UNIVERSAL FLOOR TESTER: AN OPPORTUNITY FOR IMPROVED CERAMIC TILE ASSEMBLY EVALUATION

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Abstract

The performance of a ceramic tile assembly depends upon how effectively the installation system integrates the tile covering with the existing flooring structure. Thus, it is important that ceramic tile assembly performance testing incorporates those aspects of the existing structure that are most likely to have a detrimental effect on the tile assembly in service conditions. With this precept in mind, the authors compare existing ceramic tile assembly performance test methods, including the Robinson-Type Test Method per ASTM C627 and System Crack Resistance Test Method per the soon to be published ANSI A118.12 standard, with new test methods made possible through the development of the Universal Floor Tester.

The installation of ceramic tile in North America consists in large part of thin-set application over wood-frame construction. However, the Robinson-Type Floor Tester does not measure or reflect the potential detrimental influence of joist deflection and curvature along the joists on the performance of a tile assembly under load, nor does it allow for the inclusion of seams in the sheathing in a manner consistent with building code requirements. The Universal Floor Tester enables the construction and testing of "full scale" assemblies that incorporate various joist sizes and joist products, joist spans, and sheathing configurations that contain end and edge butt joints of wood panels. With regard to thin-set application over concrete substrates, the System Crack Resistance Test Method is limited by its reliance on human operation and inability to cycle crack movement. The Universal Floor Tester incorporates a split-slab feature that allows for fully automated simulations of crack formation and cycling of crack width over time.

Thus, the authors demonstrate how the Universal Floor Tester will allow for improved evaluation of ceramic tile assemblies and highlight various test programs that have the potential to increase the industry's understanding of ceramic tile assembly performance in service. The goal is to provide consumers with more durable and reliable ceramic tile installations, which will serve to improve customer satisfaction and increase ceramic tile consumption.

Development of Selected Ceramic Tile Assembly Evaluation Methods

Robinson-Type Test Method

The advent of dry-set mortar and subsequent introduction of the thin-set method for tile installation led the Tile Council of America (TCA) Research Center to develop a ceramic tile floor system performance testing apparatus. In 1958, the late Donald Robinson, who was head of the engineering and research department of the TCA at the time, designed a testing machine that was to be used to evaluate the effects of loading, impact, wear, and vibration on ceramic tile assemblies. The tester features a wheeled carriage that is cycled by a center-mounted axle over the flooring assembly with three gravity loads applied 120-degrees apart. The flooring test assembly is restricted to 4 ft x 4 ft (1.2 m x 1.2 m) in size, and must be supported on a central pad. The loaded carriage is applied for a specified number of rotations and the specimen is inspected for damage at the end of the cycle. Depending upon the amount of damage recorded, either the test is ended, or a new cycle of loading begins. A performance rating, ranging from residential to extra heavy commercial, is determined at the end of the test, depending upon the number of cycles successfully completed.

Figure 1 - Robinson-Type Floor Tester

A standardized test method based upon the Robinson tester, ASTM C627, was written in 1970 under the auspices of ASTM Committee C-21 on Ceramic Whitewares and Related Products after four (4) years of comparative interlaboratory testing. While the ASTM C627 standard has been revised over the years, only small changes have been made, leaving the test method for the most part unchanged. The latest revision came in 1999, with the next expected in late 2005 or early 2006.

System Crack Resistance Test Method

The Material Methods and Standards Association (MMSA) created a sub-committee in 1995 to create a standard for crack isolation membranes for thin-set ceramic tile and dimension stone installation. The resulting standard, ANSI A118.12, contains various performance criteria, including a test method to evaluate the ability of a membrane to protect the tile assembly from minor in-plane substrate cracking. The System Crack Resistance Test Method uses a specially designed jig, which consists of a steel apparatus to which two (2) concrete blocks are attached: one to a fixed plate, the other to a movable plate. The ceramic tile assembly is installed over the concrete blocks.

