Building Damage Issues in Hurricanes

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1. INTRODUCTION

The assessment of property damage begins immediately after a hurricane. Homeowners, insurance adjusters, contractors, engineers, and architects examine buildings and their surroundings to determine the extent of wind and water damage. While catastrophic damage is easy to recognize, the more subtle signs of building distress are not. Many types of building distress that are inherent to different construction materials are not recognized until after a hurricane occurs and are erroneously linked to the storm. The purpose of this paper is to summarize some of the more common building damage issues witnessed during the author's inspections of thousands of hurricane-damaged structures from more than a dozen hurricanes since 1980.

In order to conduct an accurate damage assessment, it is important to have knowledge of building construction, building materials, and environmental factors, as well as an understanding of wind and water forces. Seaquist (1980) addresses some of the inherent deficiencies in building construction and how to recognize such problems. Many people focus on the highest wind speeds associated with the storm without regard to the type, height, location, and exposure of the measuring equipment. Powell et al. (1994) discusses the problems associated with extrapolating wind reports from one location to another after Hurricane Andrew.

2. WIND VS. WAVE DAMAGE

One issue in assessing hurricane damage is determining whether wind effects or wave forces or a combination of both damaged a building. Typically, this issue arises since there are separate insurance policies for wind and wave damage. Not every building owner has insurance coverage for both damage types. Therefore, an accurate determination of the causes and extent of building damage must be made. Wind and wave forces affect a building differently. Wind forces are highest at roof level whereas wave forces are greatest at the base of the building. Refer to Figure 1. FEMA (1989) has a detailed document showing how to recognize wind and wave damage to a building.

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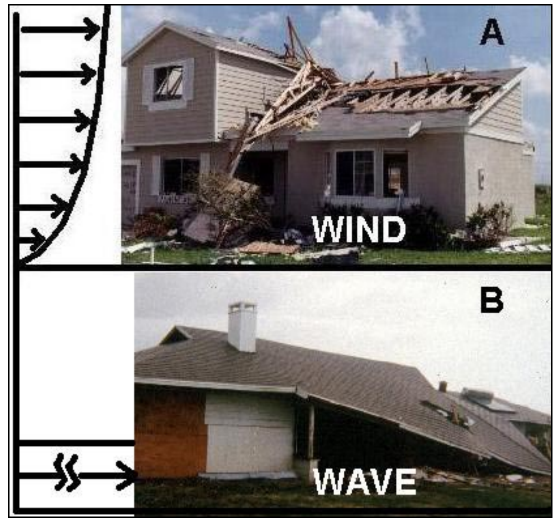

Figure 1. Examples of wind (a) and wave (b) damage to houses. Relative forces are illustrated on left with height above the ground.

Wind interacting with a building is deflected over and around it. Positive (inward) pressures are applied to the windward walls and try to push the building off its foundation. Therefore, it is important that the building be anchored properly to its foundation to resist these lateral forces. Negative (outward) pressures are applied to the side and leeward walls. The resulting "suction" forces try to peel away siding. Negative (uplift) pressures affect the roof especially along windward eaves, roof corners, and leeward ridges. These forces try to uplift and remove the roof covering. The roof is particularly susceptible to wind damage since it is the highest building component above the ground. Wind pressures on a building are not uniform but increase with height above the ground. Damage to a building caused by wind typically begins at roof level and progresses downward and inward with increasing wind velocities. Thus, the last place wind damage occurs is to the interior of the structure.

Wind damage begins with such items as television antennas, satellite dishes, unanchored air conditioners, wooden fences, gutters, storage sheds, carports, and yard items. As the wind velocity increases, cladding items on the building become susceptible to wind damage including vinyl siding, roof coverings, windows, and doors. Only the strongest winds can damage a properly designed and well-constructed building. Marshall et al. (2002) describes the various failure modes in buildings caused by high winds.

