Common Perils of Ceramic Floor Tile Systems

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ABSTRACT

Ceramic floor tile systems can provide a durable finish; however, if internal stresses are allowed to accumulate in the tile system, fractured, buckled, and/or hollow-sounding tiles may develop. Using case studies of residential structures, this paper will discuss common perils that cause damage to ceramic floor tile systems and how these perils can be avoided through proper installation and maintenance. Testing and installation standards developed by the tile industry are used to discuss methods of site testing and evaluation of data. This paper was developed using quantitative and qualitative analyses of ceramic floor tile systems installed within multiple residential structures. The analyses indicate that failure of ceramic floor tile systems is often caused or exacerbated by installation methods that deviate from published standards. It is evident that increased awareness of accepted installation standards is essential to the service life of ceramic floor tile systems.

INTRODUCTION

The analysis presented herein is based on forensic evaluations of ceramic floor tile systems installed in forty-three (43) residential structures. The evaluations were performed in response to distress observed by owners. Reported distress generally included, buckled tiles at twelve (12) of the structures, fractured tiles at twenty-nine (29) of the structures, and hollow-sounding tiles at the majority of the structures. Multiple types of distress may have been present at any one structure.

The majority of the tile systems were adhered to a concrete slab-on-grade foundation with thin-set mortar. Some of the tile systems were installed over wood framing supported by pier and beam foundations, the majority of which were installed with a thin-set mortar bed. A few of the tile systems supported by wood framing were installed with a thick mortar bed.

In addition to visual observations, field testing of the tile systems included relative elevation surveys, moisture surveys, and/or tile sounding surveys. Laboratory testing of tiles, mortars, or grouts was generally outside the scope of the assignments.

Distress in the tile systems observed during the forensic evaluations was similar to the reported distress and included buckled, fractured, and/or hollow-sounding tiles. A review of the case studies reveals the need for repair methodologies and the necessity for increased education in the construction industry.

BUCKLING

Buckling of tile flooring occurs when compressive forces induced into the tile system overcome the bond between the tile and substrate. The compressive forces are typically the result of expansive forces created during moisture or thermal exposure, and the effect from these forces may be exacerbated by restraining forces from inherent shrinkage of concrete substrates or the lack of movement joints. Because upward curvature of the substrate produces compression in the upper fibers of the floor system, certain types of foundation deformations may result in buckling of the ceramic tile finishes; however, this condition was not represented in the sample of the forensic investigations referenced in this paper.

Moisture and Thermal Exposure

Ceramic tiles expand under moisture and thermal exposure, which may cause the tile system to buckle (**Figure 1** and **Figure 2**). The expansion mechanism between these causes is significantly different in that tiles typically experience contraction after the elevated thermal exposure is abated, whereas, expansion experienced due to moisture absorption is generally nonreversible. The degree of expansion is dependent on multiple variables including the expansion and absorption rates of the tiles, the tile installation, and site conditions. Expansion is also dependent on exposure to water; for this reason water removal from the surface of the tile should be expedited. Sources of moisture intrusion should be mitigated in a timely fashion because failure to do so may increase the intensity and/or extent of tile distress.

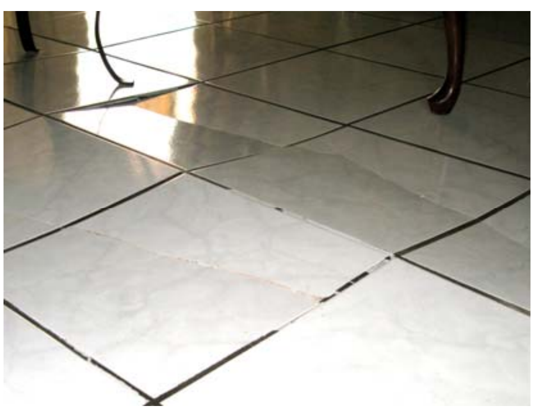

Figure 1: Buckling of tile flooring on slab.

Figure 2: Void created by tile buckling.

Test procedures to determine the coefficient of absorption of tiles are provided in ASTM Standard C373. Standards ASTM C370 and C372 respectively provide testing procedures for the coefficient of expansion of tiles exposed to moisture and thermal influences. The results of these testing procedures aid in the specifier's product selection.

The expansion of an individual tile is relatively diminutive; however, cumulative expansion of adjacent tiles may result in significant compressive forces within the tile system. These forces are controlled by the installation of movement joints within the tile system. The Tile Council of North America (TCNA) specifies that movement joints should be installed at intervals of 20 to 25 feet within the field of tile and along the perimeter of the tile system (TCNA 2011).

