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Cracking the Code for Wind Distress at Tile Roofs, A Regional Assessment

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ABSTRACT

NOAA's Office for Coastal Management estimates that climate disasters created $136 billion in damages over 2018 and 2019. Some years are worse; NOAA estimates that climate disasters cost over $300 billion in 2017 (NOAA 2020). Many of these damages are created by wind forces acting on structures. Further, regional construction practices can make damage assessments challenging.

Tile roofing is a favorite among architectural aesthetics utilized in Florida due to its visual appeal, durability, and wind resistance. With over one thousand miles of coastline, and the majority of the state consisting of a peninsula separating the Atlantic Ocean and the Gulf of Mexico, it is not uncommon for tile roofs in Florida to experience hurricane force winds. Thousands of tile roof sections have been assessed for wind-related distress by the authors of this paper. This paper will provide case studies representing the distress patterns observed by the authors. Common forms of distress observed in tile roofing will be discussed, and the case studies will provide insight into the diagnosis of wind-related distress to both clay and concrete roof tiles. Understanding distress patterns common to tile roofing allows owners, engineers, code officials, manufacturers, insurance industry professionals, the tile roofing industry, etc. to better assess the extent of damage related to wind forces and to improve the resistance of tile roofing against wind forces during natural disasters. Examples of wind-related distress and common conditions encountered during windstorm investigations provide insight into the portions of the Florida Building Code (FBC) which address remediation of damaged tile roofing.

INTRODUCTION

When Hurricane Andrew hit Florida, the storm caused more than $25 billion in property damage (Rappaport 1993). In response to Andrew, the Florida legislature created a code study commission that resulted in a state-mandated building code (the FBC). The FBC governs construction of new buildings and repairs or alterations to existing building across the entire state. The focus of this paper is the evaluation of wind-related distress to tile roofs. Understanding the FBC is key in these evaluations because the feasibility of repairs to tile roofs is commonly discussed. The goal of this paper is to aid the reader in understanding distress that is common to clay and concrete roof tiles and the sections of the FBC that are commonly applied (and misapplied) in roof tile evaluations. Proper identification of roof distress is critical prior to determination of the feasibility of roof repairs.

ROOF TILE DISTRESS

The International Hurricane Research Center (IHRC) summarized Florida hurricane-related distress in a 2007 report, prepared approximately 2 years after Hurricane Wilma. Wilma was a Category 1 storm that caused damage to tile roofs in South Florida. The IHRC report stated that tile roofs that should have withstood storms with 140 mph winds were damaged with a concentration of distress at hip and ridge tiles (Mirmiran 2007).

Hip and ridge tiles, often referred to as trim tiles, are located in zones of the roof where higher wind pressures are anticipated (**Figure 1**). Comparatively, field tiles are likely to experience lower wind pressures (ASCE 2016).

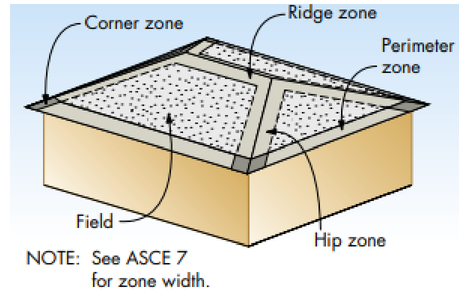

Figure 1: Wind zones (FEMA 2007)

It has been documented by other groups (The Roofing Industry Committee on Weather Issues - RICOWI 2006), and it is the authors' experience that displaced trim tiles impacting downslope tiles are the most common form of wind-related distress to tile roofs. Examples of those distress patterns are provided below (**Figure 2** - **Figure 5**).

