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Chapter 7

Field Investigations

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In determining the cause and extent of distress to a structure damaged by a hurricane, a protocol of field data collection will facilitate analysis conducted later. There is no substitute for a site visit to the subject structure shortly after a storm event to accurately document the magnitude and patterns of damage at the site prior to repair, rehabilitation, or demolition. An efficient and thorough field investigation is facilitated through diligent research prior to the site visit (see Chapter 8) and a protocol of field data collection as discussed herein.

Once on site, the professional and forensic team will conduct a repertoire of big-picture, general documentation; detailed visual observations accompanied by photographic and graphic documentation; and testing, as necessary. While conducting a field investigation, the professional and forensic team should be cognizant of safety issues that commonly result from hurricane-induced site hazards.

7.1 FIELD EQUIPMENT

The forensic and professional team should be properly prepared for a multitude of onsite conditions with standard field equipment appropriate for the evaluation of hurricane-damaged buildings. The most basic field equipment includes multiple flashlights with spare batteries; measuring devices such as tape measures of varying lengths and/or a laser-measuring device; a digital camera with spare batteries and memory cards. In addition, stocked and maintained first aid kits are an integral part of the team's standard field equipment.

Safety gear (e.g., closed, rigid-toed safety shoes, hard hats, gloves) is an essential component of standard field equipment where hazards requiring such gear are present. Properly maintained athletic shoes are generally sufficient for accessing dry, flat to moderately-sloped roofs, while the investigators may need specialized footwear to access moderately- to high-sloped roofs. In addition to specialized footwear for steep-roof access, OSHA approved safety harnesses and lanyards may be required for some roof investigations.

Where a roof inspection will be performed, a ladder of sufficient length and capacity is necessary if the building does not have other means of roof access. A collapsible ladder is recommended because it is easily transported in most vehicles; some collapsible ladders can extend beyond 20 feet. Longer extension ladders may be necessary for access to multi-story buildings.

Specialized field equipment includes properly-fitted respirators (with appropriate prior training) and disposable protective body-suits in the case of hazardous environmental conditions. If the field investigation occurs soon after the hurricane event, it should be anticipated that no power, potable water, restrooms, or food will be available at or near the site. A device may be needed to determine the vertical plumbness of building components for evaluation of permanent lateral deflection (i.e., racking). While a standard bubble-level is useful for qualitative evaluations, digital levels with a precision of 1/10 of 1 degree or greater are most useful for plumbness evaluations of walls and structural members, as they yield quantitative information which may be analyzed following the field investigation.

A device that measures horizontal levelness may be needed to determine the levelness of a building's foundation or elevated floors. A manometer or a hydrostatic altimeter (i.e., a corded liquid- or gas-type level) is most useful for smaller residential and commercial buildings featuring many interior obstructions, such as demising walls, while a traditional surveyor's level is more useful for large, unobstructed spaces, such as those found in warehouses and industrial buildings. The surveyor's level requires one operator and at least one person, perhaps two, holding the rod. A rotary laser level offers a more time-efficient solution, without sacrificing accuracy or precision, and can be operated by one or two users. Another useful addition to standard field equipment is a traditional plumb bob, which is used to determine structural plumbness and is powered simply by gravity.

For evaluation of water intrusion and the moisture condition of interior building finishes and wood framing, non-destructive (impedance-based) and minimally destructive (resistance-based) measuring devices may be utilized. For evaluation of the moisture condition of concrete, Calcium Chloride Moisture Vapor Emission or Relative Humidity Probe testing may be performed in accordance with ASTM standards. These tests require specialized equipment and properly-qualified and/or trained personnel.

The professional and forensic team should be aware of the procedures for the proper usage and inherent limitations of all field equipment. Testing equipment must be properly maintained and calibrated per the manufacturer's recommendations and proper operation of the equipment should be confirmed prior to use in the field.

While standard field equipment should be taken to all field investigations, the need for specialized equipment is identified through research conducted prior to the site visit.

