HOUSING Constructability LAB
a research lab of the University of Central Florida

Water Intrusion in Central Florida Homes During Hurricane Jeanne in September 2004

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Executive Summary

In September 2004 Hurricane Jeanne struck Florida. Most of the damage in the Orlando and surrounding central Florida area resulted from severe water intrusion. The local Home Builders Association received over 1,000 complaints from new home owners involving water intrusion. The water intrusion was perplexing for several reasons. First, most complaints were from residents of newer homes. Second, in many cases there were no obvious reasons for the intrusion (e.g., roofing materials were not blown off, windows were not damaged, there was no surrounding flooding). Water, lots of water, seemed to just appear at the base of exterior walls inside newer homes. The objective of this research is to characterize what actually happened, to explain why it happened and to develop recommendations to reduce future water intrusion. To allow better focus, the scope was limited to:

- Recent construction – homes receiving certificates of occupancy in 2001 and afterwards.
- Stucco-clad masonry (1st floor) and frame (2nd floor) walls – the predominant building system in central Florida.

Several approaches were used to collect data:

- An extensive literature search was performed in the areas of masonry walls, stucco finishes, cracks, and water intrusion.
- Experts were interviewed to discuss findings and provide direction.
- Homeowners were surveyed by telephone to learn more about their home and what they experienced during the storm.
- Home inspections were performed to learn more about affected homes.
- Selected elements of the construction process were observed to better understand workmanship issues.
- Field tests were performed on new and existing homes to measure the extent of water intrusion due to wind driven rain.

Survey results indicate that 20% of all new homes built in central Florida in 2003 experienced water intrusion related to walls during Hurricane Jeanne. A survey of homeowners that reported water intrusion revealed that:

- Although many builders experienced the problem, some builders were affected far more than their market share would suggest.
- Single and two story homes were equally affected.
- The vast majority of intrusion occurred on eastern walls, with some occurring on northeast and northern walls.

A follow-up inspection of these homes found a variety of possible causes including: poorly sealed windows, unsealed wall penetrations (dryer vents, plumbing, electrical, rain gauge, etc.), poorly sealed expansion joints, and numerous cracks of varying shapes and sizes. Findings from an earlier inspection study confirmed the prevalence of these issues throughout the central Florida new home market. This earlier study found that 50% of homes between one and two years old had significant stairstep cracking.

On-site testing was used to assess the relative importance of these factors. Testing of new homes (both under construction and occupied) revealed that stucco clad masonry walls without cracks did not leak, even without paint. Tests of homes that had leaked during Hurricane Jeanne demonstrated that cracks can facilitate water intrusion. Cracks did not need to be wide - cracks less than 0.39mm (1/64 inch) wide allowed water to penetrate the wall, run down and accumulate on the floor in one to two hours of simulated wind driven rain conditions. It is important to note that 57% of the cracks observed were wider than this, but could not be tested because they were not in a testable area of the house. It is also important to note that Hurricane Jeanne brought sustained winds of over 40 miles per hour with rain for a period of over 8 hours.

Given the prevalence of stairstep cracks in new central Florida homes and their propensity to allow water intrusion, the remaining analysis and recommendations focused on the cause, prevention and mitigation of water intrusion through stairstep cracks. The causes of the stairstep cracks observed are not obvious. No significant stairstep cracks were observed immediately after laying the block. However, after the cells were grouted and the roof was installed, numerous stairstep cracks were visible. There were no discernable cracks in the footings related to the stairstep cracks observed in the walls. No problems with soil compaction were found and the required rebar was installed in the footings. No significant stairstep cracks were observed immediately after stucco was applied. However, within one year after the homes were completed, 50% exhibited significant stairstep cracking. The most likely cause of stairstep cracking cited in the literature is differential settlement. However, the absence of discernible cracks in the footings casts some doubt on this explanation as the sole cause. A more likely cause of many stairstep cracks is shrinkage. A common cause of shrinkage cracks in masonry walls is using ‘wet’ or uncured concrete masonry units (blocks). When uncured blocks are used to construct a masonry wall, they continue to cure and experience a significant amount of shrinkage. Typical shrinkage in a 50 foot masonry wall range from 3.1 to 6.9 mm.

Recommendations are provided at two levels. Level I recommendations should be implemented immediately. They are believed to be low cost and high impact. Level II recommendations involve substantive changes to the construction process and should be carefully evaluated by each builder, possibly involving longer term testing.

Level I Recommendations

Level I recommendations should be implemented immediately. These recommendations are believed to be of low cost to the builder and high impact in terms of reducing the potential for water intrusion. Some of these recommendations merely restate existing code requirements and builders are encouraged to ensure that their subcontractors comply. Other recommendations have been suggested by others and have been successfully adopted by some builders. If adopted as a package, they should greatly reduce the potential for water intrusion through masonry walls.

Foundations: Ensure that site work for foundations meet code requirements as well as recommendations from the National Concrete Masonry Association (TEK 10-1A 2001).

> *“Footings should be placed on undisturbed native soil, unless this soil is unsuitable , weak, or soft. Unsuitable soil should be removed and replaced with compacted soil, gravel, or concrete. Similarly, tree roots and construction debris should be removed prior to placing footings.”*

Step Down Ledge: Provide a step down ledge or seat for the concrete block approximately one inch below the slab to provide holding capacity for water that penetrates the exterior surface of the wall (Lstiburek 2005).

Concrete Block: Age concrete block 21 days before use to permit early shrinkage before walls are constructed (TEK 19-2A 2004). Note that block will continue to shrink, but not as much – for example, 30% of block shrinkage will still occur after 9 months (Gulde 2006). Ensure that mortar ingredients are mixed in proper proportions.

Stucco: Ensure that stucco is installed to ASTM standard C926 for 2 coat stucco. The minimum two coat process starts with a 3/8 inch first (scratch & brown) coat followed by a 1/8 inch second (finish) coat. The first coat process includes densification with a hard float. This densification is critical, since the consolidation that occurs influences the shrinkage-cracking and water penetration characteristics of the plaster. The first coat does not require scoring. The first coat should be allowed to fully cure before applying the second coat (some experts have suggested seven days). This allows the first coat to provide the best possible substrate for the second coat, and allows the first coat to crack (if it is going to crack) before the second coat is applied. The second coat should cure for 28 days before painting. The stucco mix should be reinforced with suitable fibers to increase cohesiveness, tensile strength, impact resistance and to reduce shrinkage; ultimately reducing cracking (Melander 2003).

To reduce the risk of construction stress-induced cracking, roof tiles should be loaded five days prior to lathing installations and interior furring strips and drywall should be nailed prior to stucco installation.

Paint: Use a premium, high build, acrylic coating with the following characteristics:
- Meets Federal Specifications for resistance to wind driven rain (TT-C-555B).
- Allows water vapor transmission (high perm rating) permitting water to evaporate from the wall to the exterior.
- High flexibility/elongation to cover existing and new cracks.

Service: Near the end of the warranty period, repair all visible cracks and apply a second coat of paint. Cracks should be repaired with an elastomeric waterproof sealant patching compound. The method will depend on crack width and the sealant product, but might typically include:
- Less than 0.4 mm (1/64 inch) – apply a brush grade compound with a small brush.
- Between 0.4 mm (1/64 inch) and 0.8 mm (1/32 inch) – apply a knife grade compound.
- Between 0.8 mm (1/32 inch) and 6.4 mm (1/4 inch) – route out crack ¼ inch wide by ¼ inch deep; apply two coats of knife grade compound.

Note that commercially available caulking compounds are not suitable materials for patching hairline cracks. Because their consistency and texture is unlike that of stucco, they tend to weather differently, and attract more dirt; as a result, repairs made with caulking compounds may be highly visible, and unsightly (National Association of Certified Home Inspectors 2006). http://www.nachi.org/stucco.htm

Encourage the homeowner to observe the repair process. Reassure them that most shrinkage cracking occurs over the first few weeks and most settlement cracking happens over the first year. Remind them that cracks are continuously moving with temperature changes, moisture content and shrinkage. Remind them that they must provide regular maintenance - identifying and repairing cracks - if they wish to minimize the risk of water intrusion into their home. Provide instructions for future maintenance of cracks.

Level II Recommendations

Level II recommendations involve substantive changes to the construction process and should be carefully evaluated by each builder for impacts on market acceptance, cost, building system, and the construction process. The evaluation may also involve longer term testing of viable concepts.

Foundations: Adding reinforcement to footings can lessen the effects of differential settlement on footings and thus reduce the incidence and severity of wall cracks (TEK 10-1A 2001).

Wall/Floor Joint Details: Investigate and consider alternatives for floor/wall joint details that promote water entry into home. For example, for architectural designs with block kneewalls and raised floor slabs, pouring the floor slab directly inside the wall into "h" blocks virtually guarantees that water entering the wall will flow down the wall, onto the floor slab and inside the home.

Crack Control Strategies for Walls: Crack control strategies seek to address the combined effects of movement due to drying shrinkage, carbonation shrinkage and contraction due to temperature change (TEK 10-1A 2001). Strategies use two related techniques: control joints and reinforcement to limit crack width. Control joints are vertical separations built into the wall to reduce restraint and permit longitudinal movement. Empirical rules have been developed to guide the location of control joints in masonry structures (TEK 10-2B). Normally, however, single family homes are not large enough to warrant the use of control joints (Graber 2006) and for low-rise buildings in most regions of the United States there are no provisions in the model building codes prescribing the use of steel reinforcement or control joints (NAHB Research Center 1998). If walls are longer than 40 feet, control joints should be considered no further than 25 feet on center (Graber 2006). Where lateral or out-of-plane shear loads need to be transferred across the control joint, a shear key spanning the control joint and composed of smooth dowel bars mounted in plastic sleeves will allow the walls to move longitudinally.

The standard horizontal joint reinforcement is 9-gauge wire in either a "ladder" or "truss" configuration, available in standard lengths of 10 and 12 feet (NAHB Research Center 1998). Bond beams which serve both as structural elements and as a means of crack control are a horizontal course or courses of U-shaped masonry block into which the reinforcing steel and grout is placed. As the wall shrinks, the steel undergoes shortening, resulting in compressive stress (TEK 10-1A 2001). The surrounding masonry offsets this compression by tension. At the point where the masonry cracks and tries to open, the stress in the reinforcement turns to tension and acts to limit the width of the crack by holding it closed. The net effect is that reinforcement controls crack width by causing a greater number of smaller cracks. As horizontal reinforcement increases, crack width decreases. Smaller size reinforcement at closer spacings is more effective than larger reinforcement at wider spacings. Bond beams are typically presumed to offer tensile resistance to an area 24 inches above and below its location in the wall and horizontal joint reinforcement is usually placed in joints at a vertical spacing ranging from 8 inches to 24 inches (NAHB Research Center 1998). Graber (2006) recommends adding 9 gauge joint reinforcement every other course to help hold cracks tightly together.

Weep Holes:
Provide weep holes in the first course of block to allow water that does penetrate the exterior surface of the wall to escape (NAHB Research Center 1998, TEK 19-4A 2001, Bomberg 2006). Note that although the CABO, UBC, and ACI 530 building codes do not prescribe the use of weepholes or flashing, both BOCA and SBC require that weepholes be provided (NAHB Research Center 1998). BOCA requires a maximum spacing of 33 inches on center, and that they shall not be less than 3/16 inch in diameter. SBC prescribes maximum spacing of 48 inches on center, and that they shall be located in the first course above the foundation wall or slab, and other points of support, including structural floors, shelf angles, and lintels. Cotton sash cords (removed before putting the wall into service) and partially open head joints are the most common types of weep holes (TEK 19-4A 2001).

Several related provisions are useful to support the weepholes. First, mortar must be prevented from blocking the weepholes. This should be accomplished by ensuring that the masons minimize the mortar dropped into cavities and providing mortar collection devices (e.g., screens) at regular intervals as the wall is laid-up to disperse minor mortar droppings enough to prevent blockage (TEK 19-4A 2001). Secondly, pests must be prevented from entering the wall. This can be accomplished by inserting stainless steel wool into the openings or using proprietary plastic or metal vents (TEK 19-4A 2001). These concepts are summarized in Figure 66.

Flashings:
To better contain the water that does penetrate the exterior surface of the wall and direct it to the weepholes discussed previously, flashings should be considered (TEK 19-4A 2003). Perhaps the most critical unflashed location in current masonry construction is at the base of the walls. Flashing materials include sheet metals (stainless steel, cold-rolled copper and galvanized steel), composites and plastic/rubber compounds). Flashing should be longitudinally continuous or terminated with end dams. To attain longitudinal continuity, joints must be overlapped and bonded/joined to prevent water movement through the lap joint. Flashings should always be paired with weep holes, as described in the Level I recommendations. Typical flashing details for masonry walls are shown in Figure 67. Several proprietary systems are described in Appendix C. Challenges that must be overcome to design and install an effective flashing system include the handling of vertical grouted cells and assurance of consistent installation (Gulde 2006).

Alternative Building Systems: Alternative building systems such as cast-in-place concrete (Zoeller and Crosbie 2005) or pre-cast concrete panels may greatly reduce the risk of cracks and water intrusion associated with concrete masonry construction.

Recommendation for Homeowners

Homeowners should understand that stucco is likely to crack and that the homeowner isresponsible for ongoing maintenance of the home. Cracks should be repaired with an elastomeric waterproof sealant patching compound. The method will depend on crack width and sealant product, but might typically include:

- Less than 0.4 mm (1/64 inch) – apply a brush grade compound with a small brush
- Between 0.4 mm (1/64 inch) and 0.8 mm (1/32 inch) – apply a knife grade compound

Between 0.8 mm (1/32 inch) and 6.4 mm (1/4 inch) – route out crack ¼ inch wide by ¼ inch deep; apply two coats of knife grade compound

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I. Background and Approach

Hurricane Jeanne

2004 was an unusually active year for hurricanes in Florida, with four named storms striking the state. Three of these storms, Charlie, Francis and Jeanne crossed the Orlando metropolitan area in central Florida in the span of less than four weeks. The last of these storms, Jeanne, was unique in several respects. According to the National Hurricane Center (Lawrence and Cobb 2005), the initial track of the storm (Figure 1) passed over the islands of Guadeloupe, Puerto Rico, the Dominican Republic and Haiti, producing heavy rains. After a northern shift to the open waters of the Atlantic, the storm stalled, negotiated a wide loop and took a westward track, hitting the northern Bahamas and then the central Florida east coast as a category three hurricane (Figure 2).

Jeanne's slow forward motion contributed to torrential rainfall along its path. Total rainfall amounts averaged from five to fifteen inches, with maximum storm total rainfall of 24 inches at Camp Garcia in Vieques. Widespread rainfall of up to eight inches accompanied the storm as it moved across eastern, central and northern Florida. A narrower band of 11 to 13 inches was observed in the vicinity of the eyewall track over Osceola, Broward and Indian River counties of east central Florida. Hurricane force sustained winds about 90 nautical miles wide affected the Florida east coast from near Cape Canaveral south to Stuart. The highest wind gust reported from Florida was 128 mph at Fort Pierce Inlet. Sustained hurricane force winds spread westward and inland about halfway across Florida and tropical storm force winds affected a large portion of the remainder of central Florida. At the Orlando International Airport, maximum sustained winds were recorded at 61 mph with gusts to 77 mph, occurring at about 1055 on September 26, 2004. A nearby airport recorded a total rainfall for the storm of 5.4 inches. Detailed weather observations from the weather station at Orlando International Airport over the duration of the storm are shown in Figure 3. The data indicate that there was a combination of high wind and heavy rain for over eight hours.

According to Reuters News, Haiti's death toll from Jeanne was more than 3,000, mostly due to flooding from the torrential rains. Some 200,000 Haitians lost their homes, belongings and livelihoods in the hurricane. One direct death was reported from Puerto Rico and three direct deaths were reported in Florida. American Insurance Services group reported that the estimate of insured property losses totaled 3.44 billion dollars. Using a 2 to 1 ratio between insured losses and total damage results in a total U.S. damage estimate of 6.9 billion dollars.