Figure 2 - System Crack Resistance Tester

The apparatus is manually operated to move the concrete blocks apart at a designated rate until a specified “crack width” is reached. The assembly is inspected for cracks in the tile and is discontinued if any are found. If no cracks are found in the tile, the test is continued. An assembly exhibiting no cracks in the tile after the opening width reaches 1/16" receives a “standard performance” rating; an assembly exhibiting no cracks in the tile after the opening width reaches 1/8" receives a “high performance” rating.

Universal Floor Tester

Development of the Universal Floor Tester began in the year 2000. The primary objective was to design a fully-automated testing machine that could be used to evaluate ceramic tile assembly performance using a variety of methods. The primary feature is a weighted three-wheeled carriage, similar to the Robinson-Type Tester, which is mounted on a vertical slide instead of a center axle, eliminating the need to cut a hole in the test specimen. The vertical slide mount also allows for increased clearance below the carriage, up to approximately 40" (1 m), making it possible to evaluate ceramic tile assembly performance under loading over full-scale wood-framed flooring systems (see Figure 3a).

Figure 3a - Universal Floor Tester Full-Scale Assembly

The tester also features a sliding table mechanism that is used to split concrete pads and simulate crack formation, opening, and closing below ceramic tile assemblies (see Figure 3b). The mechanism can be opened to a maximum width of 3/8" (9 mm), with the rate of opening and closing programmed into the tester by the operator.

Figure 3b - Universal Floor Tester Sliding Table Mechanism

Current plans are for comparative testing to be performed through three (3) laboratories toward development of standardized test methods using the Universal Floor Tester.

Comparison of Evaluation Methods for Ceramic Tile Assemblies

When evaluating the results of any given test, it is important to understand how the test method incorporates aspects of the tile assembly in service. To do so, one must first understand the various aspects of the existing structure that supports the tile assembly and how they influence the performance of the tile assembly. The performance of a tile assembly depends upon how effectively the installation system integrates the tile covering with the existing flooring structure.

Ceramic Tile Assemblies for Installation over Wood Substrates

Residential construction, the largest source of ceramic tile consumption in North America, consists primarily of wood framing. Floor systems are framed using solid-sawn lumber, engineered I-joists, or wood or steel trusses, and sheathed with a single layer of plywood or oriented strand board (OSB). Minimum building code requirements are followed to ensure safety and structural integrity. However, the suitability of the flooring structure to serve as a base for ceramic tile is often an afterthought, with regard to the builder and/or design professional. The decision regarding which type of installation system to utilize, in order to provide a durable tile covering, must be made based upon the pertinent characteristics of the existing structure.

Wood frame construction presents many challenges to the tile setter, including deflection and curvature under loading (including creep), stress concentrations at sheathing seams, and movement and dimensional changes of the wood products due to changes in the moisture content of the wood materials. The discussion below will focus on deflection, curvature, and stress concentrations at sheathing seams.

Historically, deflection of the flooring system has been viewed as the most detrimental to the performance of the tile assembly over wood-frame construction, with the potential to cause cracking and delaminating of the tile and grout. In fact, the limitation of deflection has become a central design criterion in the North American tile industry. The 2005 Handbook for Ceramic Tile Installation, published by the Tile Council of North America, states in various details for tile installation over wood-frame construction: "design floor areas over which tile is to be applied to have a deflection not greater than 1/360 of the span when measured under 300 lb. concentrated load (see ASTM C627)." However, the influence of deflection on the tile assembly has traditionally been left in vague terms. Bretzfield and Woeste (2002) performed engineering analyses to investigate this issue and provide a better understanding of the dynamics of the flooring system (joists, subfloor, and underlayment) with regard to the tile assembly. Their work was based on the premise that it is curvature of the subfloor, rather than simply deflection, which stresses the tile assembly and can lead to damage. Consider that if the flooring system were perfectly rigid, but allowed to deflect vertically as a unit, no stress would be placed on the tile assembly. However, in reality, deflection of the floor is accompanied by bending that produces stress on the rigid ceramic tile covering, which does not conform to the resulting curved surface (see Figure 4).