7.2 INFORMAL ONSITE INTERVIEW

Upon arriving onsite with the appropriate field equipment and staff, and after assessing the site for potential safety hazards, the lead professional should attempt to conduct an informal interview with the property owner, his or her designee, or any other personnel on-site with knowledge of the building under investigation and the hurricane's effect on it. The professional should take thorough and legible written notes during this process and should attempt to gather information regarding the age of the building, the age of the roof and other elements of the structure, and any pre- or post-hurricane structural or cosmetic repairs or modifications to the building, structural or otherwise. Documentation of repairs or modifications (e.g., invoices, estimates, proposals, contracts, receipts) can be requested at this time, as well as a verbal or written record of building maintenance operations for industrial/commercial buildings. The interviewee should be asked to provide an overview of distress to the building that purportedly occurred as a result of the hurricane, and the timeframe when such distress was first observed. Any distress or damage that pre-existed the hurricane should be identified by the interviewee and noted in writing by the professional. The professional should request any photographs of the building taken prior to and following the hurricane, along with any construction documentation, including drawings and plans, etc.

7.3 FIELD INVESTIGATION DOCUMENTATION

7.3.1 Big-picture Documentation

After the informal onsite interview, the professional should coordinate with the team, develop a strategy for the field investigation, and begin gathering "big-picture" information regarding the subject site and building. At this stage, the professional and/or assistant will generally prepare a schematic drawing of the building if one was not provided. The team should thoroughly document the site both graphically and with photographs. Detailed procedures for graphical documentation are discussed later in this chapter. In cases where the structure no longer exists, only photographic documentation should suffice.

The team should photograph each elevation of the building and the site in all cardinal directions. Photographs of the topography of the subject site and its surroundings are helpful in establishing wind exposure, which is influenced by terrain, escarpments, obstructions, and adjacent buildings. The proximity and location of these features to the subject building should be documented. The location, height, and trunk diameter of standing or fallen trees at, and in the vicinity of, the subject site should be noted and photographed. In addition, tree stumps and disturbed ground that may indicate the prior presence of trees. Documentation of such features may be useful later in evaluating wind and storm surge forces.

Although aerial imagery or maps are best suited for determining the geographic location of the subject site, the professional should note any obvious proximity to a coastline or other body of water. The horizontal distance to the coastline or body of water can be recorded, along with the general proximity of the site to that location and whether the site is above, at, or below the adjacent sea or water level. Any scouring, erosion, or other disturbance of grade should be documented, along with patterns of debris scatter at and near the site. In some cases, the professional can identify the source of any debris, which could yield valuable information regarding the magnitude and directionality of wind and/or moving water. If a storm surge or flood affected the subject building, the team should photograph water and debris markings on the building's exterior and interior, along with markings on nearby buildings or other structures such as bridge supports and utility poles. The height of water and debris markings above grade, above finished floor, or some known reference elevation, if available, should be measured and recorded. Finally, the team should document the magnitude and type of damage to surrounding buildings and vegetation. The professional should walk or drive the vicinity of the site, if conditions allow, to gain an understanding of the effect of hurricane-induced environmental forces on the surroundings.

Gathering "big-picture" information is particularly valuable when a site is located within an area subject to damaging storm surge. Such areas are characterized by widespread structural damage with near-complete destruction of many buildings, and are often demarcated by a distinct debris line along the coast. Within the debris zone, storm surge frequently removes all evidence of wind damage to a building that may have occurred prior to the destruction of the building by storm surge. Since buildings located just inland of the debris zone will have experienced similar wind speeds to nearby buildings within the debris zone, wind damage to buildings located just inland of the debris zone can provide a good estimate of possible wind damage to buildings in the debris zone that were destroyed by storm surge.

