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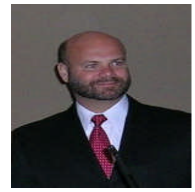

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PERFORMANCE OF ROOF SYSTEMS DURING THE 2004 AND 2005 HURRICANES IN SOUTH FLORIDA

This study examines the impacts of hurricanes on various roof systems in the South Florida area and the building code provisions that have been modified over the past 15 years to improve the performance of these roof systems under wind loading. The roof failures studied were the result of wind forces during the 2004 and 2005 hurricane, which included Hurricanes, Charlie, Ivan, Frances, Jeanne, Wilma and Katrina. The building codes considered include the South Florida Building Code, the Standard Building Code, the 2001 Florida Building Code, and the 2004 Florida Building Code.

The roof systems analyzed include mortar set tile roof systems, mechanically attached tile roof systems, adhesive set tile roof systems, asphalt shingle roofing, single ply membrane roofing, rolled membrane roofing, built-up roofing, modified bitumen membrane roofings and wood shake roof systems. This study includes a review of code modifications that were implemented after Hurricane Andrew in 1992 and how roof systems installed with these modifications behaved during the 2004 and 2005 hurricane as compared to other roof systems installed under lesser code requirements. Our study shows that the modifications to the South Florida Building Code in 1994 after Hurricane Andrew have made newer roofs installed under this code less susceptible to wind damage.

Performance of Roof Systems during the 2004 and 2005 Hurricanes in South Florida

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Introduction

During the past few years South Florida has been in the news due to the busy 2004 and 2005 hurricane seasons, which included Hurricanes Charlie, Ivan, Frances, Jeanne, Wilma, and Katrina. Depending on the specific location, building and other similar structures are required to be designed to sustain wind speeds of up to 156 mph (3-sec gust) in accordance with the Florida Building Code (FBC). In Miami-Dade and Broward Counties the design wind speeds are 146 mph and 140 mph, respectively. For the most part the FBC refers to ASCE 7, American Society of Civil Engineers – *Minimum Design Loads for Buildings and Other Structures.*

Subsequent to the 2004 and 2005 hurricane seasons the authors have inspected hundreds of roofs in South Florida for the purpose of assessing the extent of wind damage and determining whether the roofs were repairable. The purpose of this study is to summarize our findings regarding the performance of various roof systems during hurricanes and to evaluate to what extent changes in the building code have affected the ability of the various roof systems to sustain wind forces.

Background

Prior to 2002 Florida was governed by two primary building codes; the Standard Building Code (SBC), which was a model building code prevalent throughout much of the southern United States, and the South Florida Building Code (SFBC). The SFBC was applicable only in Miami-Dade and Broward Counties and both counties had their own versions, although they were basically the same. The SBC was generally applicable throughout the rest of the state.

In the late 1990s the Florida Legislature dictated that the entire state would have one building code by a specific date. At about the same time the International Building Code (IBC) was being developed to basically combine the three model building codes throughout the United States. However, the IBC was not going to be ready in time to meet the deadline set by the Florida Legislature. As a result Florida adopted its own code, the 2001 Florida Building Code, in March 2001.

The 2001 FBC was essentially a combination of the SBC and the SFBC. The old SFBC had more stringent wind load requirements and South Florida was not willing to compromise the provisions they enacted after Hurricane Andrew in 1992. Correspondingly, much of the rest of the state was not willing to enact the more stringent wind / hurricane provisions in the SFBC. The result was the creation of the High Velocity Hurricane Zone (HVHZ). The HVHZ has nothing to do with physical reality or probability of hurricanes; it was a political designation and included Miami-Dade and Broward counties only. The old provisions of the SFBC were basically incorporated into the HVHZ provisions, applicable in Miami-Dade and Broward only, while the rest of the state was governed by the main body of the code, which was the old SBC. Essentially the 2001 FBC was two codes in one.

On October 1, 2005, just prior to Hurricane Wilma, the 2004 FBC replaced the 2001 code. The 2004 FBC maintained the HVHZ provisions; however the main body of the code was replaced with IBC and is the code in effect as of the writing of this paper.

Building Code Modifications

The SBC and the SFBC in the years prior to 1996 had minimal specific regulations related to the installation of various roofing systems such as mortar set tile roofs, mechanically attached tile roofs and asphalt shingles. After Hurricane Andrew in 1992 significant changes were made to the SFBC regarding roofs. The following were some of the code modifications and introduction of the test protocols implemented in the SFBC (both Miami-Dade and Broward County versions) after Hurricane Andrew. These changes were carried over to the HVHZ provisions of the current FBC.

Asphalt Shingles. Asphalt shingle roofs after 1996 were required to be nailed in compliance with the product control approval, and installed in accordance with the roofing application standards. The introduction of this standard procedure for asphalt shingles installation did not exist in the SFBC prior to Hurricane Andrew. The major change was the disallowance of staples as fasteners to attach the shingles.

