Investigating Tile Failures on Wood-Frame Floor Systems[1]

by
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The purpose of this article is to build the case that when ceramic tile installations fail on wood framing, the forensic investigation should include an investigation from the bottom side (framing system) in concert with a parallel investigation of the top side (methods, materials, and industry standard guidelines). It is not uncommon for the homeowner, general contractor, and other parties to *assume* that the likely cause of ceramic tile or grout cracks was caused by the work of the tile contractor (TC) or the methods and materials used by the TC. As such, a forensic tile investigator is frequently called upon to determine how the observed problem is related to the work of the TC, improper preparation and use of installation materials, deficiencies in materials, and the application of installation methods not referenced in the Tile Council of North America's TCA Handbook for Ceramic Tile Installation, or the application of products not in conformance with the manufacturer's recommendations.

While the previously listed items can cause or contribute to hard-surface field problems, it is an error to assume that they are the only potential source of cracks and other in-service problems. A deficient framing system below the ceramic tile (or stone) assembly is also a possible cause for cracks in tiles and grout that can appear at any time after the TC completes the job. Another possible cause of in-service cracks is loading in excess of the assumed loads used by the design professional when designing the floor framing system. The possibility of "overloads" should be considered by the diligent investigator; discussion of detecting overload-related damage is beyond the scope of this article.

Deficient Framing System Below

As reported in the June 2008 issue of the TileLetter, the rules for designing floor systems that are intended to support ceramic tile have been clarified by ANSI A108.01, Paragraph 2.3, as follows:

> *Floor systems, including the framing system and subfloor panels over which tile will be installed, shall be in conformance with the IRC* [International Residential Code] *for residential applications, the IBC* [International Building Code] *for commercial applications, or applicable building codes. NOTE – The owner should….*

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With this change to ANSI and the TCA Handbook as well, the ceramic tile industry and the TC are relying on the assumption that the subfloor and framing system below the subfloor are in fact in conformance with the applicable building code for the project. Since the building codes specify both expected service loads and permitted deflection for floors in buildings, it is critical to the success of a specific tile installation for the floor system below *as constructed* to be in conformance with the applicable building code. For example, any deficiency in design loads can translate directly into excessive deflection of joists or floor girders. Alterations of joists and joists products outside the permitted limits of the code or joist manufacture can cause excessive deflection of a joist or joists. Deficient connections between joists and floor girders, and poor workmanship as well, can produce excessive flexibility or relative deflections of the framing that can be damaging to the tile installation above. By “relative deflection” we mean the vertical deflection of a point A relative to a point B, where A might be the top surface of an I-joist at its hanger connection to a girder and B might be the top surface of the floor girder at the same location.

In short, any excessive movement produced by code-deficient framing can be a source of tile and grout damage above. Some framing problems may be obvious to the TC, while others may be difficult to recognize and relate to cracked tile and grout above. Two examples of framing deficiencies that could produce tile and grout cracking follow.

Example—Obvious Framing Deficiency

For demonstrative purposes, assume that cracked tile and powdered grout joints were present in an area supported by wood framing and that the installation method was F144-07 from the TCA Handbook. This method requires a minimum of 19/32" T&G plywood with joists at 16-inches on-center. How then could the I-joist framing depicted in Figure 1 (next page) cause the deterioration of the hard surface above?

Figure 1. The I-joist depicted has no recognized load capacity because the bottom flange has been cut. The practice of cutting I-joist may stem from the fact that a 2x10, for example, may be notched per the code up to 1.54-inches (or D/6) in the outer thirds of the span (IRC, Figure R502.8). Since a typical depth of I-joist flanges is 1-3/8 inches, using the maximum permitted "notching rule" for a solid-sawn 2x10 on an I-joist destroys the strength and stiffness capabilities of the joist.