Water forces are greatest at the base of a building and tend to undermine the foundation and destroy the supporting walls, thereby leading to collapse of part or all of the building. Moving water exerts much greater force than air at the same velocity. One square foot of water traveling at ten miles per hour possesses as much kinetic energy as a 280 m.p.h. wind. Homes along the coastline are at greatest risk of being damaged by waves. FEMA (1997) found that over one hundred oceanfront homes were washed off their foundations during Hurricane Fran. Even homes elevated on pilings above the waves collapsed or leaned precariously when four to six feet of sand had been scoured around pilings that were only driven eight feet deep.

Water also can lift wooden buildings on pier and beam foundations, as they are buoyant and will float. The author observed numerous homes that floated landward or out to sea depending on the wind direction during Hurricane Hugo. Such homes floated when the water level reached about eight inches above the finished floor. Wooden-framed homes with brick veneer walls tended to rise and sink within the brick veneer shell. The house invariably did not come back to the same position causing distortion of the wooden frame. Wind did not cause this condition. It is important to determine the height of the water level during the storm in conjunction with time, wind direction, and wind speed relative to the building location.

3. CRACKS IN CEMENT-BASED MATERIALS

People examining their building after a hurricane invariably find cracks in concrete slab floors, brick and concrete masonry walls, stucco, etc. For insurance reasons, it becomes important to delineate between cracks inherent to the building from cracks that were caused by the storm. There are many kinds of cement-based materials used in building construction like concrete, concrete block, mortar, stucco, and plaster. These materials tend to crack during or after curing as they shrink. The extent of shrinkage cracking depends primarily on the water content of the mix and placement of control joints. Environmental factors such as the rate of hydration and evaporation can affect the severity of shrinkage cracking. For these reasons, shrinkage cracks are fairly common in cement-based materials. Shrinkage cracks are usually small in width, less than an eighth of an inch, but can extend several feet in length.

3.1 CONCRETE SLAB CRACKS

Many buildings are constructed on thin concrete slabs with shallow footings and therefore are susceptible to differential foundation movement from cyclic moisture changes in the underlying soil or settlement. Concrete slabs float on the ground and rise and fall with expansion and contraction of the underlying soil. As expansive soil dries around the foundation perimeter, the perimeter of the building settles relative to the center leading to distress in the interior and exterior finishes. Mitered corners at frieze boards open and interior doors bind. Cracks in plaster and gypsum board frequently emanate from the corners of door and window openings. Slab cracks can extend through brittle finishes bonded to the slab like ceramic tiles.

An examination of the crack interior will often determine whether the crack is new or old. Cracks become discolored with time as they accumulate dirt, paint or debris. Refer to Figure 2. Edges of the cracks become rounded with continued wear. Water entering the cracks can lead to rusting of reinforcing steel and the resulting expansion can lead to spalling the concrete. In contrast, cracks caused recently do not have these characteristics. Recent cracks appear fresh and unweathered with broken pieces of the concrete along the fractures. Concrete slab cracks associated with wind usually are found in the direct load path with failure of a building component. Refer to Figure 3.

Figure 2. Old crack in middle of concrete slab (A) and close-up view (B) showing dirt in crack. This crack was not caused by the hurricane.

Figure 3. New crack in concrete slab caused by the rotation of the steel column that failed in the wind.

3.2 MASONRY DISTRESS

Masonry walls commonly are constructed with fired-clay brick or concrete masonry units (CMU) bonded together by mortar. Mortar is a mixture of Portland cement, sand, water, and lime. The lime is utilized to increase workability of the mix. Masonry walls are susceptible to distress from differential (up and down) foundation movement. Drainage conditions, locations of trees and downspouts all affect the soil moisture content. Window and door openings are naturally weak points in the wall where the distress concentrates. Cracks and separations that open with height (V-shape) indicate settlement on either side of the crack whereas cracks tapering closed with height indicate settlement at the base of the crack. Refer to Figure 4.

Figure 4. Foundation settlement at the corner of a house (A). Close-up view (B) shows V-shaped gap between window and brick, and (C) shows stair-step crack at base of window. Note prior attempts at caulk repair. The distress was not caused by the hurricane.