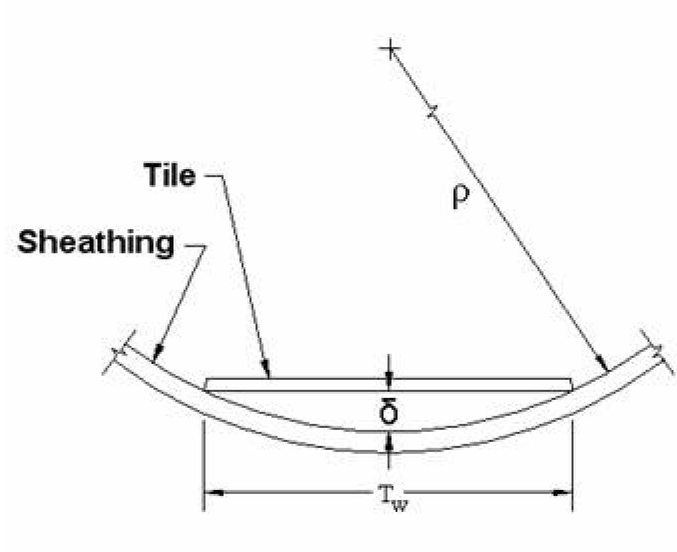

Figure 4 - Exaggerated View of Curvature of Wood Subfloor beneath Tile Covering

Through basic calculations, it was shown that the predicted curvature of sheathing panels *between joists* far exceeds that *along the joists*. The implication of their study is that sheathing stiffness is far more likely to influence tile assembly performance than joist stiffness. This finding was supported by joint testing administered by Osterberger, Mayhew, and Fine (2004) of *Trus Joist, A Weyerhaeuser Business* (engineered wood systems manufacturer) and *Laticrete International, Inc.* (ceramic tile installation systems manufacturer) on full-scale floor assemblies (15-ft and 17-ft spans).

It follows that the most straightforward, effective manner in which to improve the capability of a wood-framed floor to serve as a base for ceramic tile, in terms of limiting curvature[1], is to install a second layer of plywood or OSB. However, since the floor sheathing is comprised of panels, rather than a monolithic layer, and thin-set tile assemblies are sensitive to differential vertical movement, stress concentrations at plywood/OSB seams must also be considered to ensure a successful installation. As such, Woeste and Nielsen (2004) put forth the argument that when installing a plywood or OSB underlayment to limit curvature of the sheathing, the underlayment joints should be placed at a location of relatively low bending stress under a wide range of loading scenarios. For example, under a uniform load, the bending stress in the sheathing between joists is near zero at approximately the ¼-point between joists.

The integration of wood substrates with the Robinson-Type Floor Tester, per ASTM C627, has been limited. Typically, the wood frame assemblies tested consist of *nominal* 2 x 2′s (38 mm x 38 mm) at the desired joist spacing, which are fully supported by a concrete slab along the length of the joist span. These "simulated joists" provide a surface for nailing a single 4-ft x 4-ft (1.22 m x 1.22 m) panel of wood sheathing per building code requirements.

As a result of the test configuration, deflection and curvature of the flooring system during loading is confined to the sheathing between the fully supported joists. As discussed previously, there is evidence to show that curvature of the sheathing is of greater importance than the deflection and curvature along the joists. Thus, while the Robinson-Type Floor Tester does not fully simulate an existing flooring structure, it does incorporate one of the most significant aspects of the flooring structure with respect to tile assembly performance. This is an important point to consider, because it serves to validate the extensive use of and reliance on the Robinson-Type Floor Tester over the last thirty-five (35) years in testing tile assemblies over wood frame construction. However, there are application shortcomings that must be addressed. In the authors' view, the primary drawback is that the limited size of the test specimens prohibits the inclusion of seams in the sheathing in a manner consistent with building code requirements. Seams in the subfloor sheathing are located at areas of maximum negative bending stress (over joists). Rotations of the ends of these sheathing panels caused by loading in adjacent joist bays have the potential to inflict damage on the tile covering, and should be evaluated when testing the viability of a given tile assembly.