In addition, the movement joints should coincide with movement joints in the supporting substrate. In areas experiencing greater variations in thermal and/or moisture, such as sun rooms or exterior applications, TCNA recommends that movement joints be installed at intervals of 10 to 12 feet (TCNA 2011).

Analysis of site conditions in the cases involving buckling indicated moisture sources from plumbing leaks or moisture migration through the building envelope. Exposure to thermal forces in sunrooms may have exacerbated the distress; however, buckling caused solely by thermal effects was not observed.

Buckling in these cases may have been avoided by the installation of movement joints within the field of the tile and by including provisions for expansion along the perimeter. Movement joints within the field generally consist of a flexible material that is dyed the same color as the grout lines. Provisions for expansion at the perimeter typically include a gap between the tile system and finished wall assembly prior to installation of the baseboards. The baseboards are installed over the tile system to hide the gap from view. While provisions for expansion were evident at the perimeter of a small portion of the studied tile systems, the majority of the sites did not include expansion provisions at the perimeter. Movement joints within the field were not provided at any of the investigated sites.

Differential Foundation Movement

In addition to moisture and thermal exposure, buckling of floor tile systems may result from movement in the supporting substrate. Certain patterns of foundation movement result in compressive forces in the top fibers of the foundation. Patterns of foundation movement that produce these compressive forces include edge lift and center drop deformations. To determine if these types of deformations have occurred at the site, a relative elevation survey of the foundation should be performed. The relative elevation survey documents the overall levelness of the structure's floor, thereby allowing assessment of differential foundation movement.

The Texas Section of the American Society of Civil Engineers (ASCE) published *Guidelines for the Evaluation and Repair of Residential Foundations* to assist engineers in evaluating the performance of residential foundations. This document establishes L/360 as the performance criteria to be used to assess foundation performance and the need for foundation improvements, where L is the overall length of the foundation being evaluated (ASCE 2009). This criterion is also specified by the TCNA as a limitation of deflection for wood and concrete substrates under live load (TCNA 2011). Contours produced using the relative elevation data depict the topography of the foundation and will indicate if edge lift or center drop deformations exist at the structure.

FRACTURES AND SEPARATIONS

Buckling may fracture the tile system; however, fractures in tile systems may also be the result of impacts or rolling loads, differential foundation movement, and substrate fractures. In tile systems at pool decks and other exterior applications, fractures often coincide with movement joints or other irregularities in the supporting foundation.

Impacts or Rolling Loads

Tile flooring is susceptible to damage caused by impact (**Figure 3**). Chips and radial type fractures are common and are often the result of impacts from dropped objects. The impact fractures are typically located in high traffic areas, such as kitchens or bathrooms. Rolling loads such as those imposed by office-type chairs impart concentrated point loads at the wheels and often induce cracking (**Figure 4**).

Figure 3: Impact fracture at tile.

Figure 4: Fractures at tile from rolling load.

Differential Foundation Movement

As indicated previously, a relative elevation survey should be performed to determine if the foundation has undergone a specific pattern of deformation resulting in tile distress. Foundation deformations which result in tension along the top surface of the foundation (e.g. edge drop) may cause the tile system to fracture (**Figure 5**). Isolated deflections due to undersized or deteriorated framing members (**Figure 6**) may also result in tile fractures.

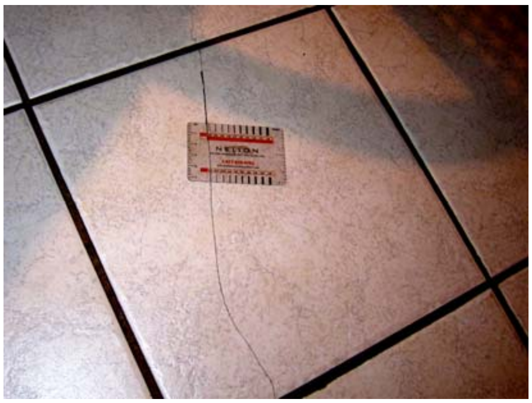

Figure 5: Fracture at tile due to differential foundation movement.

Figure 6: Deterioration of wood framing below tile floor system.

The relative elevation surveys and corresponding topography for the case studies were reviewed for distinct patterns of foundation movement that may have resulted in floor tile distress. Of the forty-three (43) case studies, thirteen (13) exhibited a specific pattern of foundation movement; however, tile distress coincided with foundation deflections in only six (6) of the sites investigated. Of these, four (4) were wood-framed pier and beam foundations and two (2) were concrete slab-on-grade foundations.

While the subsurface soil conditions at each site were generally not documented, the data indicates that foundation movement was not prevalent at the majority of the sites observed. In addition, the data indicates that tile systems supported by wood framing were more likely to sustain damage due to deterioration of the wood members from moisture sources or wood destroying pests.