Research Objective and Scope:

While the death and destruction caused by Jeanne in Florida was not on the same scale as that suffered in Haiti, damage was significant. Most of the damage in the Orlando and surrounding central Florida area resulted from severe water intrusion. The local Home Builders Association (HBA) received over 1,000 complaints from new home owners involving water intrusion. WESH, the local NBC affiliate in Orlando, developed a database of over 800 viewers that reported damage from water intrusion. The water intrusion was perplexing for several reasons. First, most complaints were from residents of newer homes. Second, in many cases there were no obvious reasons for the intrusion (e.g., roofing materials were not blown off, windows were not

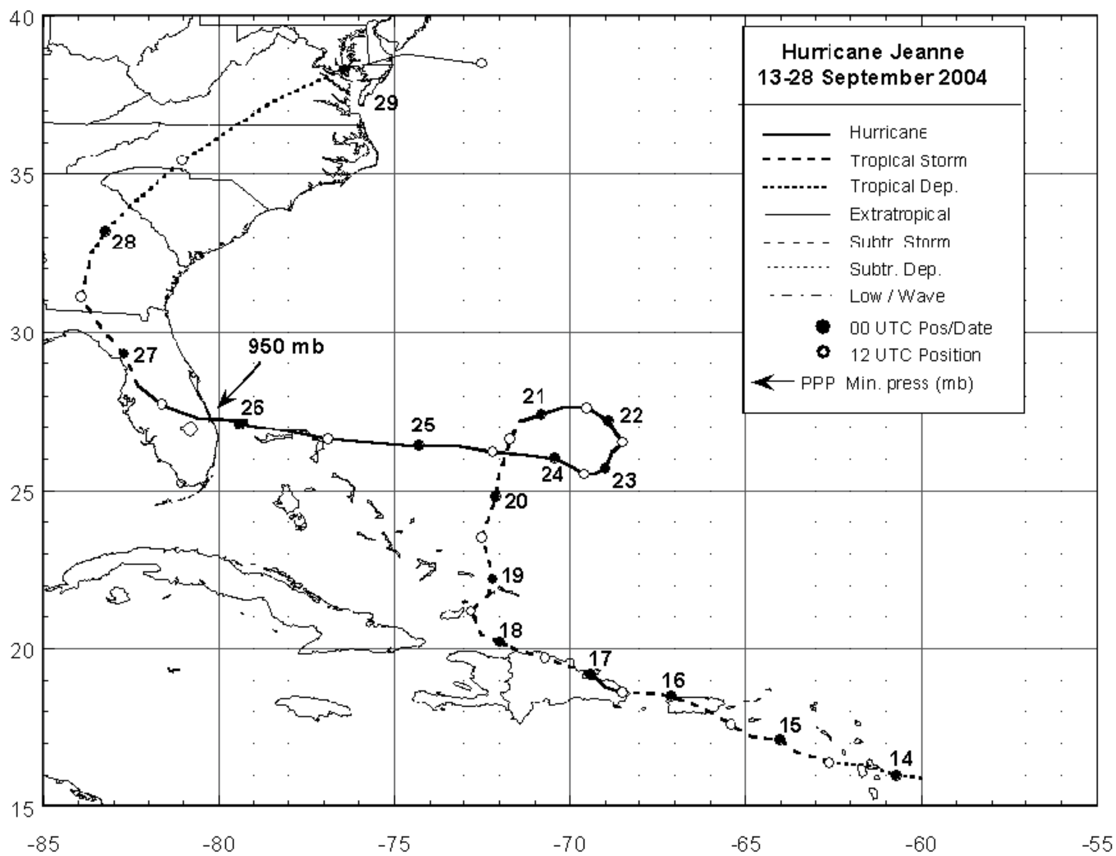

Figure 1 Track of Hurricane Jeanne (Lawrence and Cobb 2005)

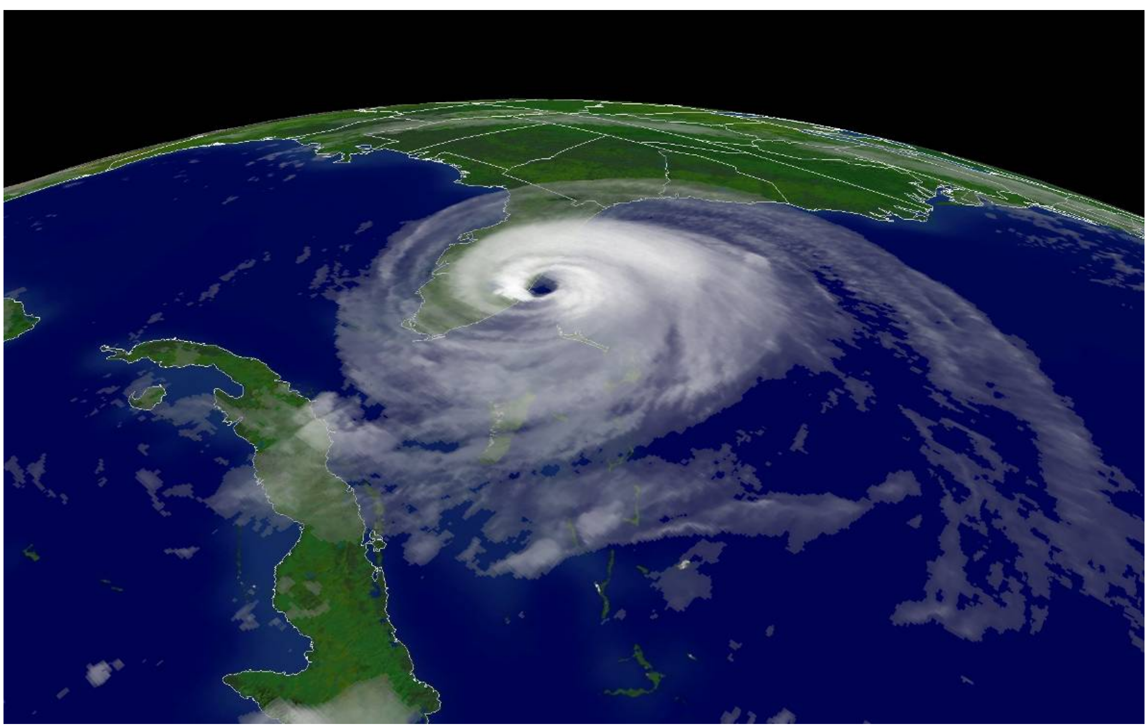

Figure 2 Hurricane Jeanne at landfall (NOAA Satellite and Information Service 2004)

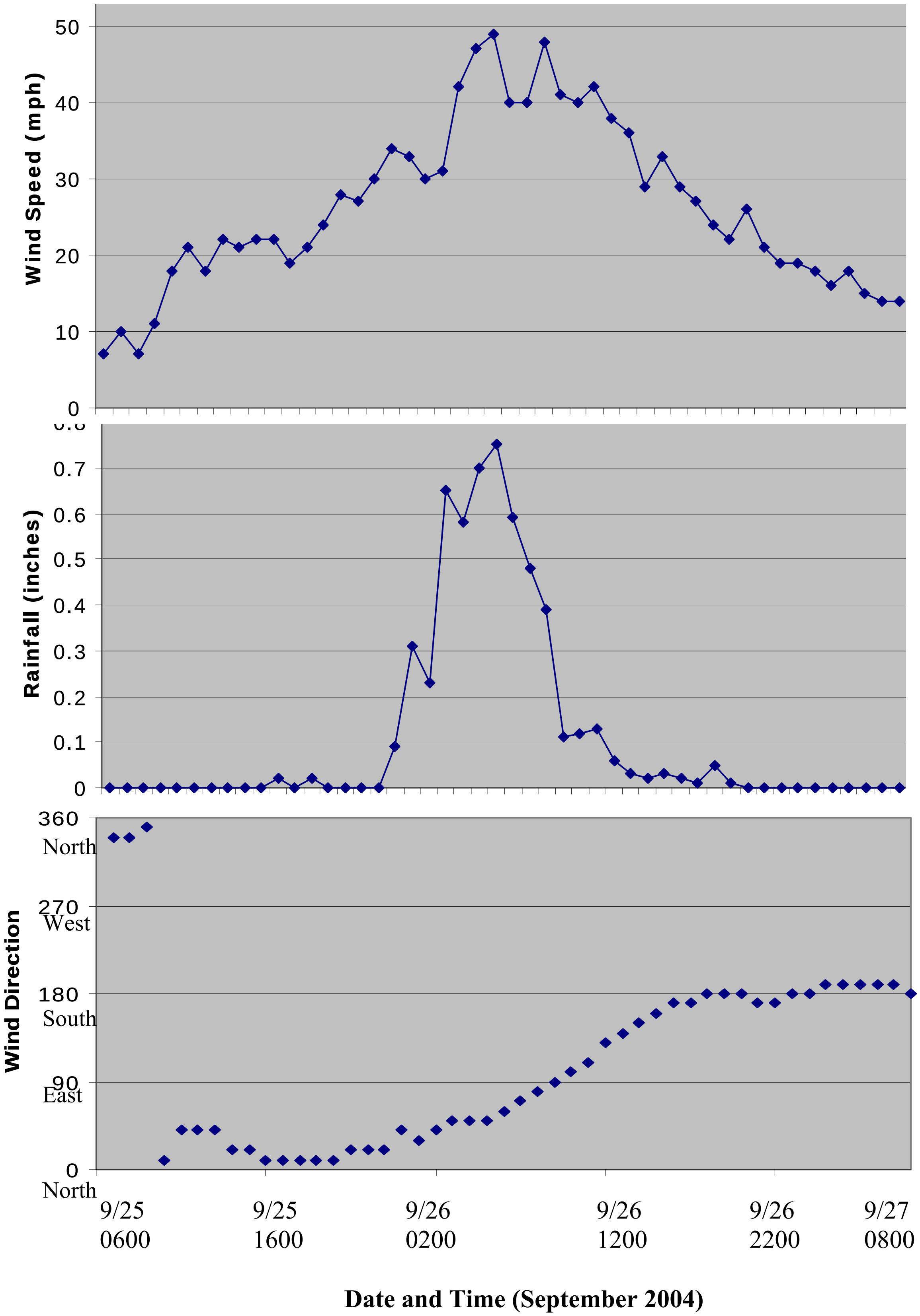

Figure 3 Weather results from Orlando (National Climatological Data Center 2004)

damaged, there was no surrounding flooding). Water, lots of water, seemed to just appear at the base of exterior walls inside newer homes.

Responding to complaints, the Home Builders Association of Metro Orlando and the Florida Home Builders Association commissioned a study by Dr. Joseph Lstiburek, a forensic engineer who investigates building failures and is internationally recognized as an authority on moisture related building problems. The study (Lstiburek 2005) identified several factors contributing to the problem and recommended a variety of potential solutions. This research seeks to build and expand upon Dr. Lstiburek's study.

The objective of this research is to characterize what actually happened, to explain why it happened and to develop recommendations to reduce the severe water intrusion that appeared to come through seemingly intact exterior walls in central Florida during Hurricane Jeanne in September 2004. To allow better focus, the scope was limited to:

- Recent construction – homes receiving certificates of occupancy in 2001 and afterwards.
- Stucco-clad masonry (1st floor) and frame (2nd floor) walls – the predominant building system in central Florida.

Several approaches were used to collect data:

- An extensive literature search was performed in the areas of masonry walls, stucco finishes, cracks, and water intrusion.
- Experts were interviewed to discuss findings and provide direction.
- Homeowners were surveyed by telephone to learn more about their home and what they experienced during the storm.
- Home inspections were performed to learn more about affected homes.
- Selected elements of the construction process were observed to better understand workmanship issues.
- Field tests were performed on new and existing homes to measure the extent of water intrusion due to wind driven rain.

It should be noted that all data from individual homeowners and builders are considered confidential and are used only to identify factors that can contribute to water intrusion and potential solutions.

II. Surveys

Two homeowner surveys were performed. The first surveyed homeowners who had reported water intrusion during Hurricane Jeanne. The second was a broader survey of new homebuyers who received a certificate of occupancy during 2003.

Survey of Homeowners Reporting Water Intrusion

In the first survey, UCF researchers telephoned homeowners who had reported water intrusion problems during Hurricane Jeanne. Researchers used a database developed by WESH, the local NBC television affiliate in Orlando. WESH has been active in reporting homebuilding issues. The objective of the survey was to learn more about the affected homes and what the homeowners experienced during the storm. Researchers included only those homes that were built between 2001 and 2004 in six central Florida counties: Brevard, Lake, Orange, Osceola, Seminole, Volusia. Homeowners that reported obvious problems (e.g., roofing materials were blown off, windows were damaged, there was surrounding flooding) were excluded.

The original WESH database contained 807 homeowners. 383 homeowners were eliminated for reasons described in Table 1. After attempting to contact the remaining 424 homeowners, 251 more homeowners were eliminated because: they could not be reached (after four attempts), they were not willing to participate, they experienced no water intrusion during Jeanne, they experienced no water intrusion related to walls, and other miscellaneous causes. Data from the remaining 173 homeowners were used to generate the results summarized below.

Table 1 Homeowners omitted from survey

Reason Omitted	#
Home built prior to 2001	145
Name but no phone number found	98
Obscure data	57
No contact info	41
E-mails with no response	21
Repeat entries	11
Not in 6 county area	7
Only 1st name and no phone number	3
Total omitted	383

The telephone survey is shown in Appendix A. Homeowners were asked 18 questions regarding their home and their experience during the storm. The profile of homeowners surveyed by county is shown in Table 2, together with an estimate (%) of new homes built by county.

Table 2 Respondent profile by county

County	# Surveyed		Built
Orange	86	50%	30%
Lake	31	18%	15%
Seminole	20	12%	9%
Brevard	17	10%	17%
Volusia	10	6%	15%
Osceola	9	5%	14%
	173	100%	

The profile of homeowners surveyed by zip code is shown in Table 3. Note that only those codes with more than 5 respondents are included.

Table 3. Respondent profile by zip code

Zip Code	Area	Surveyed
32828	Orlando (Avalon Park)	21
34787	Winter Garden	13
34711	Clermont	9
32826	Orlando (Research Park)	8
32712	Apopka	7
32746	Lake Mary	7
34786	Windermere	6
32825	Orlando	6
32940	Melbourne	5
32776	Sorrento	5
32771	Sanford	5

The profile of homeowners surveyed by the year their home was built is shown in Figure 4.

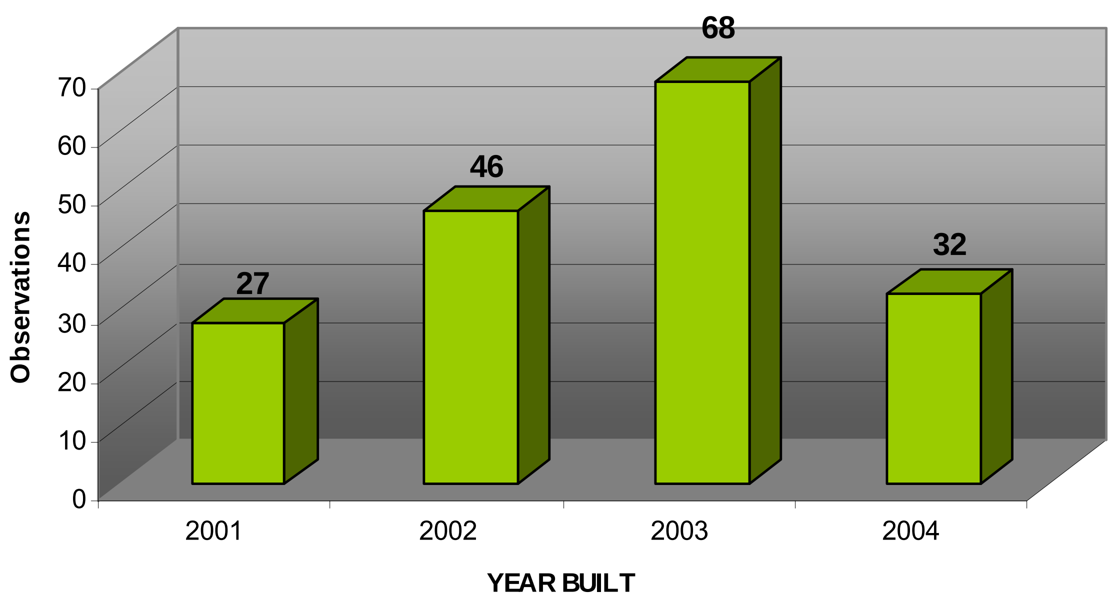

Figure 4 Respondent profile by year home was built

The profile of homeowners surveyed by their builder is shown in Figure 5. Note that the first six builders, those who had the most homes with reported water intrusion, had far more problems reported than their overall sales would suggest. Most of the remaining builders had less problems than their sales would suggest.

