# Concrete Slab Repair: Getting Flat is One Thing, Staying Flat is Another!

By Scott M. Tarr, Peter A. Craig, and Howard M. Kanare

Constructing concrete slabs to successfully receive moisture-sensitive flooring materials or coatings is not a simple process. In today's market, fast-track construction has shortened the time period provided for concrete slab drying which, along with several other factors, has led to a significant increase in moisture-related flooring problems nationwide. Steps should be taken during the design phase of a project to minimize the potential for moisture-related issues. Such steps include, among others, the requirement for a low-permeance puncture-resistant vapor retarder directly beneath the slab to minimize moisture vapor transmission from the underlying base (Craig 2004), using moderately low water-cement ratio concrete mixtures (Kanare 2005), and allowing an adequate drying period or including acceptable moisture mitigation options as a separate bid item in the contract specifications (Tarr 2005).

While excessive moisture vapor transmission/emission issues are slowly becoming better understood and publicized, problems continue to occur. In addition, new issues are becoming apparent as these problems are addressed. For example, the following is a situation that occurs very frequently when installing low-permeance floor covering systems on concrete slabs:

- The concrete slab is placed in accordance with Division 3 of the project specifications. The floor flatness (FF) requirements are met by the concrete contractor at the time of placement.
- The slab is properly cured and protected against damage by subsequent construction.
- Slab drying occurs from the exposed top surface subsequent to the curing period. As a result of the slab drying from the top down, a moisture gradient forms through the slab thickness and upward edge warping occurs. At each joint and often random crack, the slab edges deform upward creating humps throughout the floor.
- The floor covering installer declares the concrete slab unacceptable and cites the maximum gap under a 10 ft (3 m) straightedge requirement in Division 9 of the specifications. When a 10 ft (3 m) straightedge is placed level across a joint or crack, often a gap well beyond what can be considered acceptable tolerance exists at each end of the straightedge. The raised edge of the slab along joint lines must be ground flat or a leveling material must be placed (or a combination thereof) before the covering can be installed.
- As the concrete contractor, general contractor, and flooring installer did not include a budget to restore flatness, this becomes an issue of dispute that often requires litigation to settle. This conflict can be avoided if the specifications required a budget for this task. Then, if remediation is required, the budget is there, and if it not needed, the budgeted allowance is returned to the owner. However, regardless of who is deemed responsible in any particular case, the floor is "re-profiled" and the floor covering is installed.

This common scenario typically adds considerable cost to the flooring installation and has accounted for many headaches and sleepless nights. Once the warped joint lines are reprofiled to an acceptable flatness, many consider the problem to have been solved. But is the problem over? Is an unexpected problem still to come? What one, unfortunately, often painfully learns is that there can be a reverse effect in the slab that occurs when the moisture gradient through the concrete slab diminishes after a low-permeance (nonbreathable) flooring system is installed.

## Warping Relaxation

The authors have observed many instances where an acceptable surface profile was restored along joint lines, yet problems still developed within the flooring material at these locations. Unlike long-term creep, which allows unsupported edges to settle downward over an extended period of time, what is occurring is a short-term redistribution of moisture within the slab once the flooring system is installed. As the moisture gradient within the concrete diminishes, the slab warping (often referred to as curling [Tarr 2004b]) subsides and the slab relaxes. This phenomenon is referred to as warping relaxation. When involved in a project where this has become an issue, however, there is nothing relaxing about it. The reflattened slab edges now turn downward, causing a lower elevation at

*Fig. 1: Buckling of VCT tiles and cementitious underlayment attributed to warping relaxation at concrete slab joints*

*Fig: 2: Extrusion of semi-rigid joint filler due to reverse warping (photo courtesy of Herman Protze)*

the reprofiled joints. Often, this slab relaxation places the floor covering into compression. In some cases, the compressive forces are significant enough to cause debonding and/or buckling of the flooring system, which can create a tripping hazard such as that shown in Fig. 1. Where floor covering systems buckle along joints and cracks, the delaminations are commonly referred to as mole holes or mole trails.

Another condition that can be the result of warping relaxation is the extrusion of filler or leveling material from joints and cracks as shown in Fig. 2, 3, and 4. When slab edges warp upward, joints and cracks become v-shaped in profile (wider at the top surface than at the bottom). Material used to fill in these joints/cracks can be extruded out when the slab returns to its original shape and the joints/cracks close. Yet another form of distress caused by warping reversal is shown in Fig. 5. Often, isolation block-outs around columns and other through-slab structural components are in-filled well after the slab is placed. Depending on the length of time between slab placement and infilling, substantial edge warping can occur. The blockouts are screeded to the top of the surrounding slab surface at the time of filling. Therefore, significant grinding or leveling is not usually necessary for the flooring system in these locations. However, once the flooring system is installed and the moisture gradient equalizes, the warped edges of the surrounding slab relax back downward and the column infill appears to heave upward (Fig. 5).