7.3.2 Detailed Photographic Documentation

Detailed photographic documentation is an essential tool to facilitate analysis conducted after the field investigation. Clear photographic documentation may assist in communicating site conditions as they relate to information in the engineering report, and they help to demonstrate the analytical basis for the professional's conclusions. The team should photograph general site conditions as described in Section 7.3.1, items of distress, and evidence regarding the manifestation, cause, and origin of the observed distress. Specifically, photographs should clearly document observed distress to the subject building and site, previous repairs, and material, construction and/or design defects or deficiencies.

In order to trace sources of damage or distress, photographs should document conditions so that the types and locations of the damage or distress may be easily re-created while performing post-site-visit analysis. Depending on the scope and type of investigation, the team should photograph conditions at the exterior, roof, interior, attic, crawlspace, and exposed structural members. In the case where photographs will not capture useful images, items should be documented through field notes and sketches, as described later in this chapter. Since the professional will want as many photographs as needed to substantiate any conclusion in the engineering report, an over-abundance of site photographs is preferred to an insufficient amount. Photographs should be backed-up to a laptop computer, central server, and/or digital media after each site visit for redundancy, given the importance of the photographic field data in supporting the basis for the professional's opinions in the engineering report.

7.3.2.1 Building Exterior

Photographs of exterior building conditions should document distress and potential causes of distress. Veneer and exterior finishes may show a pattern or patterns of distress adequate to verify the cause(s) and origin(s) of the distress. Since environmentally-applied stresses are typically greater at corners and fenestrations than in the field of large-scale building surfaces, care should be taken to adequately document conditions at corners, re-entrant corners, openings, windows, doors, and appurtenances.

Water intrusion is a common condition observed in post-hurricane forensic investigations. When building distress includes water intrusion, documentation of both the site and exterior building items are important. Common exterior sources of water or moisture intrusion include interfaces between dissimilar construction materials, such as at exterior wall assemblies and roof-to-wall interfaces. The team should photograph interfaces that are integral to certain building components, such as window and door assemblies, sealants and gaskets, veneer terminations and connections, and roof gutter-to-downspout discharge. Further, any penetrations through the exterior veneer for mechanical, electrical, or plumbing conduit are possible sources of water or moisture intrusion and should be photographed, as should any mechanical attachment of appurtenances, such as storm shutters, satellite dishes, flag poles, antennae, etc. Patterns of lawn irrigation system spray are often visible on a building's exterior and should be photographed.

High wind pressures associated with hurricanes often result in the impact of wind-borne debris on a building. As such, the team should photograph the location, pattern, and size of impacts to the exterior, as well as penetrations resulting from these impacts. In the case of multiple impacts, the typical and maximum size of the impacts should be documented. However, where debris has penetrated the building in multiple locations, representative samples are sufficient. Finally, the team should document apparent local distress to exposed mechanical, electrical, and plumbing appurtenances for comparison to overall building distress.

7.3.2.2 Roof

Where safety allows, team members should access the roof and document its general condition, including configuration, roofing type, roof appurtenances, flashing methods, slopes of roof fields, and drainage systems. Since the performance of a roof is dependent on the original installation and maintenance of the roofing system(s), during documentation of the general roof conditions the professional should photograph evidence of the roof maintenance program. Also during the general conditions inspection, the professional should capture aspects of previous repairs including size, location, type of repair, and repair material, as well as patterns that appear in the application of previous repairs.

Roof distress may be apparent in the roofing material, flashing, appurtenances, and/or mechanical units. During the post-hurricane investigation, the professional should document distress that appears to be recent and distress that appears to pre-date the storm event.

Roof distress from windstorms generally manifests first at areas of increased wind forces, which typically are most intense at areas with an abrupt change in the building plane (i.e., edges, ridges, or gables). The professional should clearly photograph any patterns of wind-related distress, with sufficient photographs to record each of the several types of distress observed. Types of distress include wind-created openings or penetrations through the roof system that could allow for moisture intrusion into the building interior.

Distress to roof decking and/or framing may be present. The professional should document depressions or buckled areas in the roofing resulting from framing or decking distress in a manner to allow correlation to observations in the attic, interstitial, or plenum spaces. Depressions in the roofing may be the result of a long-term deflection (i.e., ponding), caused by insufficient drainage resulting in ponds of rainwater on the roof's surface. The professional should document evidence of ponding, as well as the condition of the roof's drainage system.