Unlike the Robinson-Type Floor Tester, the design of the Universal Floor Tester is such that it has the capability to load larger test specimens; specifically, flooring assemblies that can be constructed using full size joists, along with subfloor and underlayment sheathing that includes seams constructed per building code requirements (i.e., two-span minimum for sheathing panels). The ability to test such specimens represents an opportunity for important research and improved evaluation of ceramic tile installation systems.

One such opportunity for research is further investigation into the relative effects of joist stiffness versus sheathing stiffness with regard to ceramic tile assembly performance. For example, it is possible to test flooring systems with similar joist spacing and sheathing thickness, but with different joist stiffness or span. Such a test program, based on Bretzfield and Woeste (2002), could confirm that maximizing sheathing system stiffness is the optimum method to limit curvature, which can increase the reliability of ceramic tile installations over wood-frame construction.

Another opportunity for research is to evaluate the effects of variation in placement of wood underlayment joints on the performance of the tile assembly under load. Such a test program that evaluates the results from Woeste and Nielsen (2004), which were based on engineering analyses, may validate the hypothesis that placing wood underlayment joints at one joist span plus a ¼ joist span from the subfloor seam is optimum for preventing localized bending stresses from causing cracks in the tile covering.

The use of large formats (e.g., 18" x 18", 24" x 24", etc.) has become the norm in the tile industry. The latest trends include sizes up to 24" x 48" and larger. Given that the Robinson-Type Floor Tester pad is only 4 ft x 4 ft in size, limitations with regard to such "giant" format tile must be considered before evaluating the use of these tiles over wood-frame construction. It is reasonable to assume that as tile format increases, sensitivity to curvature will increase as well (see Figure 5).

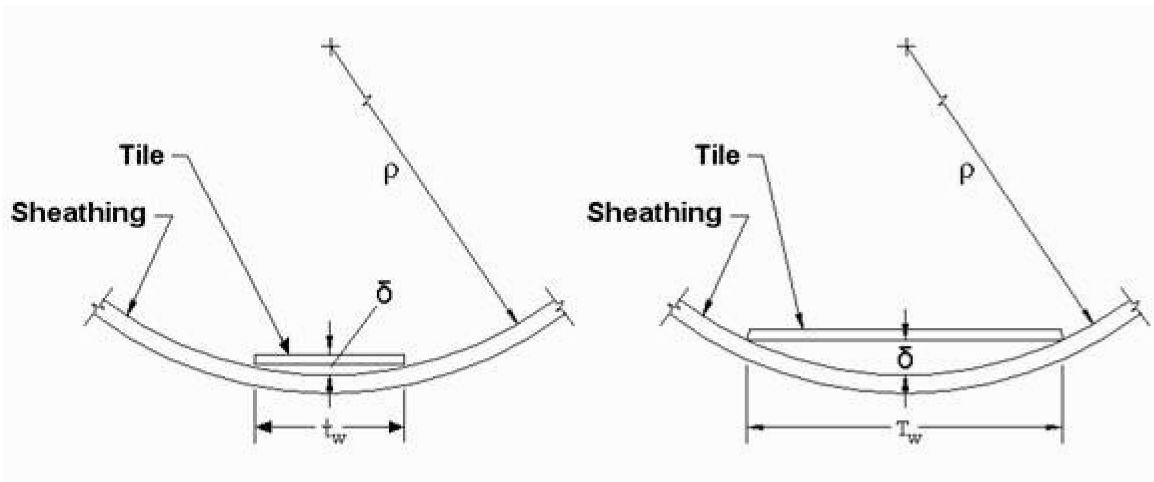

Figure 5 - Sensitivity to Curvature Increases with Tile Format

Compared to smaller format tiles, a higher proportion of these "giant" format tiles will span joints in the subfloor/underlayment and transitions from bearing walls to adjacent joists. As a result, it will be important to evaluate sensitivity of the tile to such discontinuities in the sheathing and framing. As tile size continues to increase, the Universal Floor Tester will allow for the use of larger specimens, ensuring that representative samples are tested.

