep in mind ambient temperature and relative humidity (RH) levels significantly affect MVER test results. ASTM F 1869 requires the test to be run at 21 C (70 F) ± 1.8 C (±10 F) and 50 per cent RH (±10 per cent). Test results outside these ranges are invalid.

When the ambient relative humidity is higher than the per cent RH in the upper region of the concrete, the surface of the slab absorbs moisture and MVER test results are higher. By installing the calcium

chloride kit, the relative humidity of the air beneath the dome is artificially decreased, and the moisture previously absorbed into the slab from the ambient air is measured as increased emission. Likewise, when the ambient air RH is low, the slab surface releases moisture and less is available to measure as MVER during the test. The ambient temperature during testing has a similar impact—lower temperature yields an apparently low MVER, while raising the temperature results in an apparently high MVER.

Internal slab relative humidity test

The calcium chloride test lasts from 60 to 72 hours and only measures the dynamic moisture condition at the slab surface and vapour released from approximately the upper 15 mm (0.6 in.) of the concrete. It does not determine the available moisture in the lower region of the slab. To evaluate this moisture, the internal slab relative humidity test as per ASTM F 2170, *Standard Test Method for Determining Relative Humidity in Concrete Floor Slabs Using In Situ Probes*, should be performed. This test measures the RH within the pore system of the concrete at a depth of 40 per cent slab thickness. This is the critical depth, since it is the point in the slab where the RH remains constant after the floor covering is installed and the moisture gradient changes.⁶ As mentioned previously, moisture gradient causes slab warping and subsequent relaxation.

Floor-covering and adhesive manufacturers have started establishing RH limits for the installation of their materials. Typically, a maximum of 75 per cent RH at 40 per cent depth of the slab thickness is acceptable for installation as stated in ASTM F 710, *Standard Practice for Preparing Concrete Floors to Receive Resilient Flooring*. One of the notable advantages of the RH test over its calcium chloride counterpart is it can be tracked. RH probes can either be read manually or connected to a data logger and monitored as slab drying occurs. Additionally, at a slab thickness depth of 40 per cent, the test is far less sensitive to ambient conditions than the calcium chloride test performed on the slab surface.

pH testing

Many believe vapour pressure causes flooring failures. In fact, the actual pressure exerted by moisture vapour is not more than roughly 1.38 kPa (0.2 psi). Even poorly installed floor coverings have bond strengths well in excess of this value. Failures are caused by an increase in the pH at the interface between the concrete slab and floor covering, which leads to adhesive degradation and bond failure. Most adhesives can tolerate a maximum pH of 9 or 10. Although concrete has a pH of 12.5 to 13, carbonation occurs on all concrete surfaces exposed to carbon dioxide in the atmosphere. As the slab surface carbonates, the pH decreases to a level tolerated by most adhesives.

Before any floor coverings are installed, the concrete surface should be tested for pH in accordance with ASTM F 710, *Standard Practice for Preparing Concrete Floors to Receive Resilient Flooring*. This practice provides a standard method to measure pH, although the meaning of this procedure is the subject of much debate. One of the difficulties is it requires the test be performed on a 'clean' surface, but no definition of what this means is provided. Sealers, curing compounds, waxes, and other materials must be removed before the test is performed. Grinding is the best way to remove surface contamination. However, this method can also remove concrete, distorting installation conditions at the immediate surface where flooring will be installed.



Excessive moisture and high pH in concrete floors can cause many modes of floor covering failures. A typical type of distress is debonding of adhered floor coverings, which form large bubbles and tripping hazards at joints.



Many types of vapour retarder sheet materials are available. In recent years, puncture and tear-resistant materials with extremely low permeability have become available and are preferable over ordinary polyethylene sheet. Vapour retarders should be specified to meet the requirements of ASTM E 1745, Standard Specification for Plastic Water Vapour Retarders used in Contact with Soil or Granular Fill under Concrete Slabs.

Since carbonation typically occurs at a rate of about 1 mm (39 mil) per year, grinding new slabs may remove the carbonated surface and expose the underlying concrete to an excessive pH.

Even when the pH test is properly performed and an acceptable level exists at the time of floor-covering installation, this can change

if moisture movement occurs in the slab. As moisture moves through pores in the concrete, it undergoes phase changes. Moisture in the form of vapour diffuses through concrete pores. When pores are sufficiently small, the vapour condenses to a liquid. In this form, moisture dissolves hydroxides, which can migrate to the underside of low-permeance floor coverings and raise the pH. This increase can break down some adhesives, causing flooring distress. In short, the pH of the concrete cannot be reduced. Therefore, the pH issue is controlled by limiting moisture migration—that is, blocking moisture transmission and delaying floor-covering installation until the slab moisture condition is acceptable at the surface and internally.