In addition to distress caused by elevated wind pressures, the professional should document impacts from trees and wind-borne debris. Damage caused by tree impact is generally apparent, and the professional should focus on the extent of damage caused by the impact. If roof framing is exposed and safety allows, photographs should be taken of fractured, deformed, and/or displaced roof framing and decking. The professional should photograph wind-borne debris impacts that may have caused penetrations through the roofing as well as the areas around these impacts. Wind-borne debris impacts are typically characterized by starburst and/or radial patterns within the roofing.

Items in close proximity to the roofing, such as signage elements, detached flashing, or overhanging tree canopies, may create radial abrasions in the roofing by oscillatory motion induced by wind and subsequent contact with the roofing. The professional should document these abrasions or other distress along with the item causing the distress. When possible, photographs should include broad images that capture both the causative element along with the pattern of distress in the roofing. Photographs should also include a close-up image of the roofing distress, which documents the manifestation and degree of distress.

Roof drainage systems often provide insight into the cause of certain distress. The professional should photograph external (gutters, downspouts, scuppers) and internal (in-field, recessed, roof drains) roof drainage systems, including a reference scale to determine component sizing, and photograph the presence or absence of gutters at all eaves. Discharge from the gutters may affect the performance of the foundation or create conditions conducive to moisture intrusion. Therefore, the professional should document gutter discharge locations in cases that potentially involve foundation movement or water intrusion and site distress directly adjacent to discharge points, such as erosion or staining. The professional should document and photograph the diameter of the receiving bowl and the drainage pipe, and recession or obtrusion of roof drains below or above the field of the roof, with a scale included in the photo. In addition, the professional should document any debris in or around roof drains, as well as the general condition of the drainage pipes at the interior of the building. In some instances, the professional can utilize a fiber-optic camera to evaluate if a drainage pipe is obstructed beyond points that are visible.

7.3.2.3 Attic or Plenum

Damaged areas found at the exterior are useful for identifying corresponding interior areas for evaluation and documentation in order to ascertain whether any distress at the interior can be determined as short-term (i.e., consistent with being caused by the hurricane) or long-term (i.e., pre-existing the hurricane). Photographs should be taken of short-term and long-term moisture distress to the framing and roof decking, as well as any moisture distress that may appear long-term or repetitive, such as suspected fungal growth, wood rot, wood deterioration, or corrosion. Areas of visible daylight should be photographed, as they indicate potential entry points for moisture.

The condition of any non-structural elements such as the insulation, plumbing, mechanical equipment, or electrical equipment that is housed in the attic or plenum space may also provide useful information. Displacement of the insulation may correlate with effects of wind, and damp non-structural elements may correlate with recent water intrusion. Photographs should be taken of any pipe or duct connections that have signs of moisture around them or any deficiencies that may lead to moisture intrusion, whether the deficiency is hurricane-related or a pre-existing condition. Vent penetrations through the roof and penetrations through gable end walls should be assessed and photographed if signs of moisture are present or daylight is apparent.

7.3.2.4 Building Interior

Detailed documentation of the post-hurricane condition of the building's interior is important for a thorough forensic evaluation. However, this documentation is time consuming and resource intensive, and may not be practical depending on the type and scope of the investigation. The professional must use his or her judgment in deciding which interior elements warrant detailed photographic documentation. At a minimum, general photographs showing the overall condition and configuration of interior spaces should be taken. Where detailed documentation is warranted, photographic documentation of interior conditions should include distress to wall and ceiling finishes, flooring, and built-in carpentry. In the case of penetrations through exterior wall assemblies, the interior face of the penetration should be photographed in a manner that allows correlation to exterior photographs of the same penetration.