Substrate Fractures

When ceramic tiles are adequately bonded to the substrate, the tiles and substrate will behave as a composite material. As such, fractures in the concrete substrate are frequently reflective in the ceramic tile (**Figure 7**). A commonly observed fracture in the supporting substrate is the untreated shrinkage fracture (**Figure 8**). Shrinkage is continual over the service life of a concrete member and typically results in cosmetic fractures. When thermal/moisture effects and foundation movement have been eliminated as potential causes of tile fractures, it is likely that the tile fracture is caused by shrinkage of the concrete substrate. To prevent fractures in the substrate from reflecting into the tile system, cleavage or isolation membranes can be installed between the tile and substrate.

Figure 7: Reflective fracture in tile.

Figure 8: Shrinkage fracture at concrete substrate.

Fractures at the majority of the tile systems supported by concrete substrates indicate that a cleavage membrane was not installed prior to application of the tile system. Thin-set grout was observed inside of a shrinkage fracture at one of the sites, which indicated that the fracture predated the floor tile installation. The substrate at this site continued to be unstable after tile installation and resulted in tile distress.

Tile fractures occurred at two out of the three exterior applications reviewed. Tile systems at pool decks and other exterior applications are especially susceptible to fracturing caused by fractures in the supporting substrate. The American National Standards Institute (ANSI) specifies that movement joints shall be provided in the pool deck slab to help control cracks due to expansion, contraction, and movement of the slab (ANSI 2003). Specific criteria for the installation of movement joints are not provided; however, ANSI specifies that all concrete pool decks be constructed in accordance with the recommendations provided in ACI 302.1R, *Guide for Concrete Floor and Slab Construction*.

ACI recommends movement joints be installed to limit the frequency and width of random cracks caused by volume changes (i.e. shrinkage). The layout of the movement joints should be provided by the designer or approved by the designer prior to installation of the joints (ACI 2004). Tile systems installed over the concrete slab should provide movement joints that correspond to the movement joints within the concrete slab in accordance with the TCNA recommendations (TCNA 2011). Additional movement joints for expansion at the perimeter may also be required depending on the configuration of restraining features and the type of tile system being installed.

Distress patterns in the exterior tile applications included fractures in areas of concentrated stress that naturally occurs in concrete pool decks. It is unknown if control joints were installed in the pool decks; however, movement joints were not installed in the tile system.

HOLLOW-SOUNDING TILES

Along with buckled and fractured tiles, hollow-sounding tiles were a commonly encountered claim. This condition may be distinguishable in otherwise well performing tile systems during normal use, such as walking with hard soled shoes or moving of furniture.

Similar to the field test procedure outlined in ASTM D4580, testing for hollow-sounding tiles is performed by dragging or tapping a blunt object over the tiles. A hollow-sounding tile can be described as a dull sound, which lacks a clear "ringing" tone. The presence of hollow-sounding tiles may indicate installation deficiencies, exposure to moisture or thermal sources, material defects, or the installation of a cleavage membrane; however, the presence of hollow-sounding tiles does not necessary indicate that the tile system has failed.

Installation Deficiencies

Tiles become debonded when the adhesive forces between the tile and mortar or between the mortar and substrate have been compromised. In some cases, the bond may never have been adequately developed; such tiles are considered to be "unbonded." Laboratory testing is often required to determine the cause of debonded or unbounded tiles; however, field observations and analysis indicates that poor bonding is the result of improper substrate preparation, poor mortar, and/or inadequate installation methods.

Deleterious materials, including, but not limited to, paint, dirt, laitance, curing compound, and wall texture overspray are often discovered at the substrate when exploratory testing is performed (**Figure 9**). Deleterious materials inhibit the bond between the mortar bed and the substrate from forming; therefore, removing these materials from the surface is a critical part of the substrate preparation.

In addition to proper preparation of the substrate, mortar mixes should conform and be applied in accordance with TCNA recommendations and applicable ASTM standards. Care should also be taken to ensure that the mortar is properly mixed and applied in temperate environmental conditions. Deviations from these installation standards will affect the bond between the tile and substrate, which may compromise the bonding of the tile.

Proper installation of the tile into the mortar bed is also essential. Tiles should be installed while the mortar bed is workable and should be forcibly pushed into the mortar – a practice commonly referred as "beat in". In addition, proper mortar coverage at the bonded side of the tile is required to adequately bond tiles to the substrate. For interior/dry service application, 80% of the bonded surface area should be covered (bonded) to the mortar (TCNA 2011). The mortar coverage requirement for exterior tile and tile in wet environments is increased to 95% (TCNA 2011). **Figure 10** depicts poor mortar coverage at the underside of a tile.