Thus, the Universal Floor Tester has the potential to improve the industry's understanding of the challenges associated with setting ceramic tile over wood-frame construction. Further, the results obtained from the testing discussed above will allow manufacturers and industry organizations to provide practical recommendations to tile setters to help improve the durability and reliability of their tile installations.

Ceramic Tile Assemblies for Installation over Concrete Substrates

Concrete substrates may consist of cast-in-place, precast, prestressed, and post-tensioned slabs. These slabs may be located below, on, or above grade. The common thread that binds all these substrates is the material characteristics of the concrete itself.

While concrete slabs above grade are subject to bending and deflection under loading, the most widely held concern regarding the installation of ceramic tile over concrete substrates is movement associated with cracks and joints. For example, shrinkage cracks in concrete slabs are locations of reduced stiffness. Thus, when the concrete expands and contracts with changes in temperature and moisture, the associated movement can be concentrated at the weak plane of the crack. This behavior is similar to control joints, which are actually provided to help absorb movement and prevent randomly located shrinkage cracks. As a crack or joint opens, it can cause tensile stresses to develop in the tile covering in direct bond applications. The result can be cracked tile, delaminated tile, and/or cracked grout joints.

The System Crack Resistance Tester is manually operated to simulate the opening of a crack below a tile assembly. The assembly is evaluated based upon the “crack” width reached before the tile cracks or debonds from the substrate. Thus, the System Crack Resistance Test Method provides a basic simulation of the action of a crack in a concrete slab and its potential effects on the tile assembly, which has been absent from the industry until now. However, the Universal Floor Tester has the potential to allow for more advanced simulations.

For example, the Universal Floor Tester is a fully automated machine that enables the operator to control crack opening width in a more precise fashion than manual controls allow. Thus, any variations due to operator are completely eliminated. Another advantage of the automated control is that it allows for cycled opening and closing of the crack over time without continuous operator involvement. This feature would make investigation of the effects of cycling or accelerated aging more reasonable. Finally, future research into the combined effects of crack propagation and loading is possible.

Summary

When evaluating the results of any given test, it is important to understand how the test method incorporates aspects of the tile assembly in service. To do so, one must first understand the various aspects of the existing structure that supports the tile assembly and how it influences the performance of the tile assembly. The performance of a tile assembly depends upon how effectively the installation system integrates the tile covering with the existing flooring structure.

The Universal Floor Tester can provide the tile industry with the means to evaluate tile assemblies for installation over wood substrates more completely than the Robinson-Type Tester by incorporating full span joists, sheathing seams, and larger test specimens. With regard to tile assemblies for installation over concrete, the Universal Floor Tester expands upon the capabilities of the System Crack Resistance Tester by allowing for more precise control and the ability to simulate accelerated aging by means of cycled crack opening and closing.

In essence, the Universal Floor Tester has the potential to focus future research on the most important areas to provide practical information regarding tile installation, so that consumers are provided with the most durable, reliable installations possible. The end result is an improved perception of ceramic tile performance and overall growth of the ceramic tile industry.

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Note: At the time of submission of this article, the ANSI A118.12 standard was approved by the Accredited Standards Committee on Ceramic Tile A108, but not yet reviewed by ANSI for final publication. As such, release date may vary from above.

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[1] Referring to Figure 4, a more friendly substrate for tile is one that has a larger “radius of curvature”, ρ. In the context of this paper, a larger “radius of curvature” produces less “curvature” when the word is used in a general sense. Clearly, from inspection of Figure 4, a surface having a small ρ is detrimental to a tile installation.