The authors have observed the relaxation of upward slab warping in floors of office buildings, gymnasiums, retail stores, schools, manufacturing facilities, and hospitals. The flooring does not have to be impermeable. If the emission of moisture from the slab surface is slowed significantly, the moisture gradient in the slab is reduced, which unless restricted from doing so, leads to settlement of the previously raised joint lines within the slab. This can occur using tiled flooring systems as well as nonbreathable coatings and sheet flooring systems. Even somewhat breathable systems such as ceramic or quarry tile

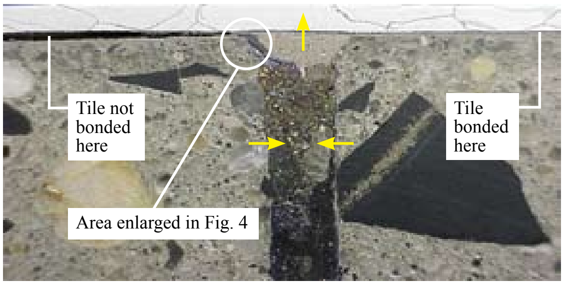


*Fig. 3: Lapped cross-section of concrete core at sawcut joint showing patching compound thrust upward. Displacement of patching compound (arrow pointing upward) is caused by narrowing of joint (arrows) as the concrete slab relaxes from its warped posture*

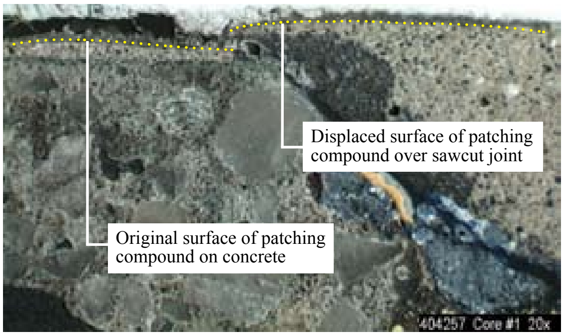


*Fig. 4: Photomicrograph in reflected light showing details of patching compound movement upward. Dotted lines indicate original surface and displaced surface due to movement. The black gap at top left is the space created when tile was pulled loose from the patching compound, forming a bubble*

*Fig. 5: Reverse warping around isolated diamond blockout at column footing*

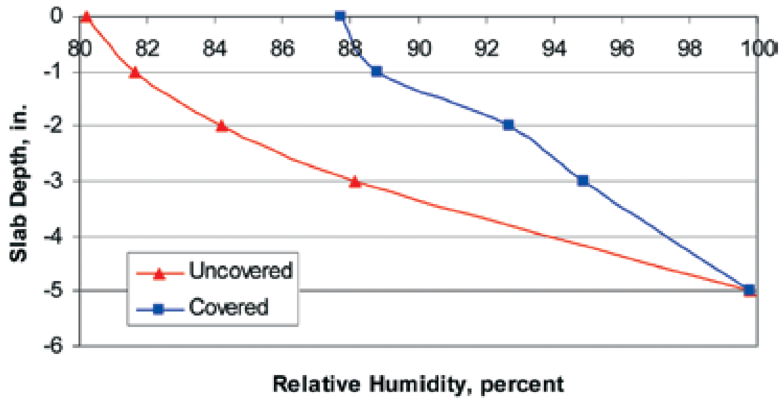


*Fig. 6: Relative moisture gradient between uncovered and covered portions of a slab*

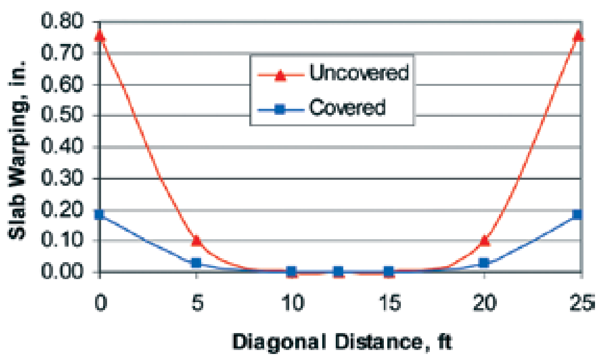


*Fig. 7: Relative warping profile between uncovered and covered slab panels*

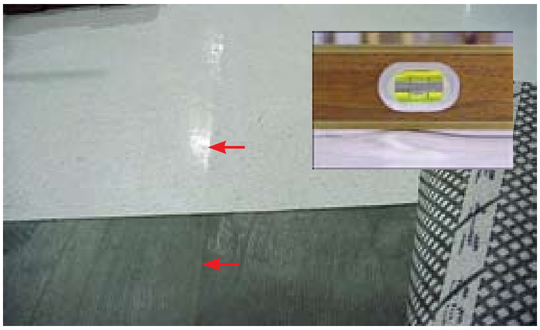

*Fig. 8: Debonding and buckling of ESD tile flooring (note hump at arrow and insert)*

*Fig. 9: Extrusion of crack filler beneath poured polyurethane gymnasium flooring*

that decrease the rate of moisture emission have been known to exhibit the problem.