Clay and concrete roof tile. Roof tiles were required to be clay, concrete or composition material of various configurations complying with the physical property requirements of the code. All tile and tile systems required to be tested. Product control approval was required for a complete tile system, which included the tile, underlayment and all tile related accessories required to provide a waterproof system. All tile systems were required to be installed over solid sheathed decks. All tile installation was required to be in accordance with the roofing application standards.

Roof tile mortar was required to be either a pre-mixed unit having a product control approval and tested in compliance with the code test protocols or a job-site mix approved by the building official and in compliance with test procedures. Typically an epoxy was added to the mortar or a foam type structural adhesive was required. Prior to this change tile roofs were typically installed with plain mortar; a mixture of Portland cement, sand and water.

The type of mortar to set the tiles and the minimum uplift forces needed were specified. In the 1996 code specific test protocols were introduced to control the installation of the mortar set tile roofs. The evidence regarding the weakness of mortar set attachment and the loss of the first course of tile on mechanically attached tile systems suggested that action was necessary. The issue regarding the loss of the first course of tile was also addressed with a code modification which required that a tile clip be installed along with the other required tile fasteners on each tile along the first course for mechanically attached roof tile systems, rink shank nails, two nails and the 35lb uplift test.

The code modifications required specific post installation testing by third party testing agencies. This was a quality control requirement for newly installed roofs. For tile roofs a tile uplift test protocol was implemented. This test requires that a minimum of 97% of the tiles tested pass a static uplift test of 35 lbf per tile for mortar or adhesive set tiles. For mechanically attached tiles the uplift test force is based on the specific tile manufacturer's product approval, which is the result of wind load analysis and off-site testing.

Evaluation of Wind Damage to Roofs

It is the opinion of the authors that wind damage to roofs is clear and evident when it exists and the determination of wind damage should be made by inspection by a qualified inspector with experience in evaluating roofs. The assessment of wind damage to the roofs is based on visual inspection.

Typically, wind damage to tile roofs includes the tile being lifted, broken and or scattered about the roof and surrounding area. Also tiles with cracks across their lower corners were observed in many cases. While cracks of this nature are often the result of restrained expansion/contraction stresses at a weak location in the tile, these tiles may also be the result of fluttering of mechanically attached tiles under wind pressure.

In general, wind damage to shingle roofs includes the shingles being lifted, folded back and or scattered about the roof and surrounding area. Characteristically, wind damage to flat roofs starts with failure at the perimeter fascia or edge flashing. The metal edge flashing is bent outward and upward, exposing the membrane edge to wind forces. As a result the membrane is torn back and off the roof deck.

Tile uplift tests and other roofing tests provided in the FBC test protocols are applicable to newly installed roofs. These tests do not provide guidance as to wind damage and they do not provide any information about the condition of the roof the day prior to the wind event. There are no standard tests or other procedures that can provide a determination as to whether or not a roof was damaged by wind.

It is not reasonable to expect an old tile roof to meet the requirements of a new roof installed with more stringent requirements. There have been cases where uplift tests as per the current code were applied to old roofs and the roofs were damaged by the actual testing itself. It is our opinion that the application of a test procedure or test protocol to an old roof for the determination of wind damage is indicative of unsound engineering judgment.

In December 2006 the 2006 Supplements to the 2004 FBC came into effect. The 2006 Supplements include a 25% rule for roofing in chapter 5 of the *Florida Existing Building*

Code that is now in effect throughout the entire state. This rule previously existed in the HVHZ provisions of the code and existed in the old SFBC in a slightly different form. The *Florida Existing Building Code* is one of seven volumes that comprise the FBC and is referenced in chapter 34 of the main buildings code volume. The 25% rule is as follows:

"Not more than 25% 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 roofing system or roof section conforms to requirements of this code."

The 25% rule applies to the total roof area or roof section. This allows separate roof sections to be replaced without having to replace all the roofs over a building and is applicable in cases where there are multiple roof sections. The term roof section is defined in the *Florida Residential Building Code* and in chapter 2 of the *Florida Existing Building Code* as follows:

"A separation or division of a roof area by existing expansion joints, parapet walls, flashing (excluding valley), difference of elevation (excluding hips and ridges), roof type or legal description; not including the roof area required for a proper tie-off with an existing system."

Behavior of roof systems during 2004 and 2005 Hurricanes

Mortar Set Tile Roof Systems:

The mortar set roof system is a method of attachment of roof tiles to the roof deck with the use of a mortar paddy. During the 2004 and 2005 hurricanes the ridge caps on concrete roof tile installations suffered the most prevalent wind damage. In turn, the dislodged ridge tiles caused impact damage to field tiles down slope. In South Florida we found that this was the most prevalent failure mechanism and was consistent with a Category 1 to Category 2 hurricane; such as Hurricane Wilma. For comparison we studied roof tiles installed prior to review of code modifications that were implemented in 1996 and roof tiles installed after these modifications.