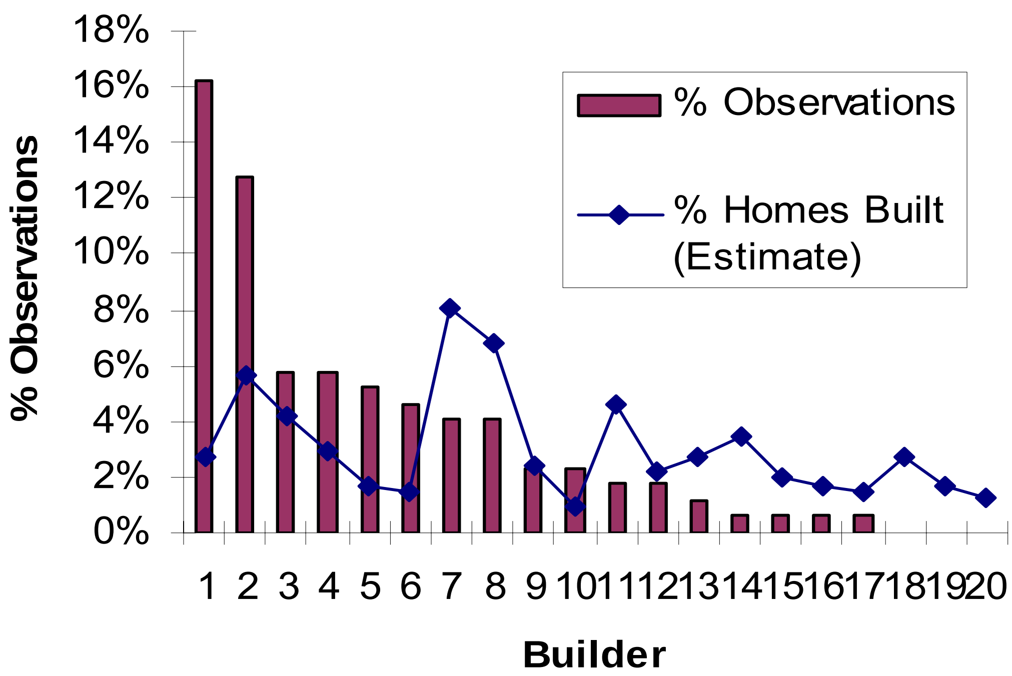

Figure 5 Respondent Profile by Builder

The profile of homeowners surveyed by primary wall finish is shown in Figure 6. Note that almost all exterior walls in the survey are stucco.

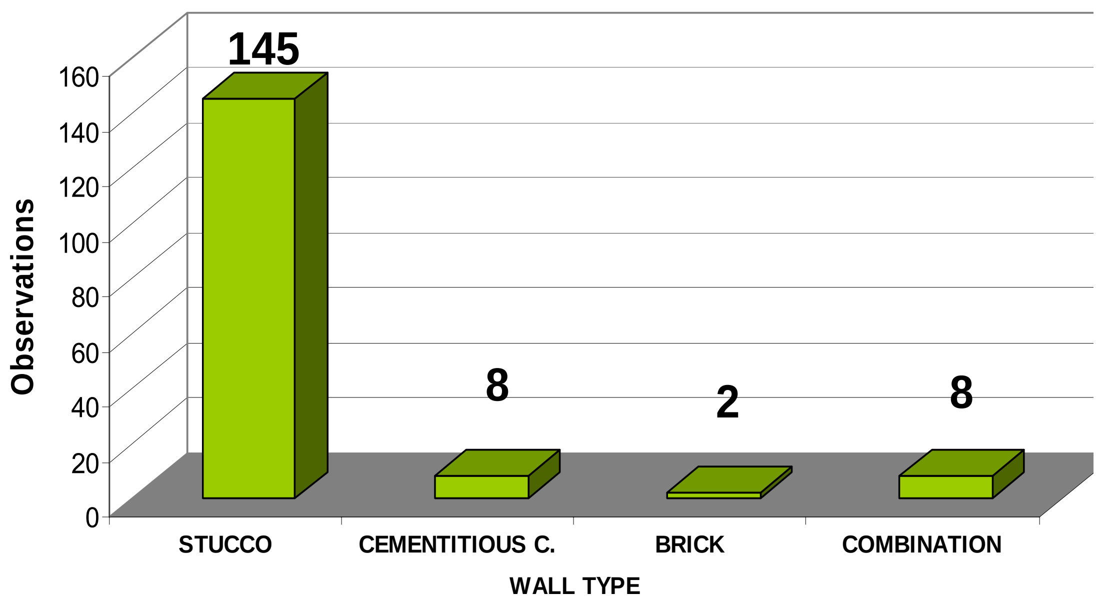

Figure 6 Respondent profile by primary wall finish

The profile of homeowners surveyed by home configuration (number of levels) is shown in Figure 7. An estimate of the comparable percentage of two story homes built is also provided for comparison. The results suggest that two story homes were more likely to have water intrusion than their sales levels suggest. This might suggest an issue with stucco-clad wood framing that is commonly used for the second floor. However, note that about one half of the respondents had single story homes. This suggests that stucco-clad block cannot be ignored.

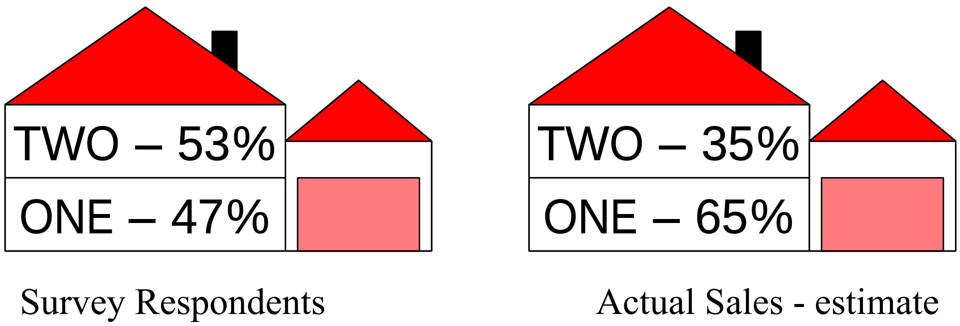

Figure 7 Respondent profile by number of levels

The profile of homeowners surveyed by the observed location of water intrusion is shown in Figure 8. Note that more than one location was reported in some homes. Most water was observed running out from under the baseboard and onto the floor. Some water was observed around the windows, on the walls and on the ceiling.

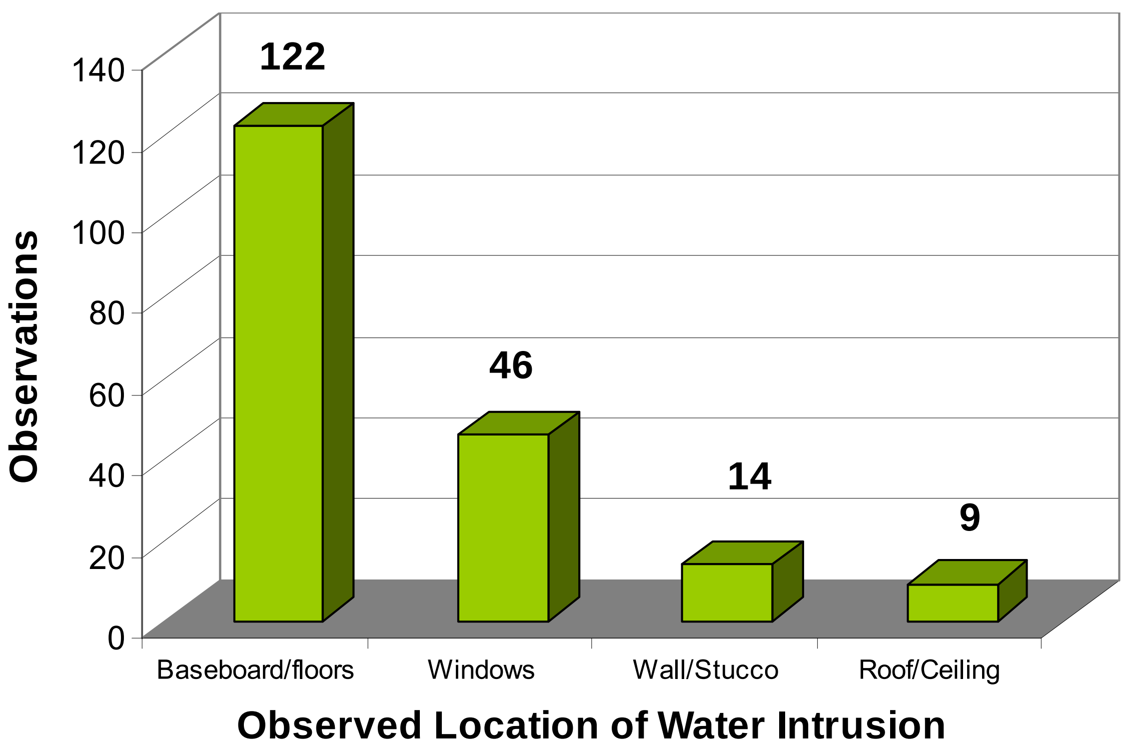

Figure 8 Respondent profile by observed location of water intrusion

The profile of homeowners surveyed by the observed direction of water intrusion is shown in Figure 9. Most water was observed on the East side of home with some intrusion on the North. As shown in Figure 3, this is consistent with the predominant winds during the period of the heaviest rain.

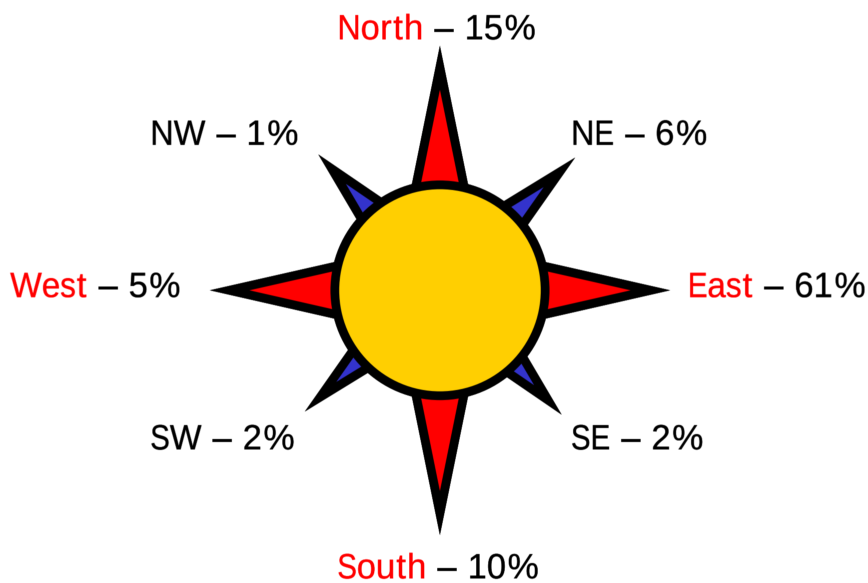

Figure 9 Respondent profile by observed direction of water intrusion

The profile of homeowners surveyed by their opinion of the reason for water intrusion is shown in Figure 10. Most homeowners did not know the cause of intrusion.

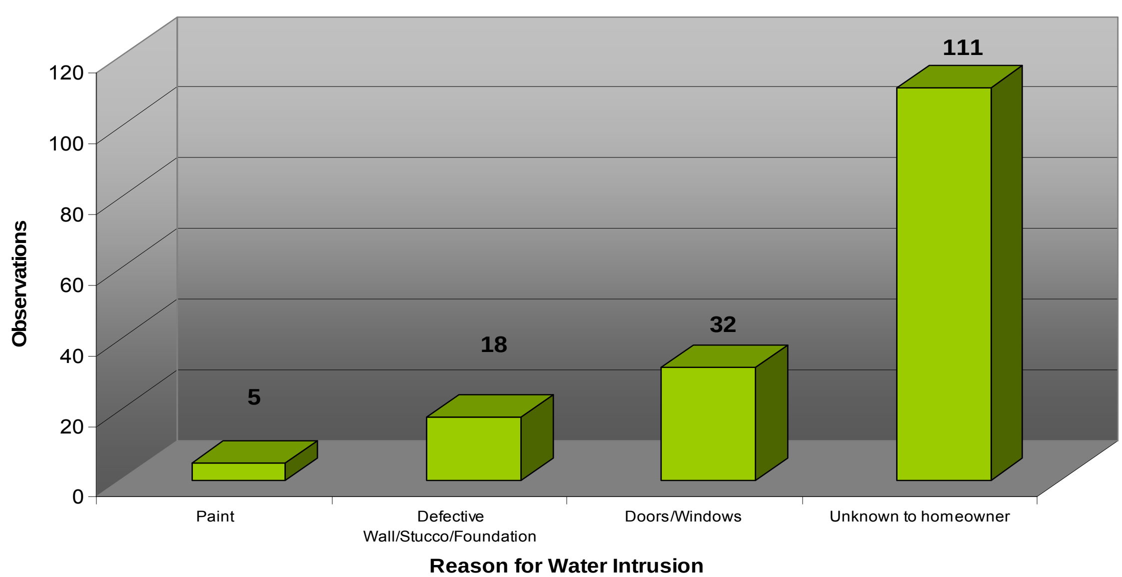

Figure 10 Respondent profile by opinion of reason for water intrusion

The profile of homeowners surveyed by the observed amount of water intrusion is shown in Figure 11. Most homeowners of both one and two story homes reported standing water.

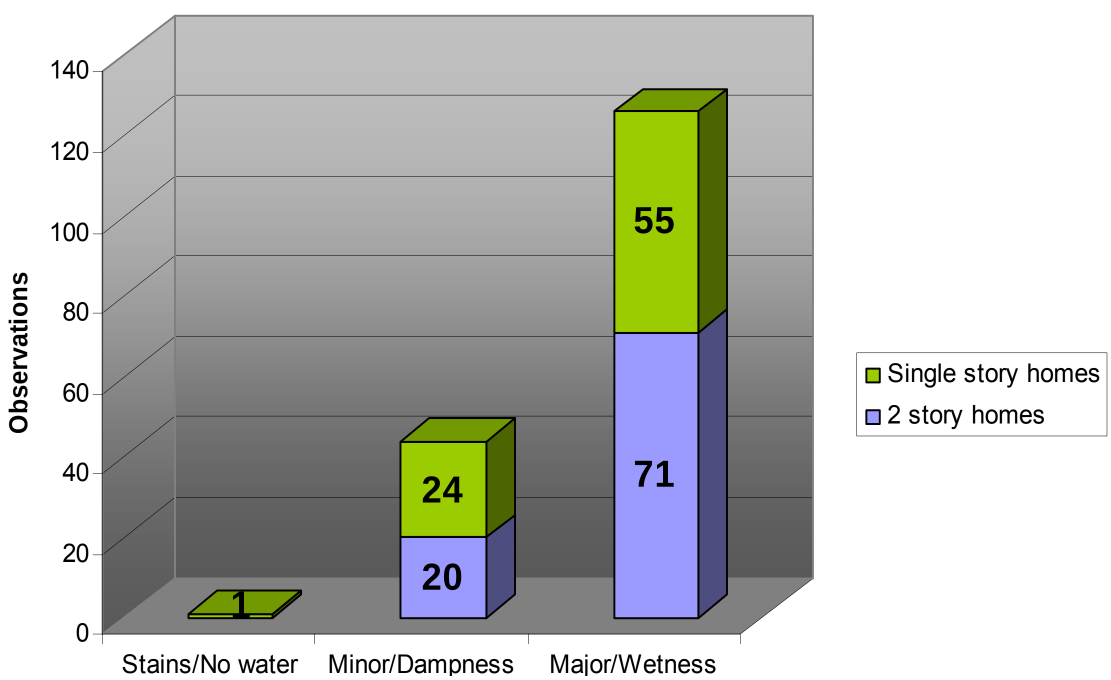

Figure 11 Respondent profile by observed amount of water intrusion

Broader Survey of New Homeowners

A second survey was conducted to estimate the overall extent of water intrusion during Hurricane Jeanne. 97 homes that were reported as entering the tax rolls in 2003 were randomly selected from property tax data bases obtained from six central Florida counties. The sample was stratified by county to assure proper representation from each county. The entire database included 32,985 homes, however, some counties included homes from earlier and later years. To obtain the needed sample size, researchers attempted to contact many additional homeowners; however, many could not be contacted or chose not to participate. The survey questions were similar to those used in the first survey and are shown in Appendix B. Survey results are summarized in Table 4. The results indicate that an average of 30% of new home buyers experienced some form of water intrusion during Hurricane Jeanne. Approximately 20% experienced water intrusion that involved walls. The sample size allows an overall accuracy of +/- 10% with 95% confidence. Thus, we are 95% confident that the true average of homes experiencing water intrusion involving walls during Hurricane Jeanne was between 10% and 30%. These numbers are substantial. Responses to specific questions yielded profiles similar to those of the first survey.

Table 4 Survey results of new homeowners

	# Surveys	# of Homes with Water Intrusion	% of Homes with Water Intrusion	# Homes with Water Intrusion Involving Walls	% Homes with Water Intrusion Involving Walls
Brevard	17	3	18%	2	12%
Orange	30	14	47%	9	30%
Lake	15	4	27%	2	13%
Seminole	8	0	0%	0	0%
Osceola	13	6	46%	6	46%
Volusia	14	2	14%	0	0%
Total	97	29	30%	19	20%

III. Field Testing: Phase I

The first Phase of field testing was performed to identify the key factors that were important in water intrusion involving walls. Walls were tested at three points in the construction process: bare block, stucco applied, and painted. The ASTM test standard C1601 ***Standard Test Method for Field Determination of Water Penetration of Masonry Wall Surfaces*** was used for testing. This test is described in the following section.