Masonry walls are also susceptible to volume changes from varying temperature and must have the necessary control joints to alleviate thermal strains and reduce cracking. Brick walls expand when heated and shrink when cooled with the greatest movement occurring in the long dimension of the wall. Thermally induced cracks tend to form near wall corners and openings where strains are concentrated. The Brick Institute of America (1991) recommends installing control joints every 15 to 20 feet along a wall to minimize cracking from thermal strains. Mortar joint cracks also are associated with steel lintels over doors and windows. Steel lintels expand and contract at different rates than the masonry. Also, rusting of the steel causes expansion that can force apart the mortar joint. Old masonry cracks become discolored with time as they accumulate dirt, paint or debris. In contrast, recent cracks appear fresh and unweathered with broken pieces of masonry along the fractures.

Masonry walls are susceptible to wind damage especially if they are non-loadbearing. Such "free-standing" walls are pushed in on the windward side and fall outward on the leeward side. Masonry walls should have wall ties to anchor the walls to the frame, however, the author has observed many buildings that did not have such ties or did not have them engage the masonry. Refer to Figure 5.

Figure 5. Windward masonry wall pushed inward by the wind (A), and leeward wall that fell outward (B). Note brick ties (circled) did not engage the masonry.

Non-loadbearing brick masonry walls that are not anchored to the building can be flexed relatively easily when pushed by hand. The wall has not been "loosened" by the wind; it just never was anchored.

Foundations on soil fill are quite prone to settlement especially if the soil is not uniformly compacted. Heavy masonry walls and chimneys are prone to rotating away from a building as the underlying soil settles. Leaning walls or chimneys can be mistaken as being caused by the hurricane. However, masonry chimneys typically fail along horizontal mortar joints and topple to the leeward side of the hurricane winds. Failure of the chimney occurs where the chimney intersects the roof or where the mortar joints are weakest. In general, mortar joints are weak in tension and can be pulled apart relatively easily. Refer to Figure 6.

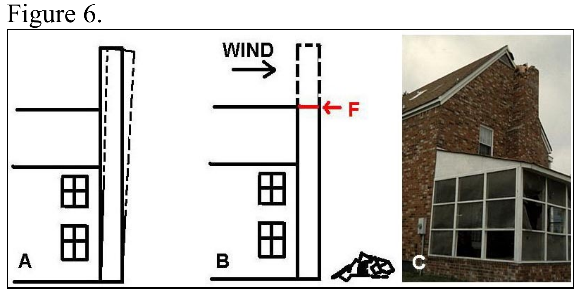

Figure 6. Leaning chimney from foundation settlement (A) and broken chimney from wind (B and C). The letter "F" indicates the failure location.

3.3 STUCCO CRACKS

Stucco is similar to mortar, typically one part Portland Cement to three parts sand with about ten percent lime. Stucco is commonly applied over an expanded wire mesh that has been fastened to the sidewall of a building. The stucco is troweled over the mesh using either a two-coat or three-coat process. Total thickness of the stucco should be between 3/4 and one inch. The appealing aspect of stucco is its low maintenance and resistance to deterioration. Various finishes and colors can be added. Cracks in stucco can also be repaired relatively easily (PCA, 1980).

Stucco frequently is applied over concrete, concrete block masonry, or wood. Quality control is essential to ensure proper performance. The addition of too much water can lead to shrinkage cracks or crazing. Also, stucco is not very flexible and will mirror underlying discontinuities in the wall. Therefore, proper control joints must be installed to prevent such cracks. Finished stucco also is porous and will absorb moisture. Therefore, stucco should not be in constant contact with water. Otherwise, the underlying metal lath can rust causing the stucco to delaminate. Such stucco damage usually occurs on wing walls and balconies that project from building overhangs. Old stucco cracks contain dirt or paint, and fracture surfaces are discolored. In some instances, rust or mildew emanates from the cracks. Refer to Figure 7.