Where mechanical, electrical, and plumbing equipment and fixtures are accessible, any distress to these items should be photographed. When site distress is water-related, potential water sources such as plumbing fixtures and condensation pans or lines should be documented for evaluation of their relationship to the cause of distress.

Moisture staining and suspected fungal growth are most often a function of water intrusion. The path of water intrusion should be documented from the area of water damage back to the source of the water. Whether the source is a penetration through the building envelope or an interior source, photographs should provide clear evidence of the path of water migration and the extent of the resulting distress.

7.3.2.5 Structural Systems

Professional judgment should be exercised when determining the appropriate extent of investigation for structural systems. For example, brittle wall finishes typically exhibit distress prior to the occurrence of damage to the structural framing; therefore, after gaining an understanding of the structural framing system, the professional can decide whether or not to perform a detailed evaluation of the structural framing based on distress to finishes.

After the investigating professional determines that the condition of the building is suitable for safe evaluation of the building's structural system, photographs should be taken of conditions at exposed areas of the structural framing. In some instances, minimal destructive measures may be taken in concert with a qualified and licensed contractor to expose areas where the structural framing is concealed by finishes. Such measures will generally require approval by the client and/or the building owner. Care should be taken while proceeding to areas of exposed structural framing, and extreme caution should be exercised while exposing structural framing or evaluating recently-exposed structural framing. This section focuses on documentation of general conditions and distress to structural systems of residential and low-rise commercial structures.

Structural framing is categorized into two main structural systems: the vertical load-carrying system and the lateral load-carrying system. The vertical load-carrying system typically consists of the foundation including foundation walls, bearing walls, columns, piers, piles, corbels, roof, and floor framing. The lateral load-carrying system typically consists of roof and floor diaphragms, vertical and horizontal bracing, shear walls, and moment frames. Both systems, including the connections between the individual members, are integral in resisting hurricane related loads. Where distress to structural framing is identified, photographs should capture the type and condition of each system, including any distress from wind, debris impact, flood, and/or storm surge from the hurricane.

For slab-on-grade foundations, erosion and scouring patterns beneath the foundation should be photographed if present. This type of distress is often found at sites that have sustained damage from flooding or storm surge. Additionally, any concrete fractures or spalls, and any displaced concrete slabs should be photographed. Detailed photographs should capture and differentiate recent ("fresh") distress from long-term distress, such as vegetation growing within cracks or fracture locations, or fractures that appear weathered, painted, or soiled, indicating a pre-existing condition. Any visually apparent sections of the foundation slab that are lifted by large uprooted trees or sections that have sagged or settled due to soil washout beneath the foundation should be documented. Accessible foundation anchorage, such as anchor bolts through wood sole plates or steel base plates, should be identified and any signs of atypical displacement or other distress should be documented. Wood sole plates or masonry veneer walls that have slipped off the foundation or base plates that are distorted should be photographed, as well as any wall (e.g., load bearing, non-load bearing, shear, etc.) that is lifted off the foundation, buckled, or bowed. Any distress to hold-down connections intended to transfer tension loads to the foundation or between floors should be documented.

Foundation systems that extend above grade, such as pier-and-beam type foundations with a crawl space, or those that support elevated floors (i.e., driven piles) commonly found along coastal or flood-prone areas, should be photographed to capture the grading and drainage beneath the building, including areas of recent erosion or scouring beneath the building. Photographs identifying the elevation difference between the interior of the building and the perimeter grading are useful. Any impact marks or waterlines visible on these structural elements should be documented.

The team should conduct an examination of the orientation and configuration of the building compared to the direction of wind, flood, and/or storm surge. Any evidence of shifting of the beams from the top of the piles or piers, out-of-plumbness of the piles or piers, misalignment of structural members, and distress to visible connections should be photographically documented. Photographs should be taken of any signs of moisture-related distress, from minor staining to long-term deterioration such as wood rot or steel corrosion. Floor joists and decking should be evaluated for any effects consistent with hydrostatic pressure impacting the floor from beneath. The effects of storm surge can include rotated or twisted joists and floor decking that is lifted from the top of the joists. These conditions should be photographed if present.