Test Equipment and Procedure

ASTM C1601 - 04 ***Standard Test Method for Field Determination of Water Penetration of Masonry Wall Surfaces*** (ASTM C1601 - 04 2004) is a pressurized water test that simulates wind driven rain. The test measures the rate of water flow out of a closed system under a given rate of air pressure and water flow that simulates wind speed and rainfall rate respectively.

A schematic of the test equipment is shown in Figure 12. The actual equipment that was fabricated and assembled to perform the test is shown in Figures 13 and 14. The test chamber and test platform work together to form the closed system that can set and maintain a given rate of air pressure and water flow inside the chamber when the chamber is installed on a wall.

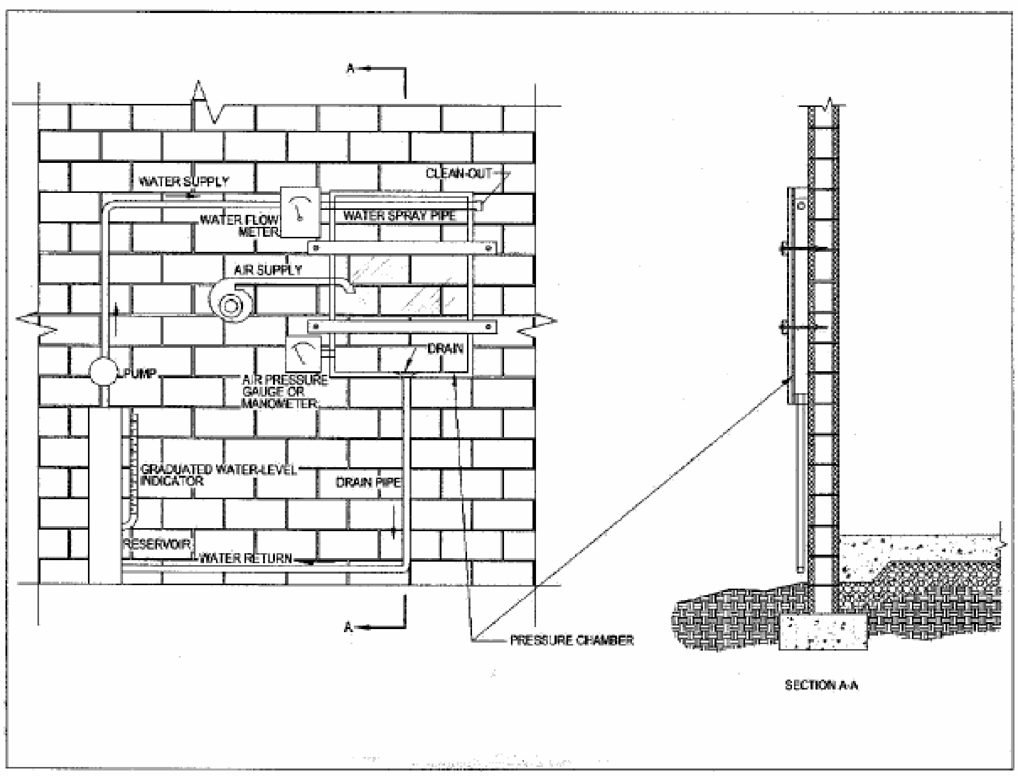

Figure 12 Schematic of test equipment and setup (ASTM 1601 - 04 2004)

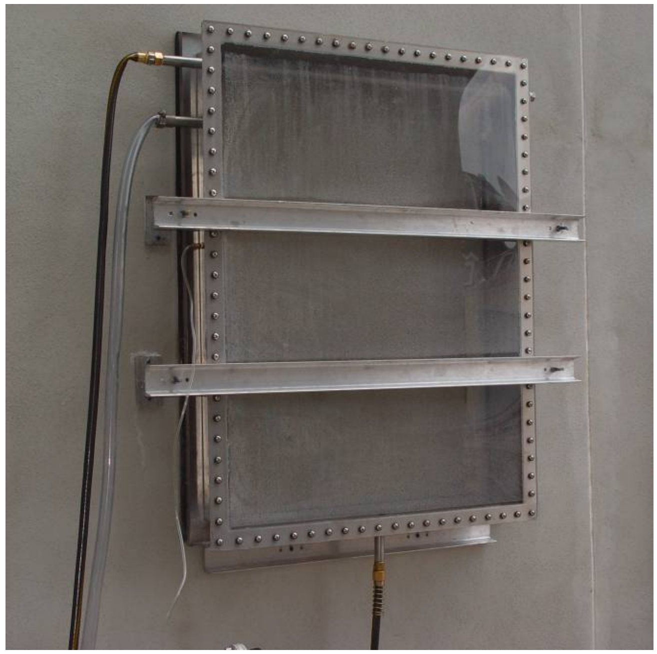

Figure 13 Test chamber installed on wall

Figure 14 Test platform with equipment

Figure 13 shows the test chamber installed on a wall. Fabricated from stainless steel sheet and plexiglass, the chamber is sealed so that it can maintain air pressure and control water for the duration of the test. The chamber has four lines - starting from the top: water infeed line (feeds a spray bar mounted on the top of the chamber), air infeed line (fed from an electric blower, the line creates air pressure inside the chamber), air pressure measurement line (connected to a manometer), and water drainage line from the bottom of the chamber. Figure 14 shows the test platform with equipment. The platform contains a water tank, two electric pumps (supply to the chamber and drainage from the chamber), an analog water flow gauge, manual valves (to control the flow of water to and from the chamber), and electrical outlets for the pumps and blower. Equipment not shown includes the electric blower used to create air pressure inside the chamber, a manometer used to measure air pressure inside the chamber, and a rheostat controller used to manually control blower speed and thus air pressure inside the chamber.

To setup the equipment for the test, the test chamber is installed on the wall with mechanical fasteners using sufficient pressure to form an air and water-resistant seal. The water lines connecting the chamber to the test platform are installed and the air supply and measurement lines connecting the chamber to the blower and manometer are installed. The water pumps are started and water flow rate is adjusted to provide 3.4 gal/sqft/hour (138 L/sqmeter/h). The chamber encloses a wall surface area of approximately 12 sqft. Simultaneously, the blower is started and adjusted to create an air pressure within the chamber of 10 lb/sqft (500 Pa). The standard test parameters are designed to simulate wind driven rain at a wind speed of 62.5 mph and rainfall amount at 5.5 inches per hour. Note that researchers have speculated that as long as a continuous sheet of water is maintained on the wall surface, the rainfall amount is not critical. If leakage is found around the perimeter of the chamber, the test is stopped, the chamber is resealed, and the procedure restarted. The standard intends that a sheet of water be developed and maintained on the wall surface during testing. If this does not occur, the test method will likely be inaccurate. This did not occur during our tests.

The test itself is divided into two phases, preconditioning and standard test conditions. During preconditioning, the water flow rate and air pressure is maintained for 30 minutes prior to starting the test. During the last five minutes of this period, the water flow rate and air pressure is again adjusted to the specified test parameters. Data is collected during standard test conditions for a four hour period. Water flow rate, air pressure within the chamber, and water level within the tank are recorded at five minute intervals. The amount and time at which water is added to the tank is also recorded along with the new water level with each addition. In addition, dampness and water movement both in front of and behind the test wall is noted and photographed.

Test Results
Walls were tested at three points in the construction process: bare block, stucco applied, and painted. Nine tests were performed for the first builder, three at each stage of the construction process. The results are shown in Table 5. Table 6 indicates how C1601 test results might be interpreted for masonry walls.

Table 5 Test results for the first builder

Wall Configuration	Average Water Intrusion (gal./Hr.)	Average for Wall Configuation
Concrete Block	6.60	
Concrete Block	12.00	
Concrete Block	40.80	19.8
Stucco	0.16	
Stucco	0.17	
Stucco	0.17	0.16
Wall Painted	0.01	
Wall Painted	0.08	
Wall Painted	0.03	0.04

Table 6 Interpreting C1601 test results for masonry walls (Monk, 1982)

Water Intrusion Rate Gal/hr	Rating
<0.375	Excellent
0.375-0.5	Average – Good
0.5 – 1.0	Questionable
>1.0	Poor

Results show that bare concrete block walls leak profusely and perform poorly in preventing water intrusion. The variation measured is likely the result of variable workmanship of the mortar joints in the area of the tests (see Figure 15). After applying stucco, all walls easily performed in the excellent category. This leakage rate compares favorably with the results from comparable testing reported (Vasudevan et al 2003). After applying paint, the leakage rate is further reduced, but not significantly. While paint can reduce water intrusion, it is clearly not the primary barrier - that is stucco coverage of the block.

A second set of field tests were performed for two additional builders to confirm these findings. Two homes were tested with stucco and no paint and two homes were tested with paint. The results are summarized in Table 7. The results confirm the earlier findings.

Table 7 Results from second set of field tests

Wall Configuration	Avg. Water Intrusion (gal/hr)	Avg. for Configuration
Stucco	0.25	
Stucco	0.12	0.18
Wall painted	0.03	
Wall painted	0.07	0.05

Figure 15 Varying workmanship of mortar joints

There are several advantages of testing homes while they are under construction. In addition to limiting potential damage, testing before the drywall is installed allows one to observe water intrusion through the wall from the inside. Of all the field tests performed on new construction, dampness and water were observed only in the three homes tested before stucco was installed (Figures 16 and 17).

Figure 16 Dampness on inside of wall during test

Figure 17 Standing water on floor during test

IV. Inspections

The next step in exploring the cause of water intrusion was a visual inspection of homes that had reported water intrusion during Hurricane Jeanne. 29 homeowners (from the WESH database) who participated in the survey allowed researchers to inspect their homes. Four additional homes that experienced water intrusion were referred to researchers and were included in the inspections. The inspections included a review of all construction details that could be observed without climbing onto the roof. This included: flashings, soffits, windows, wall penetrations (dryer vents, plumbing, electrical, rain gauge, etc.), expansion joints, lot drainage, general stucco condition (damage, telegraphing), and cracks.

Examples of various problems observed during the inspections are shown in Figures 18 through 38. The frequencies of these problems are shown in Figures 39 through 46. Note that no soffitt damage was observed. To explore the frequency of these problems in a broader context, results from a large scale 2003 home inspection effort were reviewed. In this research effort over 400 new (between one and two years old) homes in six central Florida counties underwent a thorough inspection. A profile of the top ten problems is shown in Figure 47. It should be noted that the top three problems observed – stairstep cracks (50% of homes), window corner cracks (47% of homes), and poor window caulk (38% of homes) - can contribute to water intrusion.

The inspection results suggest that water intrusion may be the result of a variety of causes. Given the prevalence of cracks in homes that leaked and the relatively high percentage of homes observed with cracks, the research team decided to focus on this factor.