Figure 2: Displaced trim tiles, tile distress downslope

Figure 3: Displaced trim tiles, tile distress at lower roof

Figure 4: Displaced hip tiles at second-level roof, tile distress downslope and at adjacent roof

Figure 5: Tile distress at adjacent/neighboring first-level roof from displaced tiles in Figure 4

Tile Installation Considerations: Mechanically fastened tiles are typically secured with one or two nails or screws per tile. The FBC requires that these fasteners penetrate the roof deck a minimum of 3/4" (FBC 2020). Recommendations for the installation of these fasteners vary when considering the clearance between the head of the fastener and the tile. The authors have contacted technical representatives at two prominent roof tile manufacturers: one recommended the clearance be approximately 1/16" to 1/8", while the other recommended that the fastener be driven such that the head does not embed the fastener hole. Further, the NRCA recommends that the fastener heads "*just touch*" the tiles (NRCA 2017). The intent of these recommendations is that roof tile fasteners should be driven so that stresses that restrain the tile do not develop at the fastener locations, thereby mitigating expansion/contraction fractures. However, fastener clearance allows free rotational movement of the tiles until the fastener head is engaged. Therefore, the range of tile movement is directly proportional to the fastener clearance (a larger fastener clearance results in a greater range of movement at the leading edge).

As illustrated in **Figure 6** and **Figure 7**, mechanically-fastened field tiles that engage with fasteners which transfer the load to the roof deck resist upward force once they contact the securing fastener heads (**Figure 7**). This resistance indicates that the fasteners have not withdrawn or disengaged from the roof deck due to previous uplift forces.

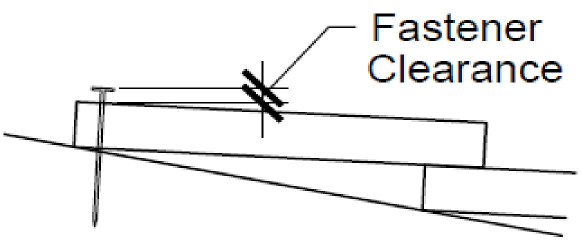

Figure 6: Field tile at rest

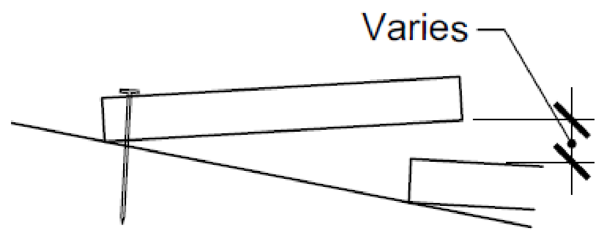

Figure 7: Field tile lifted to fastener resistance

The freedom of movement of the as-installed mechanically-fastened tiles presents a condition that may be misinterpreted as post-installation loosening of the tile fasteners. The FBC does not include guidance for allowable upward displacement at mechanically-fastened field tiles. However, there are Technical Application Standards (TAS) adopted by the Florida Building Commission. One of these, TAS-106, provides testing guidelines for inspecting newly installed tiles. The scope description in TAS-106 states that this standard "*is a product application quality control test,*" which applies to the original application of the roofing product. This standard indicates that tiles tested as a new installation should not exceed 2" of upward displacement of the leading edge (the nose or downslope edge of the tile). As a product application quality control test, TAS-106 provides acceptance testing methods for new roof tile installations, and does not provide guidelines for the testing of existing tile roof systems or testing for wind damage to mechanical fasteners. Unless the tiles were tested using TAS-106 directly after installation and were found to comply with the standard, and the same tiles were tested directly after a high wind event, the ability of a roof tile to be rotated upward at the leading edge is not a good indicator of wind-related distress, provided that the tile does not upwardly displace once the tile contacts the fastener head. Because TAS-106 is a product application quality control test, it is generally not a suitable test for evaluation of wind damage at an existing roof.

Loose conditions commonly observed at concrete and clay tile roofs include trimmed tiles, remedial tiles, original tiles placed without fasteners, and tiles placed over metal flashing. These tiles are commonly not attached to the roof deck. Modern tile manufacturers provide specific locations for fastener installations. These locations are indentions in the profile of the tiles called punchouts.

Tiles that are trimmed to accommodate valleys, hips, rise-walls, or other features of the roof may be trimmed at or downslope of the punchouts. In these conditions, the trimmed tile cannot accommodate a fastener (**Figure 8**).