It may be obvious that the cut bottom flanges are detrimental to the strength and stiffness of the joist shown in Figure 1, but the impact of the cut joist on the ability of subfloor sheathing to support a brittle floor surface may not be obvious or well understood. The cut joist, which is approximately 17" from the concrete wall, causes the effective spacing of the joists supporting the subfloor to be 32", well in excess of the 16" permitted joist spacing for method F144-07. Note that a second joist flange in Figure 1 is also cut. However, because it had a slight amount of bearing on a sill plate, we did not include in our analysis the possible impact of the cut flange on subfloor span.

The detrimental impact of the longer 32" subfloor span on the tile and grout in the affected area is severe and probably not intuitive. We studied the case where a section of floor sheathing, Case A, is supported by three code-conforming joists at 16" on-center (oc). A load of 200 lbs. represents foot traffic, appliance, dolly, or other live load. To simulate an I-joist with a cut flange, we removed the center joist in Case A resulting in Case B, a single span[2] with joist supports at 32" oc. We moved the 200-lb. load to the center of the single span as depicted in the figure for Case B.

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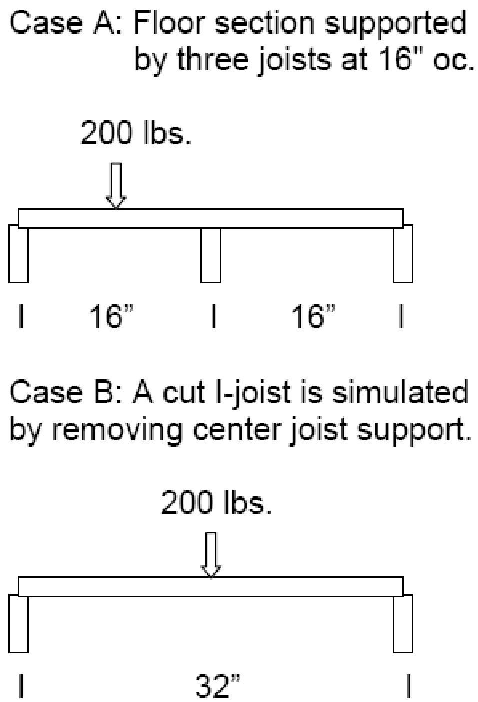
[2] The engineering term for this support condition is "simple span," whereas Case A shows a "continuous span."



Assuming the identical subfloor and tile method are supported by the joists depicted in the Case A and B drawings, the maximum deflection of the Case B subfloor/tile assembly was 11-times greater than the maximum deflection for Case A. If a specific load on the 16" span (Case A) produces a deflection of 0.01-inch, we would expect the same load to produce a maximum subfloor/tile assembly deflection of 11x0.01", or 0.11" for Case B[3]. However, for appreciating the role of subfloor span on hard-surface flooring performance, a simple rule-of-thumb would be that maximum sheathing deflection between joists is related to the *cube* of the support spacing—that is, increasing the span by a factor of two produces eight times more deflection ($2^3=8$).

We have demonstrated the theoretical impact of cutting an I-joist flange on the load response of the subfloor supporting a tile assembly. Of course, many factors in addition to the cut joist issue presented herein can contribute to in-service tile and grout problems. This example demonstrates the need for the forensic tile investigator to fully examine the installation from both the “top side” and “bottom side” before reaching final conclusions as to the contributing factors that produced the existing conditions or cracks present in an installation.

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[3] Since the number of continuous plywood subfloor spans can range from 2 to 6 (typically), the results of a simulated cut joist comparison for a greater number of continuous spans in Case A will vary from the 11 result obtained above.