Figure 9: Deleterious material at mortar and substrate below.

Figure 10: Poor mortar coverage at underside of tile.

Moisture and Thermal Exposure

As indicated previously, moisture and thermal exposure may degrade the bond between the tile system and substrate and cause the tiles to buckle; however, in some cases, debonding tile caused by exposure to moisture and thermal sources without buckling was observed. In these cases the debonding was generally isolated to a small area of tile, which limited the buildup of compressive forces within the tile system and prevented the tile system from buckling.

Material Defects

In some cases, tiles exhibit a hollow-sound that is isolated to a small area of the tile and does not extend to adjacent tiles. In this case, the hollow-sound is most likely the result of a material defect within the tile. These defects should be expected at some of the tiles and do not affect the overall performance of the tile system. Tiles exhibiting this condition were often encountered during site investigations; however, few were discovered at any single site.

Cleavage Membrane

In some cases, a cleavage membrane is installed between the tile system and the substrate. A cleavage membrane provides a bond-breaking barrier that prevents shrinkage cracks and other defects in the foundation from reflecting into the tile system. The presence of a cleavage membrane may cause tiles to sound hollow in isolated areas; however, the hollow-soundings over a cleavage membrane should not be considered tile distress.

An area of removed tile exposed a cleavage membrane at one of the sites. Hollow-sounding tiles were documented in a linear pattern extending from the exposed area, which provided the extent and location of the cleavage membrane.

REMEDIAL ACTIONS

In many cases, remedial actions may be taken to address damaged tiles without a complete replacement of the tile system. The source of the damage should first be identified and addressed. For example, a moisture intrusion source should be abated prior to tile repairs or a cleavage membrane should be installed over shrinkage cracks. Construction deficiencies such as missing movement joints should also be installed prior to remedial tile work.

After the source of the damage is remediated, buckled and fractured tiles should be removed and replaced with reserve or matching tiles after the substrate is properly prepared. Impacted tiles may be painted to match the existing tiles and coated with a clear, high-strength epoxy. Hollow-sounding tile systems that are separated less than 1/8” from the substrate may be repaired by injecting a high-strength epoxy below the tile.

Specialty contractors and craftsmen may be required to accomplish some of the remedial actions provided above. All tile work should conform to recommendations provided by the TCNA.

CONCLUSIONS

Mechanisms that typically cause damage to tile flooring include exposure to moisture/thermal effects, foundation movement, and substrate deficiencies. While these mechanisms are not controlled by the tile installer, resulting damage caused by these mechanisms may be mitigated by careful specification of materials/methods and by proper conformance to TCNA installation guidelines.

The TCNA provides a wealth of information that defines the standard for the industry; however, case studies indicate that many of the TCNA guidelines are often overlooked or ignored, including, but not limited to, provisions for expansion within the tile system and preparation of the supporting substrate. Improved education within the construction industry as to the importance of the standards and the detrimental effects of deviation from these standards would produce better performing and longer lasting floor finishes.

REFERENCES

American Concrete Institute (ACI). 2004. ACI 302.1R-04: *Guide for Concrete Floor and Slab Construction.* Farmington Hills, MI: ACI.

American National Standards Institute (ANSI). 2003. ANSI/NSPI-5: *American National Standard for Residential Inground Swimming Pools.* Alexandria, VA: NSPI.

American Society for Testing and Materials (ASTM) International. 1988 (2006) ASTM C373*: Standard Test Method for Water Absorption, Bulk Density, Apparent Porosity, and Apparent Specific Gravity of Fired Whiteware Products.* West Conshohocken, PA: ASTM International.

American Society for Testing and Materials (ASTM) International. 1994 (2012). ASTM C372: *Standard Test Method for Linear Thermal Expansion of Porcelain Enamel and Glaze Frits and Fired Ceramic Whiteware Products by the Dilatometer Method.* West Conshohocken, PA: ASTM International.

American Society for Testing and Materials (ASTM) International. 2003 (2007) ASTM D4580: *Standard Practice for Measuring Delaminations in Concrete Bridge Decks by Sounding.* West Conshohocken, PA: ASTM International.

American Society for Testing and Materials (ASTM) International. 2012. ASTM C370: *Standard Test Method for Moisture Expansion of Fired Whiteware Products*. West Conshohocken, PA: ASTM International.

The Texas Section of the American Society of Civil Engineers (ASCE). 2009. *Guidelines for the Evaluation and Repair of Residential Foundations - Version 2.*

Tile Council of North America (TCNA). 2011. *American National Standards for the Installation of Ceramic Tile*. Anderson, SC: TCNA.

Tile Council of North America (TCNA). 2011. *Handbook for Ceramic Tile Installation.* Anderson, SC: TCNA.