## Moisture Gradient and Warping Magnitude

The moisture gradient can be measured in a concrete slab using relative humidity probes installed in ports drilled to varying depths. Slab warping can also be measured using a variety of techniques that document the relative surface elevation across a slab panel. In May/June 2000, the authors had an opportunity to document the effect of a decreased moisture gradient on reducing slab warping. A spec building was constructed and remained vacant for two years before a portion of the facility was leased. The slab was 5 in. (13 cm) thick and constructed on a low permeable clay base with no vapor retarder. Prior to leasing the space, the slabs warped considerably (slab panel edges warped upward about 3/4 in. [1.9 cm] for the 14 x 20 ft [4.3 x 6.1 m] joint spacing). As the tenant was an electronics manufacturer, an electrostatic dissipative tile flooring system was installed. Within a short period of time, the tiles buckled at all joints due to warping relaxation.

As only a portion of the facility was occupied, the authors were able to document the relative moisture gradients and warping magnitudes between adjacent covered and uncovered slabs. The measured moisture gradients are compared in Fig. 6, which plots the measured moisture gradient (horizontal axis) with slab depth (vertical axis). As shown, the relative humidity of the base material beneath the slab was nearly 100% for both the covered and uncovered portions of the slab. For the uncovered slab, however, the moisture gradient that developed was large (nearly 20% relative humidity) as the slab surface was trying to reach equilibrium with the ambient air. Once the slab was covered with the low-permeance tile system, the moisture levels within the slab increased and the overall gradient was reduced by nearly half. As the moisture gradient was reduced, the warping magnitude decreased from as high as 0.80 in. (2.03 cm) to as little as 0.18 in. (0.46 cm), as shown in Fig. 7. As a result, the joints narrowed and the cementitious filler material was extruded (Fig. 3 and 4) and the ESD tiles buckled, as shown in Fig. 8. The same distress has been seen in other flooring systems such as poured polyurethane gymnasium floors, as shown in Fig. 9 (at a crack).

## Prevention and Repair

As with many concrete slab problems, the real solution to this issue is prevention—minimize excessive warping in the first place. While design methods that prevent warping are available (post-tensioning and shrinkage compensating), all other slabs, including those with moderate reinforcement (>1% steel is generally thought to be required to prevent warping), can be expected to warp upward at joints and cracks as drying/shrinkage occurs at the top surface relative to the bottom. Substantial warping is known to cause significant problems on industrial slabs (Tarr 2004a), and for covered slabs, reprofiling can be costly and time-consuming. Further, the potential for warping reversal problems can be minimized by addressing factors that contribute to warping. The most significant individual factor under the control of the design/build team is the shrinkage potential of the concrete mixture. Factors that contribute to concrete shrinkage and corresponding warping potential have been identified (Tremper and Spellman 1963). The most significant factors are aggregate, cement type, and admixtures that promote shrinkage such as calcium chloride. Additional factors include aggregate topsize and concrete slump. For given locally-available materials, the shrinkage potential is generally reduced by minimizing the paste (cement and water) quantity and maintaining a reasonable water/cement ratio.

If slab warping has occurred, the type of floor covering system to be installed may help determine how potential warping relaxation is handled. For example, if a tile system is installed, the tiles along joint lines can be replaced if distress occurs. To minimize risk of potential relaxation of the flattened slab edges once the floor is covered or aesthetic changes that accompany partial replacement of flooring are made, the void beneath the warped slab edges can be sub-sealed prior to surface grinding. Sub-sealing involves drilling a staggered series of small diameter holes along each side of the joint followed by injection of a material to fill the void beneath the slab edges. For quick turn-around, a rapid-setting, rigid polyurethane or polyurea material can be injected that allows grinding a sub-sealed joint to begin about 1 hour after the injection is completed. Once the void is filled, the slab is restricted from downward movement.

## Preventable Issue

Warping relaxation is not an isolated event. Conditions such as that shown in Fig. 5 can be found in many retail stores throughout the U.S. Most of the time, if the initial warping was only slight, the relaxation does not become an issue. Unless specifically designed to prevent warping, all slabs can be expected to warp somewhat. It is the magnitude of warping that potentially becomes an issue. As such, the shrinkage potential of the concrete mixture must be considered, regardless of the use of steel reinforcement. No climatic region of the U.S. is immune to excessive shrinkage and moisture-related problems. When upward slab warping has developed in a concrete slab to be covered or coated with a low permeance material, consideration should be given to filling the void beneath the slab edges before reprofiling the slab.

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