Example: A More Difficult Case

To the untrained eye, the stud framing in Figure 2 is attractive and may not trigger any suspicion as causing tile and grout problems on the floor above. Apparently, in this

Figure 2. Load-bearing wall without sheathing used to support the I-joist framing.

case, the homeowner elected to go with an unfinished basement, the tile was installed, and in-service grout cracks prompted an investigation. Unfortunately, the design load capacity for the “load-bearing wall” depicted in Figure 2 is *theoretically* zero because the studs are not braced by drywall, wood paneling, or wood sheathing on at least one side of the wall. Of course the wall has some capacity, but it has no *recognized* capacity according to the *National Design Specification for Wood Construction* (NDS, 2005) because the slenderness ratio is greater than 50. The slenderness ratio is defined as the length of the stud or column divided by the thickness of the stud (in this unbraced case). For the wall shown, the slenderness ratio is 92-5/8"/1.5", or about 62. Unbraced studs having a slenderness ratio greater than 50 cannot be relied on to support in-service loads as the individual studs are free to “buckle” about their “weak axis.” When drywall or sheathing is applied to the studs, the slenderness is about 26 and the stud has substantial load capacity and provides a very stiff reaction support for the joist.[4] As constructed, the bearing wall is very flexible when loaded by the first floor occupants (or

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[4] In another home having a load-bearing basement wall without sheathing, the first author could see the studs vibrate (laterally) as only one person walked through the living space above.

other live loads) and would be expected to produce tile and grout damage in some areas that are structurally related or supported by the stud wall that was *intended* to be a load-bearing wall.

The easiest way to visualize and understand the buckling of studs with no sheathing (or bracing) and how the stud deflects both laterally and downward is to place a yardstick in the vertical orientation, one end on the floor, and push downwards on the top end with your hand. The yardstick will buckle (deflect outward at the center and downward at the top) with a minimum amount of downward load. Then, ask someone to hold the yardstick against lateral movement at the mid-height and repeat the experiment. The yardstick will support about four times or 400% more load. If the yardstick is stabilized against movement at the 3^{rd} points, it will support *nine* times more load.

Drywall or sheathing is typically used to laterally brace studs in load-bearing walls. The nails attaching the drywall or sheathing to the studs provide the needed lateral restraint for the studs. When an interior load-bearing stud wall is properly designed to support the applicable dead and live loads and the studs are laterally braced as assumed by the designer, the stud wall provides a stiff (and safe) bearing support for the floor joists.

The need for bracing load-bearing basement walls is not well understood by all parties involved in wood-frame construction. Careful study of the IRC (2006) will reveal that interior load-bearing walls must be braced by sheathing or other means as is specified for exterior walls (See IRC, Sections R602.4, R602.3, and Figure R602.3(2).

Summary

We presented two cases of grossly deficient wood framing that could produce tile and grout failures in the affected area of the framing deficiency. Deficient framing in some tiled area or the total area is very possible in the field as the framing design may be deficient and the work of the various trades involved may not be in conformance or in harmony with building code provisions. In general, we believe that establishing a causal relationship between observed tile and grout damage on a flexible support system (wood framing) requires an investigation from both the bottom side (framing system) and the top side (methods, materials, and installation standards).

The top side investigation should establish the crack pattern and other damage in the tiled area. It should also document all the installation factors and materials that may have contributed directly or indirectly to the noted failures. We acknowledge that, in some cases, such as tiles with inadequate thin-set coverage, investigation from the top side may be sufficient to conclude that “some tiles are broken because they were not bonded” to the substrate. However, in other cases where lack of bond-coat coverage or support is not definitive, or cracks are forming in specific patterns relative to the framing members below, we believe an investigation from the bottom (the framing system to include the subfloor) is necessary to relate or eliminate the damage above to the framing system below. One possible outcome of the framing system investigation is that the existing floor is code-conforming as required by ANSI A108.01, and the damage pattern above has no relationship with the framing system below. This outcome may be very important in bringing focus to the method selected, materials used, and installation or workmanship. Reaching a conclusion on a tile complaint without exploring all *possibilities* may lead to an erroneous conclusion by the forensic investigator.

Concluding Remarks

The potential value of a forensic team approach in the investigation of tile (and stone) flooring failures was demonstrated and discussed. It may be necessary for the forensic investigator or forensic team to have a diverse background in both hard-surface installations and materials, as well as expertise in the area of code-conforming wood construction. We believe that local and registered engineers with experience in code-conforming wood construction can be engaged to effectively assist the installation expert in accurately determining the cause or causes of in-service tile flooring failures.

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