One of the residences used in this study was located in the Miami, Florida area. The house is a 2-story single family home with a mortar set concrete tile roof system over a plywood roof deck and wood roof trusses. This house was built in 1991 and the roof was original. During our damaged assessment for the Hurricane Wilma we found several broken, missing and dislodged field tiles. The damage to these tiles was generally consistent with wind damage. The observed repairs needed because of the wind damage in this case exceeded 25% of the total roof area. (Photo 1)

Photo 1: Mortar set roof system, with wind damage over 25%.

The second residence is a 2-story single family home located in Broward County, also with a concrete tile roof system over a plywood roof deck and wood roof trusses. The ridge tiles were installed with mortar and the field tiles were installed with a foam-type structural adhesive. This roof was installed in 2000. We found a few broken field tiles and numerous missing ridge tiles. The damage to the field tiles appeared to be the result of impact from the dislodged ridge tiles. The observed repairs needed because of the wind damage in this case were approximately 3% of the total roof area. (Photo 2)

Photo 2: Foam set roof system with scattered roof ridge tiles and minimal wind damage to the field tiles. (Ridge tiles installed with mortar only.)

The conditions observed in the residences above were the typical conditions observed in most of the inspected residences. During our inspections we found many of the mortar-set field tiles, mainly on the roofs installed prior to the code modifications in the 1996 SFBC, were loose throughout the roof area. The loose tiles were in place and had not been dislodged or otherwise damaged. The failure plane was between the tiles and the mortar. (Photo 3) The condition of mortar-set roof tiles being loose in place with the bond failure plane between the tile and the mortar is not consistent with damage caused by wind forces. It is our opinion that wind does not gently pry roof tiles loose from their mortar paddies and leave them in place and not otherwise visibly damaged.

Photo 3: Loose tiles in place with the failure plane between the tiles and the mortar.

We evaluated 325 buildings, with a mortar set roof systems that were reportedly affected by the 2004 and 2005 hurricanes. Approximately 300 of the roofs were installed prior to 1996. We found that approximately thirty-two of these older roofs had wind damage over 25%. The other 25 roofs were installed after 1996 and only one of them was found with wind damage over the 25%.

Mechanically fastened tile roof systems:

A mechanically fastened tile roof system is another method of attachment of roof tiles to the roof deck. Typically these tiles are installed with either one or two nails through pre-formed holes at the upper portion of the tile. The tiles are either nailed directly to the plywood roof deck through the membrane or through wood battens on top of the membrane. For comparison we studied roof tiles installed prior to the code modifications that were implemented in SFBC (1996 Broward County Edition and 1994 Dade County version) and roof tiles installed after these modifications as previously discussed.

The first residence is a 2-story single family home located in the Broward County with a nailed down concrete tile roof system over a plywood roof deck and wood roof trusses. This house was built in 1991. During our post damaged assessment for the Hurricane Wilma we found missing and dislodged ridge tiles and several tiles with new cracks across their lower corners. Cracks of this nature can be caused by fluttering of the tiles under wind pressure. The observed repairs needed because of the wind damage in this case were approximately 15% of the total roof area. (Photo 4)

Photo 4: Nail down roof tiles with wind damage to the field tiles.

The second residence used in this study was located in the Broward County. The house is a 2-story single family home with a nailed down concrete tile roof system over a plywood roof deck and wood roof trusses. This house was built in 1997. During our post damaged assessment for the Hurricane Wilma we found a few missing and dislodged ridge and rake tiles. The damage to these tiles was generally consistent with wind damage. The observed repairs needed because of the wind damage in this case was approximately 5% of the total roof area. (Photo 5)

Photo 5: Nail down roof tiles with minimal wind damage to the field tiles.

We evaluated 150 buildings with mechanically attached roof tiles, that were reportedly affected by the 2004 and 2005 hurricanes. Approximately 94 of the roofs were installed prior to 1996. We found that six of the older roofs had wind damage over 25%. We found that in the other 56 roofs that were installed after 1996 only two of the roofs had wind damage over the 25%.

It has been claimed that roof tiles, which are mechanically attached instead of mortared in place, have become “loose” due to wind. However, this is how mechanically attached roof tiles are supposed to be. When roof tiles are installed with screws or nails the fasteners should not be driven flush with the tile because doing so does not allow the tile to expand and contract due to environmental effects and it may cause the unsupported end of the tile to lift and be more susceptible to catching the wind.