Specifying mitigation

Few construction specifications contain procedures to deal with cases where excessive moisture still exists at the time the schedule requires installation of the floor covering. However, one way to avoid disputes is to specify acceptable mitigation procedures and to require these as separate bid items. This way, mitigation is a budgeted item and is part of the overall construction process funded by the owner. If the slab dries to an acceptable condition and mitigation is not required, the budgeted funds are freed up.

The most common mitigation methods include accelerated drying, applying a topical moisture suppression system (MSS), and installing a floor covering, which is less sensitive to moisture vapour emission. Accelerated drying can be done from above, within, or below the slab. However, it is most often done from above by cycling heated, dehumidified air through the enclosed building and venting moist air. In cases where effective subslab vapour retarders are used, accelerated drying can mitigate high moisture conditions. It is critical to note this method dries the slab from the surface downward and can render calcium chloride testing inaccurate, making it necessary to use in-slab RH tests to measure moisture deeper in the concrete.

Topical MSS treatments can be very effective, but many products claim to reduce vapour emissions without offering data to support their effectiveness. When considering an MSS product, be sure to



Curing methods must be considered during the design process. These authors recommend using a moisture-retaining curing cover, where an absorbent material is saturated and placed flat on the slab.

request information such as the permeance and bond strength of the MSS. It is also a good idea to carefully check references and warranty coverage.

MSS products must be applied to clean slab surfaces, which are free of contamination that would inhibit bonding to the concrete. Most effective treatments require preparing the slab with a light shotblast to achieve a concrete surface profile (CSP) of 3 to 4, as measured using the International Concrete Repair Institute (ICRI) surface profile identification system.⁷ If the profile is greater than CSP 4, a levelling course should be applied prior to the MSS, ensuring continuous and adequate coverage. If the application rate does not result in adequate coverage (*i.e.* MSS thickness), vapour can continue to penetrate and lead to flooring distress.

Another popular option is to select a finish flooring, which is less sensitive to moisture vapour emissions. These may include open-backed carpeting, breathable coatings, and materials such as ceramic or quarry tiles, which use cementitious adhesives. Other finishing techniques, such as diamond polishing, can also be effective alternatives for moisture-sensitive flooring. While these finishes may be breathable, vapour can still become trapped beneath objects, such as furniture placed on the floor. In cases where there is a source of food and favourable temperature and moisture conditions, mould growth can also occur.

Conclusion

There are several design and construction factors, which can help minimize the potential for moisture-related distress of floor coverings and coatings on concrete slabs. The key issues to focus on include minimizing free water in the concrete mix design, preventing vapour transmission (from below), and delaying flooring installation until the vapour emission and available free moisture (from within the concrete) are at acceptable levels. Additionally, when construction schedules and ambient conditions may not allow slab drying to occur naturally, a separate bid item for acceptable methods of mitigation creates an available budget and approved course of action if excessive

moisture is measured during construction. Paying attention to these details can minimize flooring distress and prevent associated legal conflicts. ❧

Notes

¹ See Kanare, H. M., "Specifying Better Concrete Floors for Floor Coverings," *The Construction Specifier*, September 2003.

² See American Concrete Institute (ACI) 302.1R-04, *Guide for Concrete Floor and Slab Construction*.

³ See Kanare, H. M., *Concrete Floors and Moisture*, Portland Cement Association EB 119, January 2005, 156 pp.

⁴ See Holtz, R. D. and Kovacs, W. D., *An Introduction to Geotechnical Engineering*, Prentice-Hall, New Jersey, 1981.

⁵ See Tarr, S., Craig, P., and Kanare, H., "Concrete Slab Repair: Getting Flat is One Thing, Staying Flat is Another," *Concrete Repair Bulletin* (January/February 2006) from the International Concrete Repair Institute (ICRI).

⁶ See Hedenblad, G., *Drying of Construction Water in Concrete*, Stockholm, Bygghälsningsrådet, 1997.

⁷ See ICRI's *Guideline for Selecting and Specifying Concrete Surface Preparation for Sealers, Coatings, and Polymer Overlays* (Guideline 03732).

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