Figure 18 Stucco cracking and damage around flashing

Figure 19 Cracks in window caulking

Figure 20 Water damage around and under window

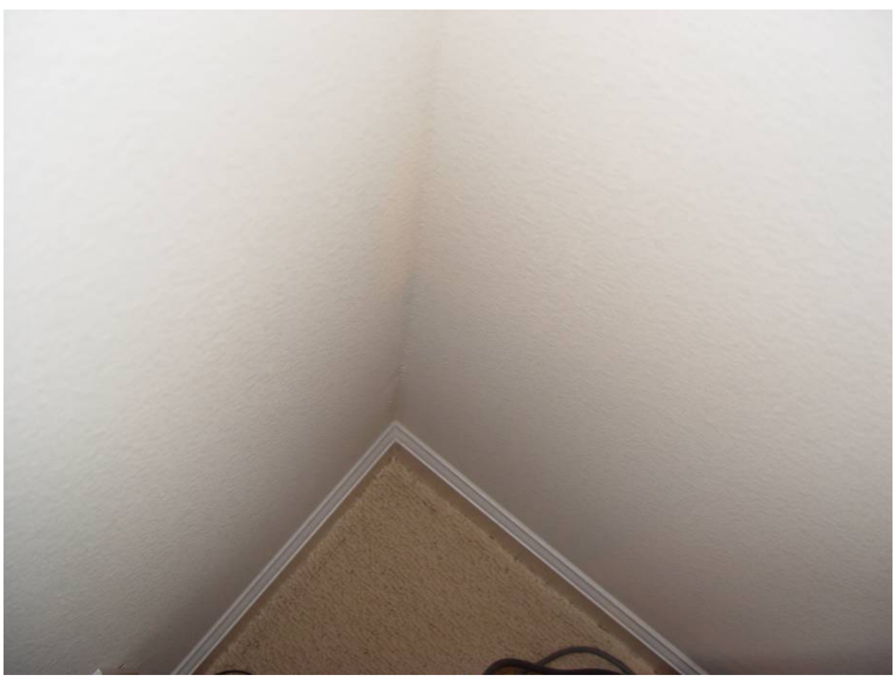

Figure 21 Water damage in corner

Figure 22 Unsealed penetration for electrical outlet

Figure 23 Unsealed penetration for wiring

Figure 24 Crack at 1st/2nd floor expansion joint from poor workmanship

Figure 25 Crack at 1st/2nd floor expansion joint

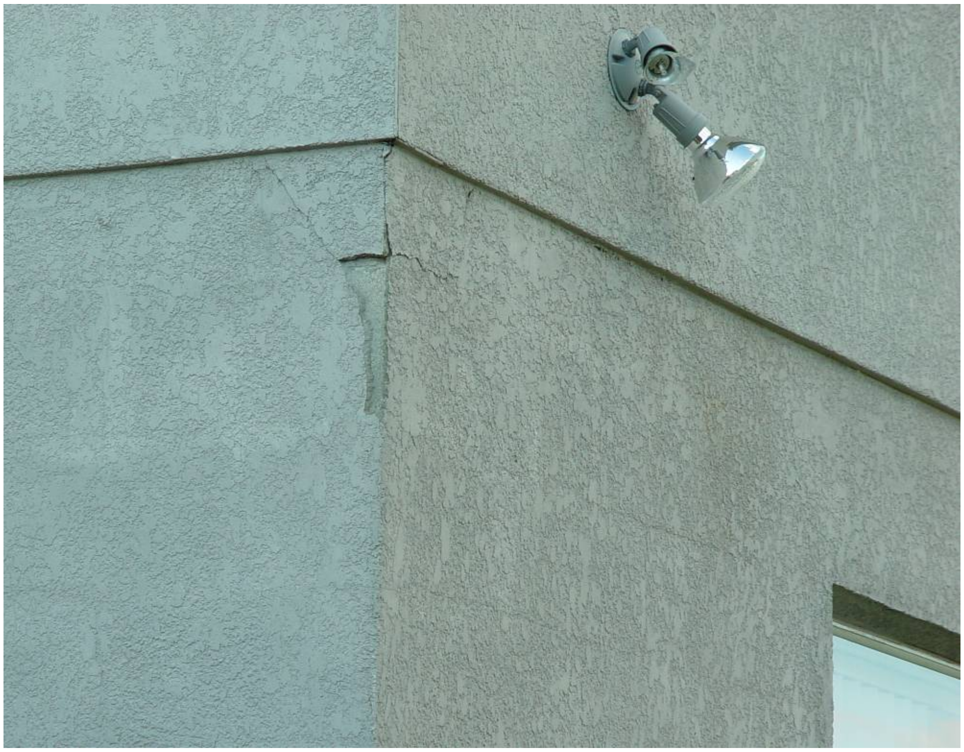

Figure 26 Stucco damage on corner

Figure 27 Stucco telegraphing

Figure 28 Reparied horizontal crack on 2nd floor frame wall

Figure 29 Patch of stairstep crack using elastomeric compound

Figure 30 Window corner crack

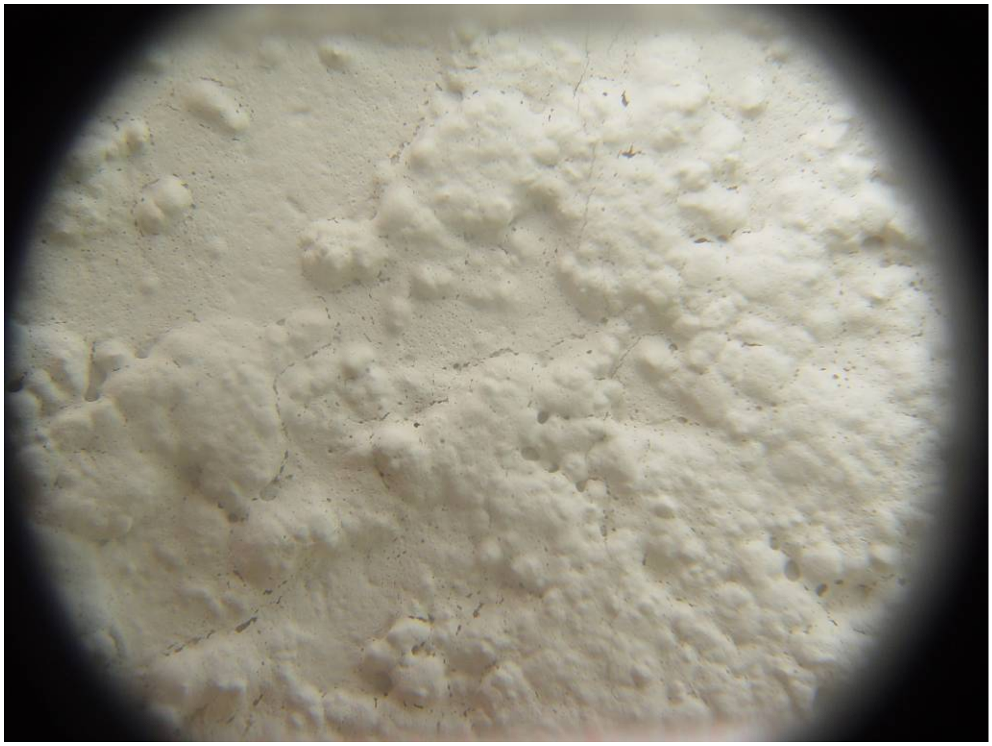

Figure 31 Tiny micro-cracks in stucco seen through 5X jeweler's loop

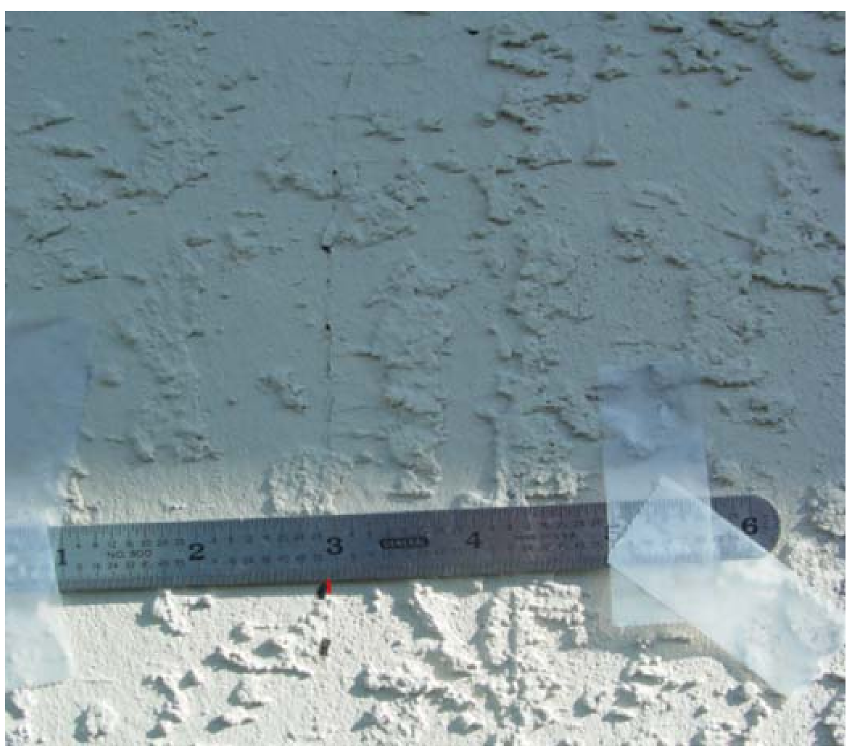

Figure 32 The smallest crack measured - 0.13mm wide

Figure 33 Typical crack less than 0.39 mm (1/64 inch) wide

Figure 34 Typical stairstep crack less than 0.39mm (1/64 inch) wide

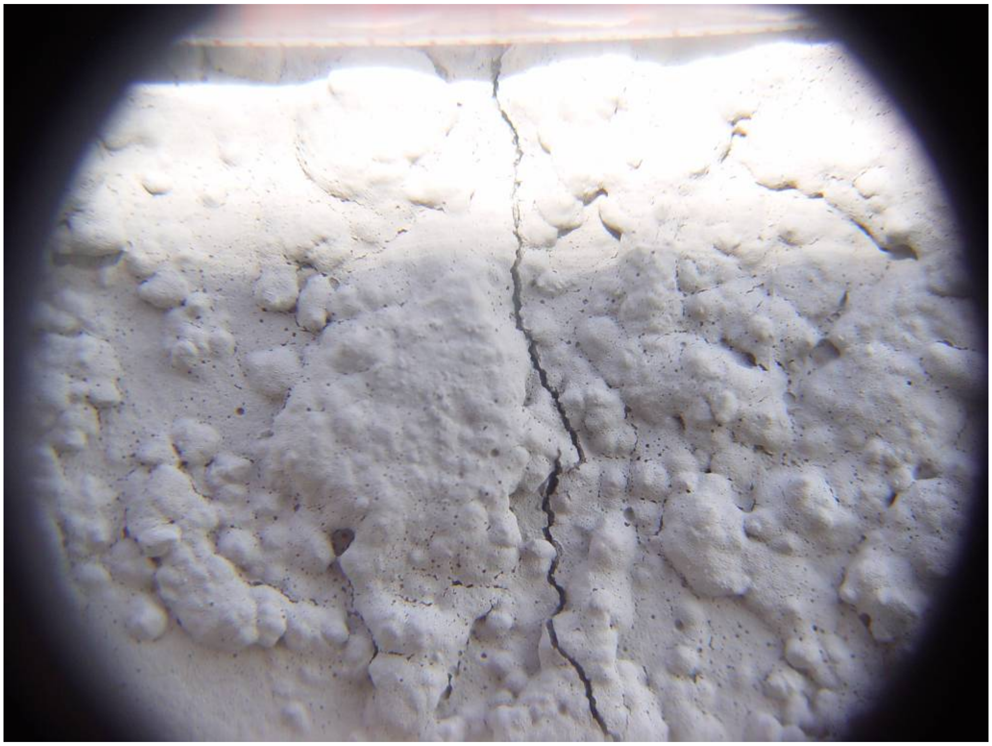

Figure 35 Typical crack between 0.39mm (1/64 inch) and 0.58mm (1/48 inch) wide

Figure 36 Typical stairstep crack between 0.39mm (1/64 inch) and 0.58mm (1/48 inch) wide