The fastener punchouts of tiles are broken by the fasteners when they are installed. Therefore, if these punchouts remain intact, it is a reliable indication that the tile was never fastened to the roof with a mechanical fastener (**Figure 9**). Remedial tiles may be differentiated by manufacturing stamps or variations in color, finish, or profile. At roofs with battens, a remedial tile often has the upslope lug removed so that the remedial tile can slide over the batten.

Figure 8: No punctured punchout at a trimmed tile

Figure 9: Field tile without punctured punchouts

Tiles situated over metal flashing such as valley flashing, roof and rise-wall interface flashing, or vent flashing aprons are not typically installed with mechanical fasteners to avoid perforating the solid metal flashing and to mitigate water intrusion. When tile weight and friction are relied upon for the tile installation, the tiles commonly experience downslope sliding due to the lack of attachment to the deck. The authors commonly observe field tiles without punctured punchouts and utilizing deteriorated sealant adhesive as the as-built attachment.

Loose Tiles: Roof evaluators may be tasked with assessing the condition of loose tiles amid concerns of loose trim and field tiles or uplifted tile fasteners. When evaluating loose trim tiles with attachment limited to mortar bedding, it is important to recognize that wind pressures are not the only cause of unadherence:

- **Embedment**. The National Roofing Contractors Association (NRCA) specifies that trim tiles are to be set into a full mortar bed; poor embedment depths will result in reduced bonds between the tiles and the mortar (NRCA 2017);
- **Installation**. Inadequate installation of the trim tiles may result in a lack of bond or a poor bond due to improperly preparing the tiles, mis-proportioning the mortar mix, or inadequate setting or curing times (FIU 1994);
- **Deterioration**. Expansion/contraction of the tile roofing may deteriorate the system resulting in a loss of bond between the tiles and the mortar bed (FIU 1994).

Where a mortar bed bond exists at trim tiles, wind forces acting on the trim tiles must exceed the weight of the trim tiles and the bond strength to result in debonded trim tiles. Once this wind force breaks the bond, it is free to displace the trim tile because the force is greater than the weight of the tile. This dynamic has resulted in the wind-related distress observed by the authors and other consultants after high wind events. However, because the mortar bond at trim tiles is susceptible to installation deficiencies and deterioration, loose tiles along hips and ridges are common and not indicative of wind-related distress. Therefore, only displacement of these mortar-set trim tiles can reliably be attributed to wind forces.

Observations of distress patterns and evaluations of tile fasteners provide insight into the conditions experienced by the roof. The fasteners may be evaluated at roof level or from the underside, inside the attic. Screw fasteners that have experienced uplift failures are expected to be accompanied with withdrawal failure of the roof sheathing between the threads. Observation of the fasteners in the attic space allows the evaluator to determine if the screw fasteners have experienced such a failure. It is the experience of these authors that the as-installed penetration of tile roof fasteners varies. As a result, the measurement of the screw penetration alone is not a good determination of uplift failure. The fasteners depicted in **Figure 10** and **Figure 11** occurred at a representative tile roof installation condition. The images are exemplary of fastener penetrations that vary from one tile to another; however, there is no distress consistent with uplift failure at the roof deck or at the fasteners.

Figure 10: Approximately 1/4" tile fastener penetration

Figure 11: Approximately 1/2" tile fastener penetration

Fractured Tiles: In addition to displaced trim tiles, another common form of tile distress related to a wind event is fractured tiles due to impact by displaced tiles. However, there are other causes for fractured tiles, and roof evaluators must differentiate between the potential causes of fractured roof tiles.

Foot traffic is one common cause of fracturing of clay or concrete roof tiles. Mechanically-fastened roof tiles are generally simply supported with a span between the end bearing points. Loads applied to the tiles are transferred to the roof deck at the end bearing points.