Asphalt Shingle Roofs:

The effects of hurricane force winds were most evident and widespread with regard to asphalt shingle installations. Nonetheless, there was direct correlation to the age of the shingles and the amount of damage sustained. Shingle roof systems approximately eight years and less in age encountered little to no damage, while shingle roof systems dating from post hurricane Andrew or older sustained, in many cases, significant shingle tab losses.

One of the residences used in this study is a 1-story single family home located in the Miami-Dade County with an asphalt shingle roofing system over a plywood roof deck and wood roof trusses. This house was built in 1987. During our post Hurricane Wilma inspection of this roof we found several torn and missing shingles. We also found that the shingles had lost a significant amount of their granules and that black asphalt showed in many places. The observed repairs needed because of the wind damage in this case exceeded 25% of the total roof area. (Photo 6)

Photo 6: Asphalt shingle roofing with wind damage over 25% to the entire roof area.

The second residence was also located in the Miami-Dade County. The house is a 1-story single family home with an asphalt shingle roofing system over a plywood roof deck and wood roof trusses. This house was built in 2000. During our post Hurricane Wilma inspection we found a few torn and missing edge shingles. The damage to these shingles was generally consistent with wind damage. The observed repairs needed because of the wind damage in this case were approximately 1% of the total roof area. (Photo 7)

Photo 7: Asphalt shingle roofing with minimal wind damage.

We evaluated 96 buildings, with the asphalt shingle roofs, that were affected by the 2004 and 2005 hurricanes. Approximately 74 of the roofs were installed prior to 1996. We found that sixteen of the older roofs had wind damage over 25%. On the other 22 roofs that were installed after 1996 only two of the roofs had wind damage over the 25%.

Other Roofs Systems:

There was minimal visible wind damage to the single ply membrane roofs inspected by our office as a result of the 2004 and 2005 hurricanes. Where wind damage was found it included the membrane being lifted at the roof edges and corners and fastener withdrawal in the fields.

The effects of hurricane force winds were most evident and widespread with regard to flat roofs. The effects of wind forces were related to the age of the membranes. Rolled membranes and modified bitumen membrane roofs eight years and less in age encountered minimal damage, while membrane roofs installed prior to 1996 sustained more significant losses.

The majority of the residences inspected by this office with the built-up-roof (BUR) had damage consistent with wind damage. For gravel surfaced BUR, the top layer of the gravel was typically displaced and accumulated at the edges of the roofs.

The wood shake roofs inspected had spot locations where the shakes were newly missing or broken. The damage to the shakes at these locations was consistent with wind damage. We also found that the cedar shakes were split, curled and severely deteriorated as a result of long-term exposure. The lower edges of the shakes were splintered, rotted and were easily crushed. This condition was consistent with the age of the shakes and not consistent with damage caused by wind forces. The edges of the shakes at the splits and breaks were severely weathered. This type of roof is rare but not non-existent is South Florida. (Photo 8)

Photo 8: Wood shakes roofing

Summary of Results

	TOTAL NUMBER OF ROOF INSPECTED	NUMBER OF ROOFS WITH WIND DAMAGE OVER 25%	PERCENTAGE OF ROOFS WITH WIND DAMAGE OVER 25%
MORTAR SET TILE ROOFS			
ROOFS INSTALLED PRIOR TO 1996	300	32	10.7
ROOFS INSTALLED AFTER 1996	25	1	4
MECHANICALLY ATTACHED TILE ROOFS			
ROOFS INSTALLED PRIOR TO 1996	94	6	6.4
ROOFS INSTALLED AFTER 1996	56	2	3.6
ASPHALT SHINGLE ROOFS			
ROOFS INSTALLED PRIOR TO 1996	74	16	21.6
ROOFS INSTALLED AFTER 1996	22	2	9

Conclusions

This study shows that the code modifications after Hurricane Andrew in the mid 1990's made a positive impact on the performance of roofs installed after 1996. From our inspection of hundreds of roofs throughout South Florida we found that the amount of mortar set concrete tile roof system with wind damage exceeding the 25% was reduced by approximately 7%, the amount of mechanically attached roof systems with wind damage exceeding the 25% was reduced by approximately 3% and the amount of asphalt shingle roofs with wind damage exceeding the 25% was reduced by approximately 13%. In the majority of the cases the roof systems installed after the adoption of code modifications resulted in a decrease in severity of roof damages.

It should be noted that the roofs evaluated were the result of requests for engineering consulting services by the insurance industry. We would typically not be called in cases where the insurance company had decided to replace the roof or where the claimed damage was minimal and there was no dispute between the homeowner and the insurance company. As such, the roofs evaluated typically had hurricane damage to the extent that there was not an agreement between the homeowner and the insurance company regarding the reparability of the roof.

List abbreviations

Florida Building Code (FBC)
Standard Building Code (SBC)
International Building Code (IBC)
High Velocity Hurricane Zone (HVHZ)
American Society of Civil Engineers (ASCE)

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