Figure 37 Typical crack between 0.58mm (1/48 inch) and 0.78 (1/32 inch) wide


Figure 38 Typical stairstep crack greater than 0.78 mm (1/32 inch) wide

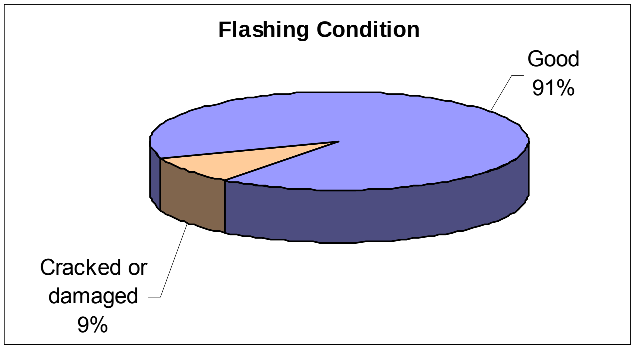

Figure 39 Condition of flashings in homes that leaked

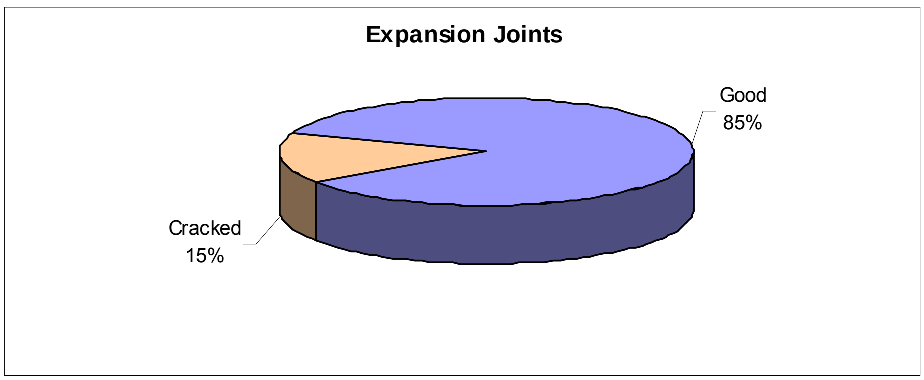

Figure 40 Condition of expansion joints in homes that leaked

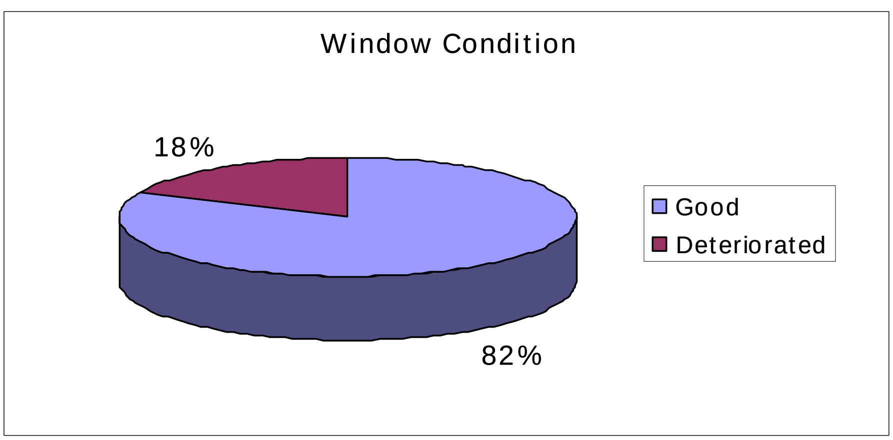

Figure 41 Condition of window sealing in homes that leaked

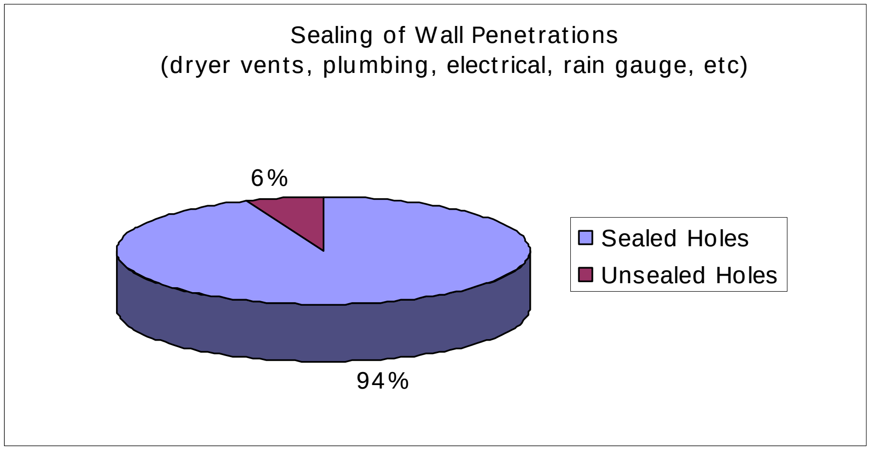

Figure 42 Condition of wall penetrations in homes that leaked

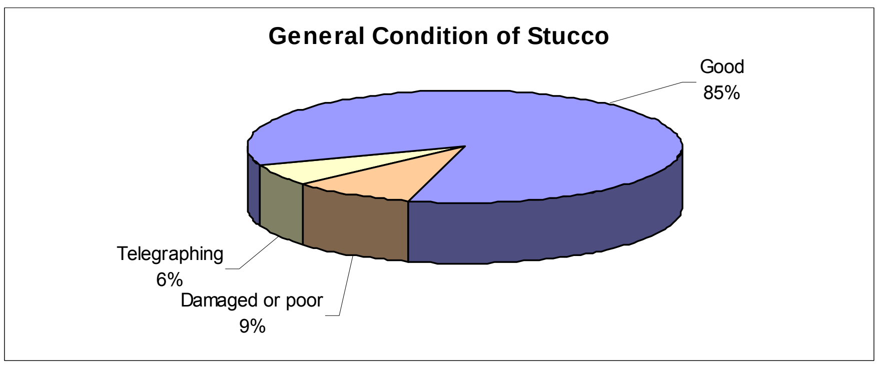

Figure 43 General condition of stucco in homes that leaked

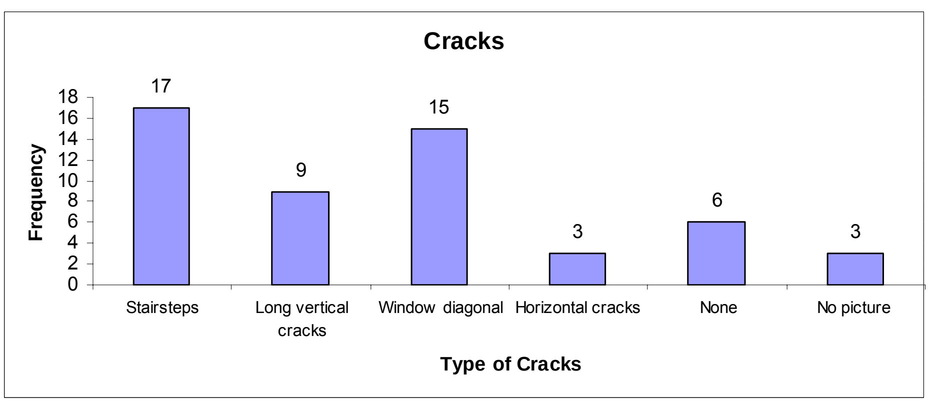

Figure 44 Cracks observed in homes that leaked

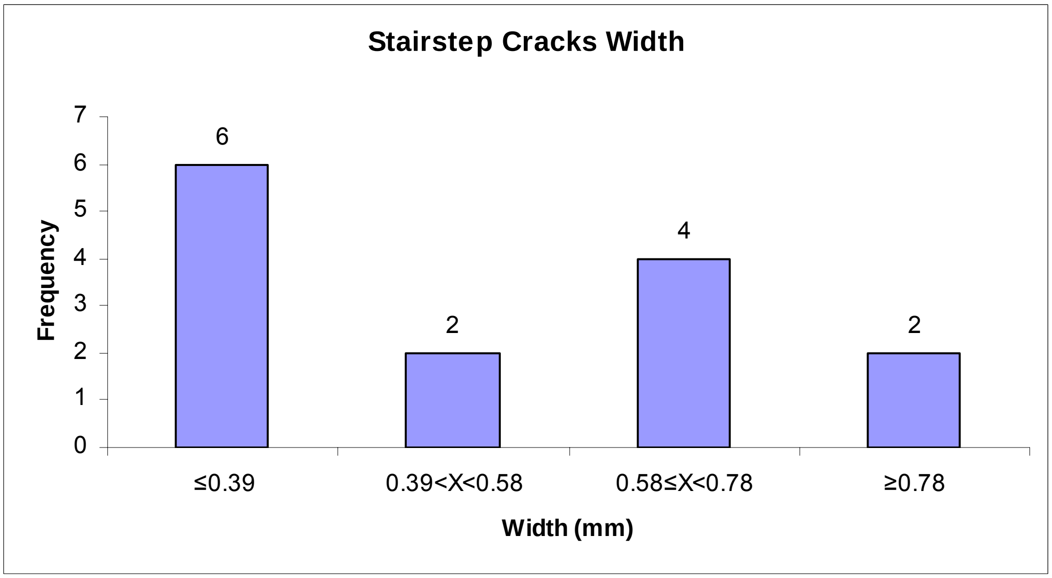

Figure 45 Typical stairstep crack width in homes that leaked

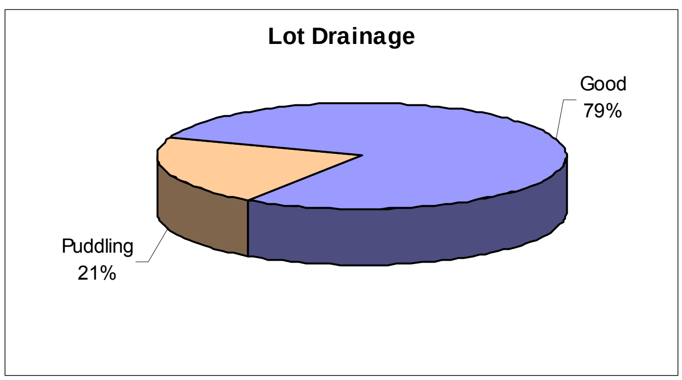

Figure 46 Condition of lot drainage in homes that leaked

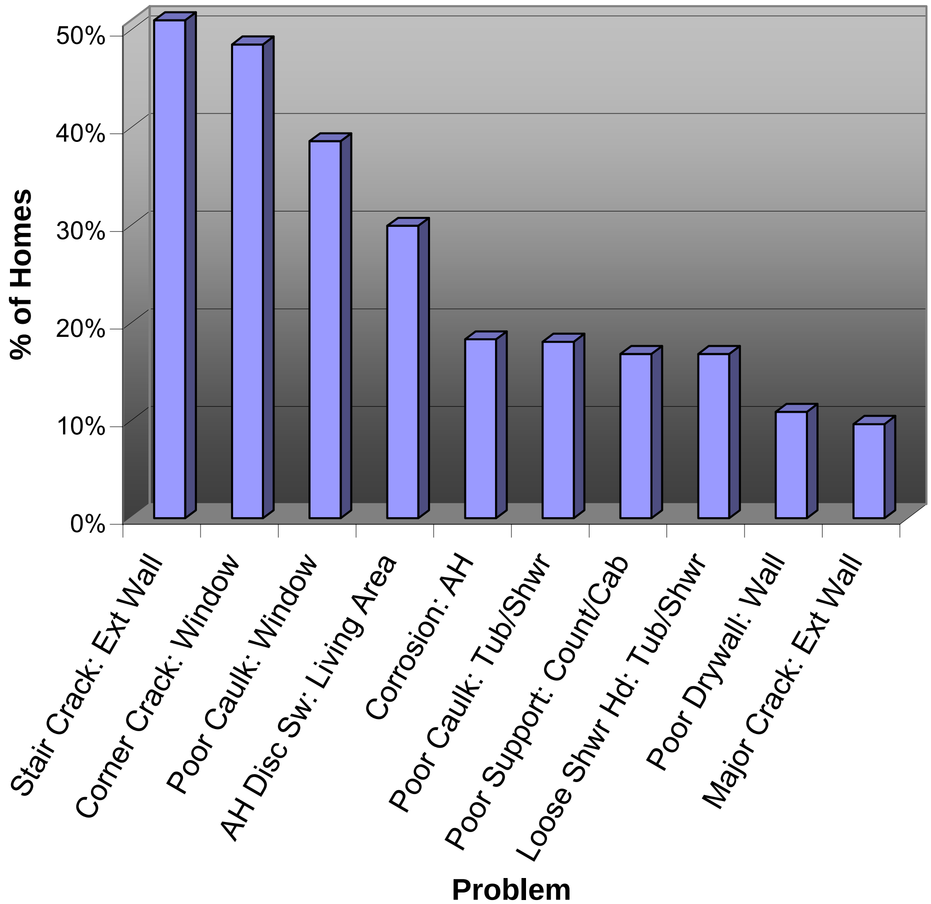

Figure 47 Top ten problems observed in new homes in central Florida (Mullens 2005)

V. Testing: Phase II

The second phase of testing sought to explore and measure water infiltration in selected homes that had been inspected. All of these homes experienced water intrusion during Hurricane Jeanne. Home tests were limited by a number of factors. The most limiting factor was the willingness of the homeowner to have their home tested, especially after the significant damage that was incurred during the hurricane. Most of this damage had subsequently been repaired. To limit possible water damage during testing, tests were limited to homes with garage walls that had no potentially damageable carpet, workbenches, home furnishing or other items stored in the test area. Note that since water can move horizontally within the wall, this does not guarantee that water will not flow beyond the garage into the living area. Five homes were selected for testing, based on features of interest observed during the inspections.

Home #1
Home #1 was tested because leakage was observed in the garage during the storm (Figure 48), but no likely reasons were observed during the inspection. There was some minor cracking along the underside of the expansion joint (Figure 49). Micro cracks such as those shown in Figure 31 were also observed, but were not believed to be the source of intrusion. C1601 test results showed no significant water loss through the masonry wall, .06 gallons per hour, and no observable water leakage on the inside of the wall. This was consistent with our previous findings that masonry walls without cracks did not leak. To further explore the cause of leakage, a spray rack was used to spray the horizontal expansion joint at the ceiling line of the garage and a penetration for the sprinkler system rain gauge located at the same level (Figure 50). The rack was then raised to spray the stucco-wood frame wall over the expansion joint. Each spray rack test was performed for 20-30 minutes and used a water flow rate that provided a thorough wetting of the wall. Spray rack testing revealed a stream of water exiting an electrical outlet on the inside of the garage directly beneath the penetration for the rain gauge (Figure 51). A closer inspection of the penetration indicated that it was not well sealed. No leakage was observed for the stucco-wood frame wall or the expansion joint. To verify the spray rack test results, a new home was also tested with the spray rack. The test covered an upper level stucco-wood frame wall, the horizontal expansion joint below this wall, and a window on the lower level wall beneath the expansion joint. The window was tested at three different levels: 6” above the sill, mid-window, and over the header. No leakage was observed.

Home #2
Home #2 was tested because it had the narrowest crack (about 0.13 mm wide and 37 inches long) observed in the garage area where it was testable (see Figure 52). C1601 test results showed no significant water loss through the masonry wall, .10 gallons per hour, and no observable water leakage on the inside of the wall.

Home #3
Home #3 was tested because it had a large stairstep crack (>0.78mm) in the garage area that had been patched by the owner (Figure 53). The test was performed over an 18 inch length of the crack. C1601 test results showed little water loss through the masonry wall, .33 gallons per hour, significantly higher than the other painted walls tested, but still in the excellent range. Two and one half hours into the test, dampness was observed on the inside of the wall and three and a

quarter hours into the test, water droplets started to form and run from the same level as the crack (Figure 54).

Home #4

Home #4 was tested because it had a stairstep crack less than 0.39 mm wide in the garage area (Figure 55). The test was performed over a 54 inch long segment of the crack. C1601 test results showed water loss of .65 gallons per hour, in the questionable range. Dampness was first observed on the inside of the garage wall near the end of the preconditioning phase of the test (30 minutes after start). After one hour into the formal test, dampness was observed on the inside of the wall (Figure 56). After one hour and forty minutes into the formal test, water droplets started to run down the bottom of the wall to the floor (Figure 57).

Home #5

Home #5 provided several valuable features for testing. First, the mortar joints could easily be seen telegraphing through the stucco. Second, there were multiple stairstep cracks less than 0.39mm wide in a testable area of the garage wall. Finally, the opposite garage wall was equally telegraphed, but did not contain any cracks. Two tests were performed, one on each wall. C1601 test results for the wall with no cracks showed no significant water loss, .15 gallons per hour, and no observable water leakage on the inside of the wall. The test of the wall with cracks was performed over two lengthy stairstep cracks, one 64 inches long and the other 48 inches long (Figure 58). C1601 test results showed heavy water loss, 2.5 gallons per hour. The first signs of dampness on the inside of the garage wall were observed at 15 minutes into the formal test. By 60 minutes into the test water was accumulating on the floor.

Summary

Test results clearly showed the role of cracks in facilitating water intrusion. Cracks did not need to be wide to allow water intrusion. The widest cracks that were found in a testable garage area were less than 0.39mm (1/64 inch) wide. Yet, these cracks allowed water to penetrate the wall. It is likely that the larger cracks observed in other, non-testable walls (see Figure 45) would contribute to even greater water intrusion.

Figure 48 Discoloration in garage from water intrusion during storm

Figure 49 Minor cracking under expansion joint

Figure 50 Spray rack mounted above test chamber – note rain gauge to right of spray rack

Figure 51 Note leak out of electrical outlet (directly under rain gauge penetration)

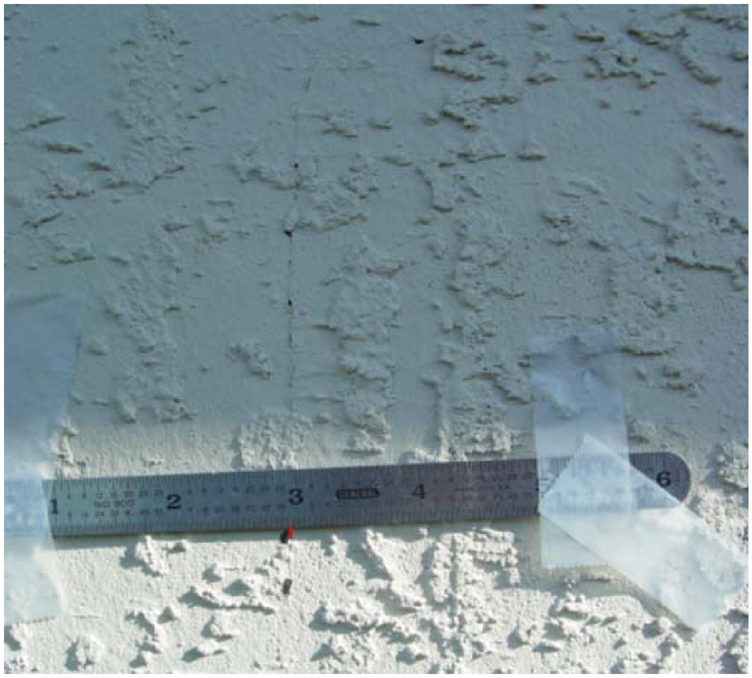

Figure 52 Home #2 with smallest crack measured (0.13mm wide) – testing revealed no intrusion

Figure 53 Home #3 test wall with stairstep crack that had been repaired

Figure 54 Home #3 showing through-wall stairstep crack (not repaired on inside) and small water leakage out of crack (see arrow)

Figure 55 Home #4 showing stairstep crack

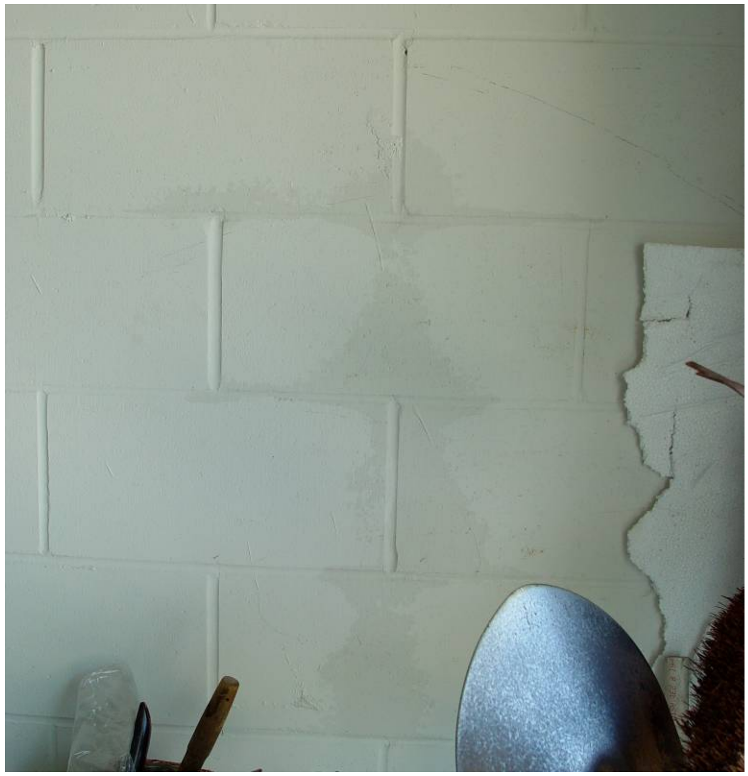

Figure 56 Home #4 showing through-wall stairstep crack and growing dampness

Figure 57 Home #4 growing dampness and drips forming near floor

Figure 58 Home #5 showing stairstep cracks

VI. Construction Process Review

To explore possible causes of cracks in masonry walls, researchers observed homes in progressive stages of completion, starting with footings and ending with stucco application.

Footing Observations
Footings from two builders were observed at two levels of completion: after rebar was installed in the trench and after concrete was poured. The research team was joined by an expert in concrete construction to assist with the observations. After observing a number of footing trenches with rebar installed (Figure 59) and discussing the issue with the builders' construction managers, researchers could find no definitive causes of cracks related to the footings. Simple push rod insertion into the base of the trenches suggested solid, uniform compaction. Occasionally, the soil was less compact under footing penetrations for freshwater and drainage lines (Figure 60). The construction managers indicated that when an area was in doubt (such as built on fill), more sophisticated compaction tests were performed to certify that requirements were met. Observations also revealed that the required rebar was installed.

After concrete was poured, researchers found no evidence of cracks in the footings. One possible contributor to future cracking was observed – when vertical rebar was placed in the footing as a tie to rebar in the walls, the concrete pour was sometimes incomplete around the rebar (Figure 61).

Wall Observations
Bare concrete block walls from three builders were observed at two levels of completion: immediately after laying the block and after grouting the cells/installing the roof. Observations during and immediately after laying the block found no stairstep cracks or lengthy straight cracks. Most walls did exhibit numerous shorter cracks and voids in the mortar joints (Figure 62). Some walls had few cracks and voids while others had a crack or void that touched almost every block.

After grouting the cells and installing the roof, observations revealed numerous instances of stairstep cracks, visible from both inside (Figure 63)and outside the walls (Figure 64). The formation of the stairstep cracks during this time suggests several potential causes of stress: grouting the cells, installing the roof, ground settlement, or drying. It is interesting to note several related findings:

- Some stairstep cracks span the vertical grouted cells (Figure 64).
- Some mortar joints that exhibited cracks could be scraped out using a piece of wood.
- There were no discernable cracks in the footings related to the stairstep cracks observed in the walls.
- Cracks were observed in slabs (Figure 65), but they did not appear to be correlated to cracks in footings (none were observed) or to observed stairstep cracks in walls.

Stucco Observations
Four stucco sub-contractors were interviewed and their application processes observed. Observations revealed very few cracks immediately after stucco was applied. It is useful to compare actual stucco application processes to industry standards as described in ASTM C 926 –

98a Standard Specification for Application of Portland Cement-Based Plaster (ASTM C 926 – 98a 2005), the Portland Cement Plaster/Stucco Manual (Melander et al 2003), and a follow up conversation with staff from the Portland Cement Association (Farny 2006). Standards call for a two or three coat stucco process for masonry walls. The minimum two coat process starts with a 3/8 inch first (scratch & brown) coat followed by a 1/8 inch second (finish) coat. The first coat process includes densification with a hard float. This densification is critical, since the consolidation that occurs influences the shrinkage-cracking and water penetration characteristics of the plaster. The first coat does not require scoring. The first coat should be allowed to fully cure before applying the second coat (some experts have suggested seven days). This allows the first coat to provide the best possible substrate for the second coat, and allows the first coat to crack (if it is going to crack) before the second coat is applied. The second coat should cure for 28 days before painting.

Contractor processes varied greatly. Two contractors applied two full, covering coats of stucco with a total depth of at least ½ inch. The remaining two contractors applied only one full, covering coat of stucco. A final partial, texturing coat was applied soon after the first. Total stucco depth was approximately ½ inch for one contractor and 3/8 inch for the other. These contractors indicated that it was common to use less than ½ inch of stucco in a single coat application, since builders wanted to control costs and cycle times and since this cementitious coating did not require inspection.

One of the two-coat contractors applied a 1/8 inch first coat without densification, scored the surface, and allowed it to cure overnight before application of the 3/8 inch second coat. The second coat was densified with a hard float immediately before a soft float was used to give the desired surface finish. The second two-coat contractor allowed the surface to dry several hours before applying the final coat on the same day. One one-coat contractor densified with a hard float immediately before a soft float was used to give the desired surface finish.

Three contractors used polyester fiber in their stucco mix. Two of these contractors expressed confidence that fibers actually reduced cracking. The third contractor suggested that it was simply a marketing device.

All four contractors reported that their builders used pH testing to determine when the completed stucco could be painted. Most builders waited between 7-10 days before beginning testing. No builders reported waiting a full 28 days before painting as recommended by the Portland Cement Association (Melander et al 2003).

Figure 59 Layout of steel rebar in foundation trench

Figure 60 Foundation penetrations for freshwater and drain lines

Figure 61 Incomplete concrete pour around vertical steel in foundation

Figure 62 Typical cracks and voids observed in mortar joints in masonry walls

Figure 63 Extended stairstep crack on inside wall after grouting cells and installing roof

Figure 64 Extended stairstep crack (arrow) on outside wall after grouting cells and installing roof (note that crack extends through vertical grouted cell)

Figure 65 Typical crack in floor slab

VII. Analysis of Findings

Survey results indicate that 20% of all new homes built in central Florida in 2003 experienced water intrusion related to walls during Hurricane Jeanne. A survey of homeowners that reported water intrusion revealed that:

- Although many builders experienced the problem, some builders were affected far more than their market share would suggest.
- Single and two story homes were equally affected.
- The vast majority of intrusion occurred on eastern walls, with some occurring on northeast and northern walls.

A follow-up inspection of these homes found a variety of possible causes including: poorly sealed windows, unsealed wall penetrations (dryer vents, plumbing, electrical, rain gauge, etc.), poorly sealed expansion joints, and numerous cracks of varying shapes and sizes. Findings from an earlier inspection study confirmed the prevalence of these issues throughout the central Florida new home market.