Foot traffic near the middle of a roof tile, between the bearing points, induces a bending moment into the unreinforced roof tile, which can cause the tile to fracture. The authors have frequently, directly observed fracturing of roof tiles from foot traffic. Foot traffic distress has been observed and documented in varying patterns/shapes and can appear as starburst, vertical, diagonal, horizontal, curvilinear, or corner fractures. **Figure 12** through **Figure 15** depict examples of foot traffic fracture patterns/shapes, although these patterns do not constitute an exhaustive set of all types of foot traffic fracture patterns/shapes.

Figure 12: Starburst and transverse fractures at tiles fractured by roof contractor foot traffic during a site visit

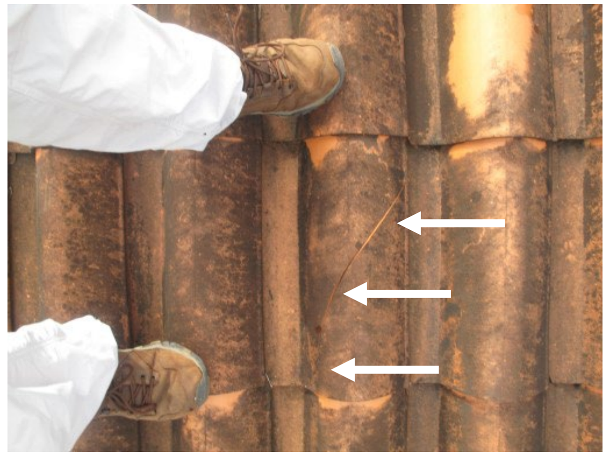

Figure 13: Curvilinear fracture in a clay Spanish S-style field tile observed to occur during a site visit

Figure 14: Intersecting longitudinal and transverse fractures at a concrete double S-shape field tile observed to occur during a site visit

Figure 15: Curvilinear fracture in a concrete single S-shaped field tile observed to occur during a site visit

Another common cause of roof tile distress is moisture- and/or thermal-induced differential expansion/contraction of the roof tiles and substrate. Corner fractures are typically consistent with restraint of in-plane movement due to friction and/or contact between tiles. Tiles are susceptible to fracture at the thinnest (weakest) portion of their cross-section when internal tensile stresses, such as those related to these thermal and moisture effects, exceed the tensile strength of the tile material. Also, tiles with debris and/or irregularities along the side lap can experience irregular stresses at the corners, potentially resulting in fractures. Lower corner fractures can extend vertically along the side of the tile (**Figure 16**), and in some cases, can extend the full height of the tile, generally in a "scallop" fracture pattern.

Figure 16: Fracture at the lower right-hand corner with vertical extension at a field tile embedded in ridge mortar lacking displacement under finger pressure

Additionally, improperly mixed or cured concrete can result in weakened sections and a higher likelihood of concrete roof tile breakage (TRI 1999). Locations of lower corner fractures, or other fractured tiles for that matter, can include field tiles embedded in hip and ridge mortar beds (**Figure 16**). These mortar beds restrain the field tiles from wind-related or other movement. The authors have also observed lower corner fractures at tiles embedded in hip or ridge mortar and at tiles installed with adhesive foam, which are adhered to the deck and are not free to move. Such instances make it clear that corner fractures can occur irrespective to the effects of wind pressures.

Although less common, mechanical damage, is another form of tile roofing distress. This type of distress is commonly associated with maintenance or inspection activities. A limited number of the evaluated roofs exhibited uncommon forms of distress, such as sporadic fractured tiles adjacent to tiles with withdrawn fasteners. The authors performed destructive testing on more than twenty (20) field tiles at four different condominium properties to evaluate for mechanical damage. Field tiles upwardly loaded with a load-cell hook near the middle of the leading edges generally failed with withdrawn fasteners at the loaded tiles and diagonal fracture patterns at the side overlapping tiles (**Figure 17**). This pattern of distress is not consistent with wind loading as wind pressures would act along a grouping of tiles.

Figure 17: Upward pressure applied to the indicated tile resulted in a withdrawn screw fastener of the loaded tile and a diagonal fracture at the adjacent overlapping tile

Golf course communities are common in Florida, and these communities have the added potential for roofing distress due to golf ball impacts. Multi-building complexes have been observed to exhibit a higher concentration of fractured tiles along the path between the tee box and the green (**Figure 18**). The distress pattern for golf balls commonly includes a circular fracture with fractures radiating from the center (**Figure 19**); however, this is not always the case.