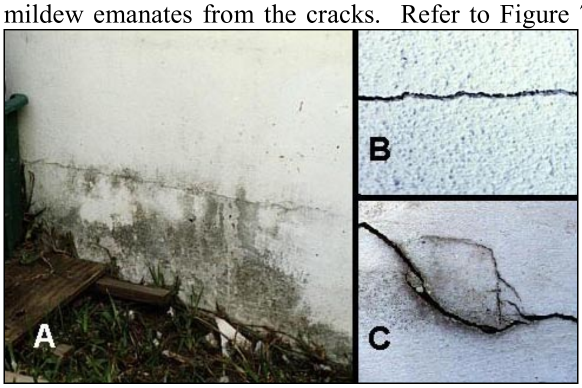

Figure 7. Old cracks in stucco: at the base of the wall where there is an underlying joint between the bottom plate and foundation (A), paint in crack (B), and mildew in crack (C).

Hurricane winds can cause cracks in stucco especially where the stucco bridges a joint that flexes (Figure 8). Fresh stucco cracks are sharp and unweathered. Merging cracks occasionally contain loose pieces of the stucco material. Localized damage can occur where flying debris strikes the stucco clad wall.

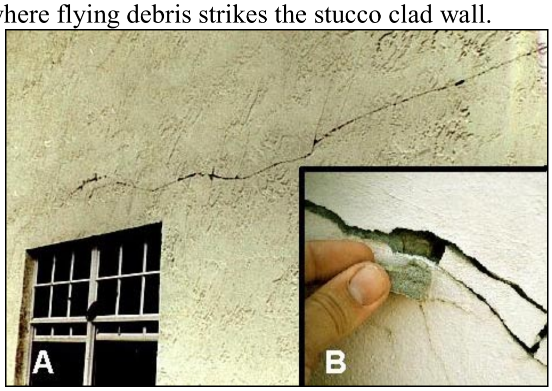

Figure 8. Fresh crack in stucco wall after hurricane where it bridged a joint between the bottom of the gable framing and the underlying concrete tie-beam (A). Note unweathered condition of crack and loose pieces of stucco (B).

4. FOGGED INSULATED GLASS

People occasionally find "fogged" insulated glass windows after a hurricane. In order to determine whether the unit failed as a result of hurricane winds or not, an inspection of the unit and its surroundings must be performed.

Insulating glass assemblies are comprised of two glass panes separated by an aluminum spacer around the perimeter. The spacer is cemented to the two panes with primary and secondary seals. A moisture absorbent material (desiccant) is contained within the air space. This gas will expand and contract with changes in temperature placing stresses on the seals. Exposure to ultraviolet rays and moisture also can affect the seals. Spetz (1992) showed several manufacturing deficiencies in the making of insulated glass like "skipped" areas on the primary and second seals, improper spacer coverage, and spacer misalignment. Smith (1993) concluded that improper installation and handling procedures commonly cause seal failures. Fogging of the window forms as moisture condenses in the air space between the glass panes causing the unit to become dull or opaque (Figure 9).

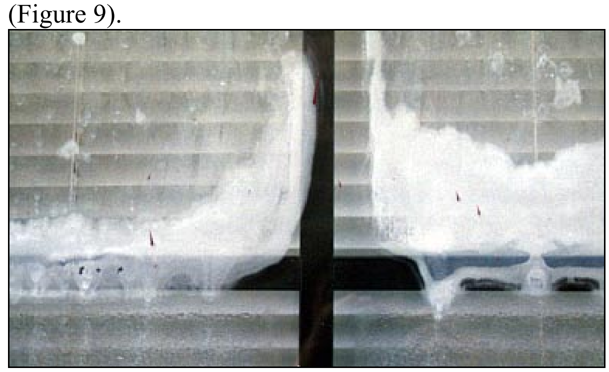

Figure 9. Mineral residue inside "fogged" window unit indicated the seals failed quite some time ago.

Typically, windows with southern and western exposures are more susceptible to fogging because of extreme temperature (expansion/contraction) changes and UV degradation of the sealants. The presence of mineral build-up or "scum" between the panes indicates the unit failed a long time ago.

High winds from a hurricane can cause or promote seal failure. Such glass damage increases with height above the ground and occurs in high positive and high negative pressure zones. Typically, winds strong enough to break window seals also can break the glass.

5. REFERENCES (available upon request)