On-site testing was used to assess the relative importance of these factors. Testing of new homes (both under construction and occupied) revealed that stucco clad masonry walls without cracks did not leak, even without paint. Tests of homes that had leaked during Hurricane Jeanne demonstrated that cracks can facilitate water intrusion. Cracks did not need to be wide - cracks less than 0.39mm (1/64 inch) wide allowed water to penetrate the wall, run down and accumulate on the floor in one to two hours of simulated wind driven rain conditions. It is important to note that 57% of the cracks observed were wider than this, but could not be tested because they were not in a testable area of the house. It is also important to note that Hurricane Jeanne brought sustained winds of over 40 miles per hour with rain for a period of over 8 hours. Finally, test results demonstrated that very small cracks – for example, the smallest crack tested, 0.13mm wide - allowed no significant water intrusion.

These findings are consistent with the literature. Lstiburek (2005) reported that stucco without cracks does not leak – paint or no paint; however, the presence of cracks caused all mass wall assemblies to pass water. Grimm (1980) states that water penetration occurs through cracks in masonry wider than 0.1 mm. Rain penetration is caused by capillary suction of the masonry units and mortar and by the pressure of wind driven rain, which forces water into pores and cracks in the face of mortar and of masonry units, but more importantly, into cracks between mortar and masonry units and between masonry and other building elements. Straube (2006) contributes that smaller cracks in masonry/stucco wick water by capillarity - suction pressure inward rises inversely with crack width. As cracks grow beyond 0.3mm, capillarity matters less and less and is not important in cracks greater than 0.5mm. Wind pressure becomes important in cracks above 0.3mm. Flow rates through a crack vary with the crack width squared. Therefore, larger cracks permit significantly greater flow in wind driven rain conditions.

Given the prevalence of stairstep cracks in new central Florida homes and their propensity to allow water intrusion, the remaining analysis and recommendations focus on the cause, prevention and mitigation of water intrusion through stairstep cracks.

The causes of the stairstep cracks observed are not obvious. No significant stairstep cracks were observed immediately after laying the block. However, after the cells were grouted and the roof was installed, numerous stairstep cracks were visible. Cells are typically grouted one to two days after laying the block and the roof is installed soon after that. The formation of stairstep cracks during this time suggests several potential causes of stress: shrinkage, settlement, grouting the cells, or installing the roof. Related findings include:

- Some stairstep cracks span the vertical columns formed by the grouted cells.
- Some mortar joints that exhibited cracks could be scraped out using a piece of wood.
- There were no discernable cracks in the footings related to the stairstep cracks observed in the walls. Furthermore, no problems with soil compaction were found and the required rebar was installed in the footings.
- Cracks were observed in slabs, but they did not appear to be correlated to cracks in footings (none were observed) or to observed stairstep cracks in walls.

No significant stairstep cracks were observed immediately after stucco was applied. However, within one year after the homes were completed, 50% exhibited significant stairstep cracking.

The literature provides some background in this area. Cracking in stucco usually takes one of several forms (Melander et al 2003):

- Shrinkage cracks - develop as excess water evaporates from the drying stucco mix. Shrinkage cracks in base coat stucco occur very early on and cannot be seen after the finish color coat is applied. Shrinkage cracks in the finish color coat take the form of hairline cracks (straight line or random) or craze cracks (random, egg shell). Shrinkage cracking is the result of a rapid dry out and most commonly occurs on hot, windy days.
- Structural cracks - occur in stucco when stress is transferred to the plaster from the base structure (concrete masonry units). This stress can originate in ground movement, foundation creep/sag, or movement limited to the base structure itself. Normally, structural cracking in stucco will not occur when stucco is applied over an uncracked concrete or masonry base.

The stairstep cracks observed do not match the profile of stucco shrinkage cracks. Therefore, structural causes in the base structure (concrete masonry units) must be examined. The most common causes of cracking in concrete masonry include: shrinkage, differential movement, deflection, structural overload and differential settlement (TEK 10-1A 2001). The most likely cause of stairstep cracking cited is differential settlement (TEK 10-1A 2001, Lstiburek 2005, Straub 2006). However, the absence of discernible cracks in the footings casts some doubt on this explanation as the sole cause of stairstep cracks - the footing would have had to deflect enough to cause the stairstep cracking in the masonry wall, without itself cracking. While one expert (Lyttle 2006) indicated that some subtle settling might occur without cracking the footings, all indicated that this was not likely (Graber 2006, Lyttle 2006). Therefore, either the footings were settling and cracking without being observable or there were other causes of stairstep cracks.

Experts also indicate that stairstep cracks can be caused by shrinkage (Forcon International Corp. 1992, Graber 2006, Gulde 2006, Lyttle 2006). Although mortar, grout and concrete masonry units (CMU) are all concrete products, the CMU has been shown to be the primary indicator of overall wall shrinkage, principally because it represents the largest portion of the wall (TEK 10-

1A 2001). A common cause of shrinkage cracks in masonry walls is using ‘wet’ or uncured CMUs (Forcon International Corp. 1992, TEK 10-1A 2001, Gulde 2006). When uncured CMUs are used to construct a masonry wall, they continue to cure and experience a significant amount of shrinkage (Forcon International Corp. 1992). Typical shrinkage in a 50 foot masonry wall range from 3.1 to 6.9 mm. In a masonry wall, shrinkage cracks usually find a weakened point in the wall such as a location of several penetrations for piping or conduit. From this point, they run vertically most often in a stair-stepping fashion following the mortar joints. If there is an exceptionally good bond between the mortar joints and masonry units, the shrinkage crack may extend through the masonry units themselves thereby making a vertical crack. Mortar composition can also contribute to shrinkage cracks: excess cement (TEK 10-1A 2001) and excess sand (Lyttle 2006).

VIII. Recommendations for Homebuilders

This section presents recommendations to homebuilders to reduce the incidence and magnitude of water intrusion during hurricanes. Given the prevalence of stairstep cracks in new central Florida homes and their propensity to allow water intrusion, the recommendations focus on the reduction of water intrusion through stairstep cracks. Several recommendations are also provided for homeowners. Recommendations are provided at two levels. Level I recommendations should be implemented immediately. They are believed to be low cost and high impact. Level II recommendations involve substantive changes to the construction process and should be carefully evaluated by each builder, possibly involving longer term testing.

Level I Recommendations

Level I recommendations should be implemented immediately. These recommendations are believed to be of low cost to the builder and high impact in terms of reducing the potential for water intrusion. Some of these recommendations merely restate existing code requirements and builders are encouraged to ensure that their subcontractors comply. Other recommendations have been suggested by others and have been successfully adopted by some builders. If adopted as a package, they should greatly reduce the potential for water intrusion through masonry walls.

Foundations: Ensure that site work for foundations meet code requirements as well as recommendations from the National Concrete Masonry Association (TEK 10-1A 2001).

> *"Footings should be placed on undisturbed native soil, unless this soil is unsuitable , weak, or soft. Unsuitable soil should be removed and replaced with compacted soil, gravel, or concrete. Similarly, tree roots and construction debris should be removed prior to placing footings."*

Step Down Ledge: Provide a step down ledge or seat for the concrete block approximately one inch below the slab to provide holding capacity for water that penetrates the exterior surface of the wall (Lstiburek 2005).

Concrete Block: Age concrete block 21 days before use to permit early shrinkage before walls are constructed (TEK 19-2A 2004). Note that block will continue to shrink, but not as much – for example, 30% of block shrinkage will still occur after 9 months (Gulde 2006). Ensure that mortar ingredients are mixed in proper proportions.

Stucco: Ensure that stucco is installed to ASTM standard C926 for 2 coat stucco. The minimum two coat process starts with a 3/8 inch first (scratch & brown) coat followed by a 1/8 inch second (finish) coat. The first coat process includes densification with a hard float. This densification is critical, since the consolidation that occurs influences the shrinkage-cracking and water penetration characteristics of the plaster. The first coat does not require scoring. The first coat should be allowed to fully cure before applying the second coat (some experts have suggested seven days). This allows the first coat to provide the best possible substrate for the second coat, and allows the first coat to crack (if it is going to crack) before the second coat is applied. The second coat should cure for 28 days before painting. The stucco mix should be reinforced with suitable fibers to increase cohesiveness, tensile strength, impact resistance and to reduce shrinkage; ultimately reducing cracking (Melander 2003).

To reduce the risk of construction stress-induced cracking, roof tiles should be loaded five days prior to lathing installations and interior furring strips and drywall should be nailed prior to stucco installation.

Paint: Use a premium, high build, acrylic coating with the following characteristics:
- Meets Federal Specifications for resistance to wind driven rain (TT-C-555B).
- Allows water vapor transmission (high perm rating) permitting water to evaporate from the wall to the exterior.
- High flexibility/elongation to cover existing and new cracks.

Service: Near the end of the warranty period, repair all visible cracks and apply a second coat of paint. Cracks should be repaired with an elastomeric waterproof sealant patching compound. The method will depend on crack width and the sealant product, but might typically include:
- Less than 0.4 mm (1/64 inch) – apply a brush grade compound with a small brush.
- Between 0.4 mm (1/64 inch) and 0.8 mm (1/32 inch) – apply a knife grade compound.
- Between 0.8 mm (1/32 inch) and 6.4 mm (1/4 inch) – route out crack ¼ inch wide by ¼ inch deep; apply two coats of knife grade compound.

Note that commercially available caulking compounds are not suitable materials for patching hairline cracks. Because their consistency and texture is unlike that of stucco, they tend to weather differently, and attract more dirt; as a result, repairs made with caulking compounds may be highly visible, and unsightly (National Association of Certified Home Inspectors 2006). http://www.nachi.org/stucco.htm

Encourage the homeowner to observe the repair process. Reassure them that most shrinkage cracking occurs over the first few weeks and most settlement cracking happens over the first year. Remind them that cracks are continuously moving with temperature changes, moisture content and shrinkage. Remind them that they must provide regular maintenance - identifying and repairing cracks - if they wish to minimize the risk of water intrusion into their home. Provide instructions for future maintenance of cracks.

Finally, a disclaimer from the Stucco Manufacturers Association (2005) should be noted:

> *"Cracks that appear within the first 30 days after installation and are larger than 1/16" (the thickness of a penny) can be filled or repaired with the same color coat material. Cracks that are patched and re-appear could indicate a structural or substrate movement problem, necessitating the use of an elastomeric coating. If a crack is visible from more than 10' away or is a source of leaking, it should be patched. Patching small hairline cracks (smaller than 1/16") is not recommended. Small cracks will not accept material, and the resulting patch will detract from the natural beauty of the stucco and will serve no useful purpose. If these hairline cracks must be repaired, they could be fog coated."*

Level II Recommendations

Level II recommendations involve substantive changes to the construction process and should be carefully evaluated by each builder for impacts on market acceptance, cost, building system, and the construction process. The evaluation may also involve longer term testing of viable concepts.

Foundations: Adding reinforcement to footings can lessen the effects of differential settlement on footings and thus reduce the incidence and severity of wall cracks (TEK 10-1A 2001).

Wall/Floor Joint Details: Investigate and consider alternatives for floor/wall joint details that promote water entry into home. For example, for architectural designs with block kneewalls and raised floor slabs, pouring the floor slab directly inside the wall into “h” blocks virtually guarantees that water entering the wall will flow down the wall, onto the floor slab and inside the home.

Crack Control Strategies for Walls: Crack control strategies seek to address the combined effects of movement due to drying shrinkage, carbonation shrinkage and contraction due to temperature change (TEK 10-1A 2001). Strategies use two related techniques: control joints and reinforcement to limit crack width. Control joints are vertical separations built into the wall to reduce restraint and permit longitudinal movement. Empirical rules have been developed to guide the location of control joints in masonry structures (TEK 10-2B). Normally, however, single family homes are not large enough to warrant the use of control joints (Graber 2006) and for low-rise buildings in most regions of the United States there are no provisions in the model building codes prescribing the use of steel reinforcement or control joints (NAHB Research Center 1998). If walls are longer than 40 feet, control joints should be considered no further than 25 feet on center (Graber 2006). Where lateral or out-of-plane shear loads need to be transferred across the control joint, a shear key spanning the control joint and composed of smooth dowel bars mounted in plastic sleeves will allow the walls to move longitudinally.

The standard horizontal joint reinforcement is 9-gauge wire in either a “ladder” or “truss” configuration, available in standard lengths of 10 and 12 feet (NAHB Research Center 1998). Bond beams which serve both as structural elements and as a means of crack control are a horizontal course or courses of U-shaped masonry block into which the reinforcing steel and grout is placed. As the wall shrinks, the steel undergoes shortening, resulting in compressive stress (TEK 10-1A 2001). The surrounding masonry offsets this compression by tension. At the point where the masonry cracks and tries to open, the stress in the reinforcement turns to tension and acts to limit the width of the crack by holding it closed. The net effect is that reinforcement controls crack width by causing a greater number of smaller cracks. As horizontal reinforcement increases, crack width decreases. Smaller size reinforcement at closer spacings is more effective than larger reinforcement at wider spacings. Bond beams are typically presumed to offer tensile resistance to an area 24 inches above and below its location in the wall and horizontal joint reinforcement is usually placed in joints at a vertical spacing ranging from 8 inches to 24 inches (NAHB Research Center 1998). Graber (2006) recommends adding 9 gauge joint reinforcement every other course to help hold cracks tightly together.

Weep Holes:
Provide weep holes in the first course of block to allow water that does penetrate the exterior surface of the wall to escape (NAHB Research Center 1998, TEK 19-4A 2001, Bomberg 2006). Note that although the CABO, UBC, and ACI 530 building codes do not prescribe the use of weepholes or flashing, both BOCA and SBC require that weepholes be provided (NAHB Research Center 1998). BOCA requires a maximum spacing of 33 inches on center, and that they

shall not be less than 3/16 inch in diameter. SBC prescribes maximum spacing of 48 inches on center, and that they shall be located in the first course above the foundation wall or slab, and other points of support, including structural floors, shelf angles, and lintels. Cotton sash cords (removed before putting the wall into service) and partially open head joints are the most common types of weep holes (TEK 19-4A 2001).

Several related provisions are useful to support the weepholes. First, mortar must be prevented from blocking the weepholes. This should be accomplished by ensuring that the masons minimize the mortar dropped into cavities and providing mortar collection devices (e.g., screens) at regular intervals as the wall is laid-up to disperse minor mortar droppings enough to prevent blockage (TEK 19-4A 2001). Secondly, pests must be prevented from entering the wall. This can be accomplished by inserting stainless steel wool into the openings or using proprietary plastic or metal vents (TEK 19-4A 2001). These concepts are summarized in Figure 66.

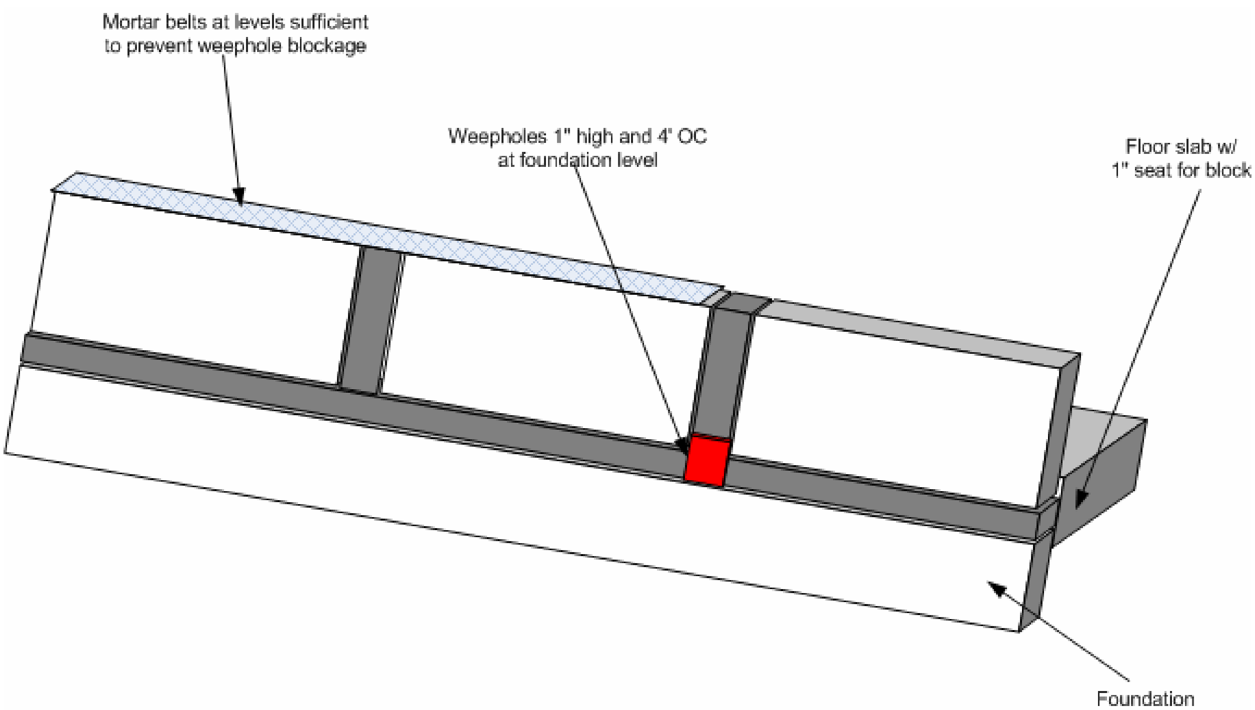

Figure 66 Weephole concepts in concrete block wall

Flashings:
To better contain the water that does penetrate the exterior surface of the wall and direct it to the weepholes discussed previously, flashings should be considered (TEK 19-4A 2003). Perhaps the most critical unflashed location in current masonry construction is at the base of the walls. Flashing materials include sheet metals (stainless steel, cold-rolled copper and galvanized steel), composites and plastic/rubber compounds). Flashing should be longitudinally continuous or terminated with end dams. To attain longitudinal continuity, joints must be overlapped and bonded/joined to prevent water movement through the lap joint. Flashings should always be

paired with weep holes, as described in the Level I recommendations. Typical flashing details for masonry walls are shown in Figure 67. Several proprietary systems are described in Appendix C. Challenges that must be overcome to design and install an effective flashing system include the handling of vertical grouted cells and assurance of consistent installation (Gulde 2006).