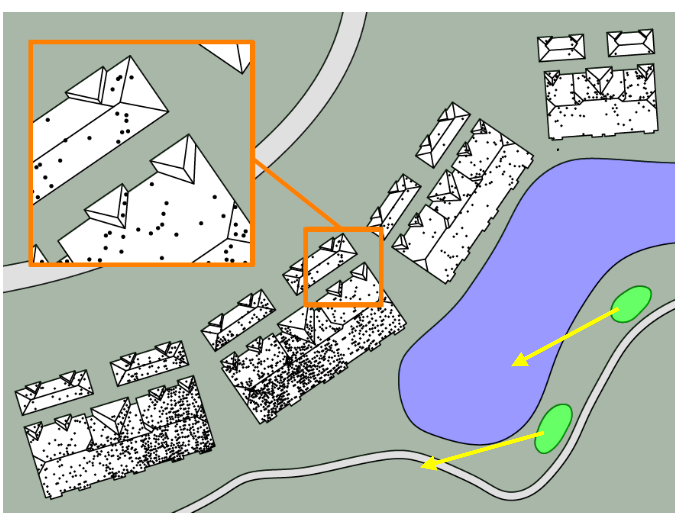

Figure 18: Concentrations of fractured tiles consistent with golf ball impact (arrows point from tee boxes toward green)

Figure 19: Fractured field tiles consistent with golf ball impact adjacent to a golf course fairway

Uncommon events may also result in tile fractures such as tree limb impacts or lightning strikes. Discrete areas of displaced and fractured tiles with charred roof sheathing and melted underlayment are indicators of lightning strikes (**Figure 20** and **Figure 21**).

Figure 20: Fractured/displaced tiles with melted underlayment

Figure 21: Fractured/displaced tiles with melted underlayment and charred roof sheathing

TILE ROOFING REPAIR

Roof evaluators determining the extent of wind-related distress are often tasked with determining the feasibility of the repair of roof systems.
Section 706.1.1 of the 2020 FBC, Existing edition (FEBC) states that *"Not more than 25 percent of the total roof area or roof section of any existing building or structure shall be repaired, replaced or recovered in any 12-month period unless the entire existing roofing system or roof section is replaced to conform to requirements of this code."* (FEBC 2020). This section indicates that if 25% or more of the tile roofing is being repaired within a 12-month period, then the entire roof section must be brought up to current code requirements. When the original roofing meets current code requirements, the entire tile roofing may not require replacement. However, this 25% threshold has become the regional rule of thumb to determine if roofing requires full replacement.

To perform a proper repair of tiles, remedial tiles of like-kind material and profile must be used for tile replacements. Proper remedial tile selection ensures interlocking between the remedial and existing tiles. The use of differently-shaped remedial tiles during spot repairs can disrupt interlocking connections, could provide inadequate nesting/support of the remedial tiles, and can even cause deterioration of the underlayment if it is exposed to sunlight due to tile profile differences. Several roof tile manufacturers have discontinued product lines, making it difficult to acquire like-kind remedial roof tiles for some profiles or products, though some discontinued roof tiles can be obtained from roof tile salvage yards and online resale sites.

All roof repairs must conform to the current edition of the FEBC. Repair methodology is addressed in Section 706.5 (Reinstallation/Reuse of Materials) of the 2020 FEBC. This section was updated in the 2020 version of the code, and as quoted below, the new language is underlined. Section 706.5 of the 2020 FEBC states:

> *"Existing <u>or salvaged</u> slate, clay or <u>concrete</u> tile shall be permitted for reinstallation <u>or reuse, to repair an existing slate or tile roof, except that salvaged slate or tile shall be of like kind in both material and profile.</u> Damaged, cracked or broken slate or tile*

> *shall not be reinstalled. The building official may permit salvaged slate, clay and concrete tile to be installed on additions and new construction, when the tile is tested in compliance with the provisions of Section 1507 or 1523 of the Florida Building Code, Building (HVHZ shall comply with Section 1523) and installed in accordance with Section 1507 or 1518 of the Florida Building Code, Building (HVHZ shall comply with Section 1518)."*

This new language provides clarification of the intent of this section and is now straightforward in acknowledgement that undamaged salvaged tiles are an approved repair material.