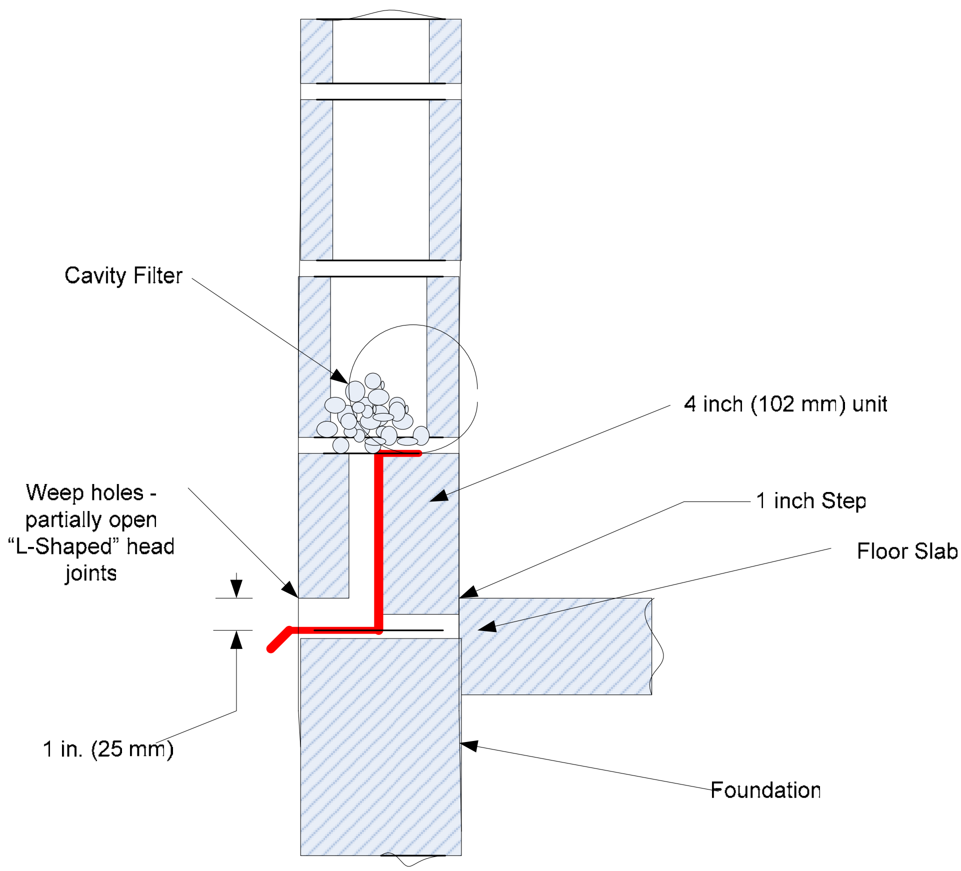

Figure 67 Flashing details for masonry construction (adapted from TEK 19-5A 2003)

Alternative Building Systems: Alternative building systems such as cast-in-place concrete (Zoeller and Crosbie 2005) or pre-cast concrete panels may greatly reduce the risk of cracks and water intrusion associated with concrete masonry construction.

Recommendation for Homeowners

Homeowners should understand that stucco is likely to crack and that the homeowner isresponsible for ongoing maintenance of the home. Cracks should be repaired with an elastomeric waterproof sealant patching compound. The method will depend on crack width and sealant product, but might typically include:

- Less than 0.4 mm (1/64 inch) – apply a brush grade compound with a small brush
- Between 0.4 mm (1/64 inch) and 0.8 mm (1/32 inch) – apply a knife grade compound

- Between 0.8 mm (1/32 inch) and 6.4 mm (1/4 inch) – route out crack ¼ inch wide by ¼ inch deep; apply two coats of knife grade compound

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Appendix A

UCF Housing Constructability Lab Hurricane Questionnaire:

Water Intrusion of Exterior Masonry Walls during Hurricane Jeanne - *WESH Call Ins*

Home #: ______________________________ Phone #: _______________________________

Homeowner: ____

Hello, my name is ______________________ and I'm an engineering research student at the University of Central Florida. I'm calling regarding the water intrusion into homes during the hurricanes of 2004. It's a follow up, on a telephone survey conducted by WESH-TV. The research we're doing at the university is to better understand water intrusion into new homes during hurricane Jeanne. Do you mind answering some questions regarding your home… it will not take more than five minutes? Note: This is for statistical use only and no personal information will be divulged without your approval.

____

1. What year was your home finished?

☐ 2001 ☐ 2002 ☐ 2003 ☐ mid- 2004? ☐ other – *terminate call*

2. Who was the builder? (Company name)

____

3. What is your five-digit zip code? ______________________________

4. What direction does the front of your house face?

☐ North ☐ South ☐ East ☐ West

5. How many stories is your home?

☐ 1 ☐ 2 or more

6. What type of structure is your home (concrete block, poured concrete, wood frame, etc.)?

7. What material covers your walls?

☐ Stucco ☐ Brick ☐ Siding ☐ Mortar ☐ Other _________________________________

8. Did you repaint the exterior of your home before the hurricanes?

☐ Yes… What brand and type of paint?

____

☐ No

9. Did you board up your windows in preparation for hurricane Jeanne?

□ Yes □ No

10. Did you experience water intrusion into your home during hurricane Jeanne?

□ Yes □ No- *terminate call*

11. Was there an obvious reason for the water intrusion?

□ Yes, if so… □ doors □ windows □ missing shingles □ holes from debris □ other _______________

□ No- *onto question # 8*

12. Did the water intrusion <u>involve</u> the walls of your home?

□ Yes? ↓ □ No – *terminate call*

13. Where in the walls did you see water coming in, and can you please be specific?

□ windows □ baseboards/floor □ electrical outlets □ ceiling □ other ______________________________

14. *If a multiple story home…* Did you experience leaks on the 2nd floor?
□ Yes? ↓ □ No- *onto question # 11*
□ windows □ baseboards/floor □ electrical outlets □ ceiling □ other ______________________________

Notes:

15. How much water came into your home?

□ stain(s) only, no water observed □ minor intrusion, including damp carpet
□ major intrusion, including wet carpet

16. Which wall of your home sustained the most water intrusion?

□ North □ South □ East □ West

17. Did you contact the builder about your damage? □ Yes ↓ □ No -> on to question #9

- Has the builder responded to your case? □ Yes ↓ □ No -> on to question #9
- Did they identify the cause for leakage? □ Yes ↓ □ No -> on to question #9
- Did they fix your problem? □ Yes ↓ □ No

18. Would you be willing to let a UCF industrial engineering research team try to duplicate the leak and measure the potential for hurricane water intrusion on a wall of your home?

□ Yes, we may be contacting you in the future to explain more about the test
□ No

Thank you for your time.
If you need to contact us please call the UCF Industrial Engineering Housing Constructability Lab @ 407-823-4686

NOTES:

Appendix B
UCF Housing Constructability Lab Hurricane Questionnaire:
Water Intrusion of Exterior Masonry Walls during Hurricane Jeanne in Central Florida – Broader Survey

Home #: ____________________________ Phone #: _____________________________

Homeowner: ______________________________ County/zip__________________Date: ____________

Hello, my name is ______________________ and I'm a researcher at the University of Central Florida. I'm calling as part of a survey regarding the water intrusion into homes during the hurricane Jeanne of 2004 (the last hurricane of the season). Do you mind answering some questions regarding your home… it will not take more than five minutes?

1. What year was your home finished?

□ 2003 □ Other- terminate call

2. Who was the builder? (Company name)
____

3. (If not available) What is your five-digit zip code? ____________________

4. How many stories is your home?

□ 1 □ 2 or more

5. What type of structure is your home (concrete block, poured concrete, wood frame, etc.)?

□ Concrete Block □ Concrete Precast □ Wood Frame □ Steel Frame □ Other

6. What material covers your walls?

□ Stucco □ Brick □ Siding □ Mortar □ Other _______________________________

7. Did you experience water intrusion into your home during hurricane Jeanne?

□ Yes □ No- *terminate call*

8. Was there an obvious reason for the water intrusion?

□ Yes, if so… □ doors □ windows □ roof □ holes from debris □ other ______________
□ No

9. Did the water intrusion involve the walls of your home?

□ Yes? ↓   □ No – *terminate call*

10. Where in the walls did you see water coming in, and can you please be specific?

□ windows   □ baseboards/floor □ electrical outlets   □ ceiling   □ other

____

11. *If a multiple story home…* Did you experience leaks on the 2nd floor?

□ Yes? ↓   □ No
□ windows   □ baseboards/floor □ electrical outlets   □ ceiling   □ other

____

Notes:

12. How much water came into your home?

□ stain(s) only, no water observed   □ minor intrusion, including damp carpet
□ major intrusion, including wet carpet

13. Which wall of your home sustained the most water intrusion?

□ North   □ South   □ East   □ West

14. Did you contact the builder about your damage?   □ Yes ↓   □ No -> on to question #8

- Has the builder responded to your case?   □ Yes ↓   □ No -> on to question #8
- Did they identify the cause for leakage?   □ Yes ↓   □ No -> on to question #8
- Did they fix your problem?   □ Yes ↓   □ No

Thank you for your time.
If you need to contact us please call the UCF Industrial Engineering Housing Constructability Lab @ 407-823-4686

NOTES:

Appendix C
Proprietary Flashing Systems for Single Wythe Masonry Walls

1. MTI single wythe wall system
To prevent moisture in walls of buildings and drain out water in walls, MTI uses cavity weep, floor edging and mortar belt.

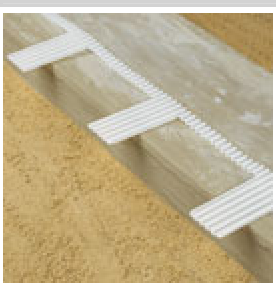
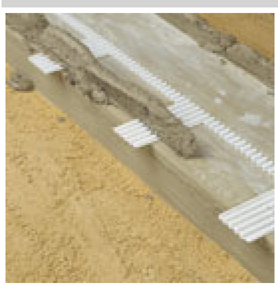
Cavity Weep
The cavity weep is installed on the foundation wall to drain out any water that may accumulate in core of block or run down inside of wall will pass by edge of floor and not onto floor. It weeps the wall at the bottom of the core.

Mortar Belt
This is installed on the center of walls to stop and hold trash mortar away from core sides and bottoms. It also stops trash mortar from plugging weep holes.

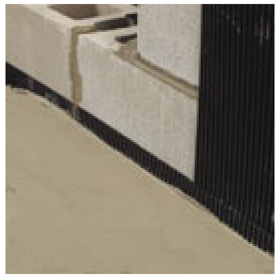
Floor Edging
This is installed between the edge of the concrete floor and the base of the wall to prevent water from flowing on to the floor.

Installations

1. Position Cavity Weep on foundation wall.
2. Place mortar on Cavity Weep and lay masonry units.
3. Score weeps at wall line and crack off while mortar is still plastic.
4. Brush finish joints.
5. If possible, top of floor should be a minimum of 1" higher than the bottom of the weeped core.
6. Install Floor Edging 2" higher than top of floor and pour the floor.

1	2	3	4
			
Exterior View	Exterior View	Exterior View	Exterior View
5	6		

Interior View



Interior View

Cavity Weep Installation:

1. Place Cavity Weep on foundation wall with continuous belt in core and legs extending out from face of wall about 1" to 1.5".
2. Place bed joint of mortar on Cavity Weep and lay masonry units.
3. Tool joints and lightly score legs at face of wall and crack off by pushing downward.
4. Finish tool joint and brush.

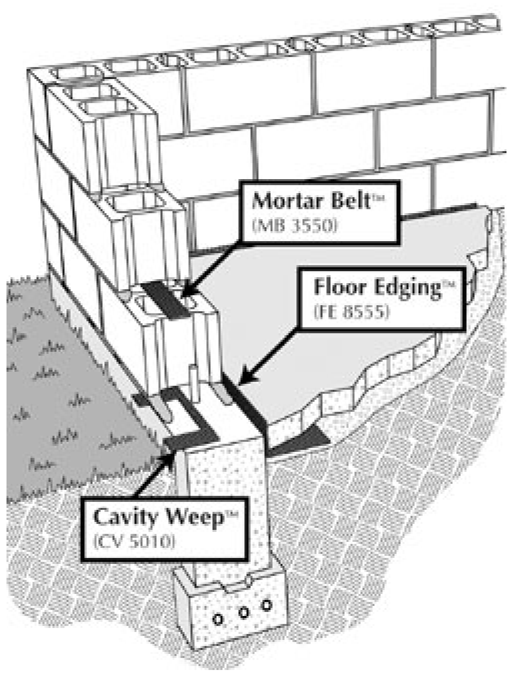
Floor Edging Installation:

1. Fasten Floor Edging to wall 2' on center.
2. Top edge of Floor Edging must be a minimum of 2" higher than top of concrete floor.

Mortar Belt Installation:

1. Center on wall every 4 to 6 courses.

CAUTION: Mortar Belt should not be used when masonry unit cells are less than 5" wide.



2. Mortar Net single wythe wall
Mortar Net uses Blok-Flash and pea stones to absorb moisture and drain water in walls. The pea stone also are used to block mortar droppings from clogging weepholes.

Installation
1. Lay the course(s) of block below the desired flashing level until above finish grade. Eliminate Step 1 if you lay BLOK-FLASH® on a formed concrete foundation above grade.

2. Install the BLOK-FLASH® course by spacing two units on each block or evenly along a formed concrete foundation or slab. The drip edge on the BLOK-FLASH® weep spout should extend slightly beyond the exterior face of the block unit it is resting on a minimum 4" above finish grade.

3. Span the continuous row of BLOK-FLASH® with BLOK-FLASH® bridge units. This will serve to divert descending water into adjoining BLOK-FLASH® units.

4. If the walls are reinforced, simply eliminate the BLOK-FLASH® unit and adjoining bridges at the grouted core. Cross-bed the webs adjacent to the core to be grouted making sure to overlap the BLOK-FLASH® flange. This will prevent grout from spreading beyond the intended core.

5. Utilize standard mortar spreading techniques with mortar lapped, first over the inner and second over the outer flanges of the BLOK-FLASH® units. This will stabilize the units during installation and later will help divert moisture into the BLOK-FLASH® units.

6. Reduce clogging from mortar and grout droppings by installing a 2" to 3" layer of pea stone into the core cavity above the BLOK-FLASH® locations. This will suspend mortar droppings and/or loose fill insulation in the core allowing moisture to flow down the inside face of the block and into the BLOK-FLASH®. Loose fill insulation poured in lifts will prevent mortar and grout droppings from clogging the core cavities at all levels of the wall.

7. Tool all head and bed joints and remove any obstruction from the weep spouts.

Warning: BLOK-FLASH® is one part of a drainage system that will perform best when used in conjunction with integral water repellant in the C.M.U. and mortar, reducing bridging and promoting the downward migration of moisture into the BLOK-FLASH®. Also, foam filling CMU cores may inhibit the downward migration of moisture, preventing any single-wythe flashing system from draining. Use loose fill, inserts or other insulation methods that will not obstruct the drain-ability of the wall system. Contact your nearest masonry supplier for information on these systems.

Blok-Flash.