Previous editions of the FEBC, such as the 2017 edition, included Section 602.2 (*New and Replacement Materials*), which stated that "*Like materials shall be permitted for repairs and alterations, provided no dangerous or unsafe condition, as defined in Chapter 2, is created*." This section of the code indicated that "*like materials*," such as a surplus of tiles on hand, harvesting matching roof tiles from an adjacent roof section, roof tiles from roof tile salvage/bone yards, roof tiles from online resale sites, or otherwise acquired roof tiles can be used for approved repairs. Based on the language, the FEBC previously allowed, and currently allows, roofs with discontinued tiles to be repaired with salvaged tiles, provided that the tiles are "*like-kind in both material and profile*" materials are utilized for replacement and "*not more than 25% of the total roof area or roof section*" requires replacement within any 12-month period.

The authors and their colleagues have contacted multiple city and county building departments throughout Florida. All building departments that were contacted indicated that the use of salvaged roof tiles, whether discontinued or not, is an acceptable method of repair as long as "*like kind*" roof tiles are utilized for replacement, and the extent of repairs are less than 25% of any given roof section within any 12-month period. This is consistent with the aforementioned code language and the position taken by TRI stated below.

Of further consideration with respect to tile roof repairs is the fact that according to the repair procedures set forth in the *Florida High Wind Clay and Concrete Tile Installation Manual 5th Edition,* isolated tiles can be replaced without compromising adjacent tiles (FRSA/TRI 2012). The authors have also contacted technical representatives with a prominent tile roofing adhesive foam/sealant manufacturer, who indicated that isolated field tiles can be replaced using adhesive foam attachment without compromising the underlayment or the adjacent roof tiles. Furthermore, according to the Tile Roofing Industrial Alliance (TRI), tile roofs are "*easy to maintain and repair*" and "*tiles are easiest to repair because they are individually installed*" (TRI and PCA 2014).

The authors have observed multiple ongoing isolated roof tile replacements at residential and commercial structures. Those replacements have revealed that removal of isolated fastened field tiles can indeed be performed without damaging the tile(s) intended to be replaced or the adjacent tiles. Roof industry tools, such as a V-notched, L-shaped rebar, can be used to remove roof tile fasteners, without necessarily damaging the roof tiles, making individual tile replacements feasible.

A common repair observed at tile roofs involves adhering tile fragments together with sealant, adhesive, and/or mortar. The structural integrity of these repaired tiles is diminished and the FBC prohibits this form of repair (FBC 2020). Tile fragments from broken tiles should not be used to repair the fractured tiles. Fractured tiles should be replaced with tiles suitable for the tile roofing installed at the structure. Typically, the attachment of these replacement tiles is achieved using mechanical fasteners or adhesives; when adhesives are utilized, it is important that the contractor consider the compatibility of these adhesives with the existing underlayment.

CONCLUSION

Evaluation of tile roofing for repair or replacement related to wind distress requires proper determination of the extent of wind-related distress and the cataloging of the distress. Common forms of wind-related distress were discussed, including the displacement of hip and ridge tiles that fracture impacted downslope tiles. The Florida Building Commission, in concert with the International Code Council, has developed a building code that addresses and accommodates tile roofing repairs. As climate change causes more frequent and devastating storms, tile roofing evaluators must understand materials and repair techniques compliant with the code to reduce the economic impact of future storms. With over $300 billion of damages attributable to weather events in 2017 alone, proper identification of wind-related distress and consideration of the opportunities for roofing repair are critical to the implementation of reasonable, efficient, and cost-effective roof repairs.

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