Visible portions of foundations that extend well below grade, such as drilled piers, driven piles, basement walls, etc., should be documented in the same manner as above-grade foundation systems, with photographs taken to record out-of-plumb and/or displaced walls, piles, or piers. Settlement of foundation walls, piles, or piers should be documented. This may entail assessing the levelness of the interior finished floor in conjunction with evaluating the foundation.

After assessing the building from the exterior, accessible areas of the vertical and lateral load-carrying systems may be documented concurrently with other portions of the interior. For many buildings, the structural framing is concealed by architectural finishes so typical areas of exposed framing such as mechanical chases, stairwells, attic spaces, and plenum spaces should be investigated and photographed to reveal any signs of distress, deficiencies, and signs of pre-existing conditions. While nondestructive testing including wall plumbness and relative floor levelness measurements and moisture measurements at the wall may be sufficient to indicate structural or water damage at concealed framing locations, destructive testing measures, including the removal of finishes, may be necessary to identify the nature and extent of the damage.

For wood-framed structures, noticeable bowing of wall studs or bracing, noticeable deflection of beams and joists, fresh cracks or splitting wood, signs of fastener pull-out or distress, and distress to exposed hold-down or seated connections should be photographed. For steel-framed or similar type structures, the same type of photographic documentation should be conducted including any member distortion or displacement. If pre-existing distress such as wood deterioration or steel corrosion is evident, the professional should photograph these conditions. If steel corrosion is severe, the professional should use some method to determine the extent of metal loss and thus structural degradation. Bracing members should be evaluated for compressive failure (i.e., buckling) or tensile failure (i.e., separated members or fastener pullout), and any such conditions should be photographed.

Photographs of the structural framing systems as observed from within the attic and/or plenum space should include the general framing and roof decking type, condition of the exposed framing and connections at walls, as well as the roof, and the condition of non-structural elements present within the space. Photographs should include evidence of recent distress, including fresh cracks or splits in wood, paint lines differentiating previous connection locations in metal framing, or pulled out and loose fasteners. Close-up photographs within gaps, openings, and fractures in members where cobwebs, paint, or other debris exists can often show whether the distress potentially pre-existed the hurricane or not. The condition of structural framing supports (i.e., columns, bearing walls) and previous repairs at the support locations should be documented. Photographs should include locations of connection failure between the roof-to-wall framing, connections at ridges, hips, and bracing, as well as areas of long-term repair that may indicate a history of distress or deficiencies prior to the hurricane.

7.3.3 Detailed Graphic Documentation

Accurate graphic mapping of distress by the professional and forensic team can be of great benefit during the analysis phase of the hurricane investigation. If construction documents or to-scale floor plans were obtained during the pre-site or interview portion of the investigation, they should be verified to the as-built conditions at the building to assure accuracy. If no plans were obtained, field sketches of the building being investigated can be created, including the locations of windows, doors, roof penetrations, roof appurtenances, roof top HVAC units, and other building features, in order to document the distress observed and to record field measurements and data. For some investigations, good quality aerial photographs may suffice in lieu of floor plans.

The professional and forensic team can use these plans to map the location and type of distress observed, and it is suggested that a pre-established, consistent set of symbols and colors be used at each floor level and roof level of the building. The accurate graphical mapping of distress provides the professional with a powerful tool to identify patterns to the distress and to identify the locations of the source(s) of water intrusion or other damage to the building. For example, overlaying the distress map of the roof on a distress map of the upper floor plan of the structure will help identify damage related to water intrusion from the roof.

When the hurricane investigation involves field testing, testing locations should be accurately mapped or otherwise identified. On investigations involving water intrusion, accurate mapping of all water damage locations, any areas of suspected fungal growth, and any moisture readings taken should be clearly recorded on the plans. On investigations involving structural damage, structural data, such as plumbness measurements, should be located and clearly recorded on the plans including any directionality to the readings. If an elevation survey of the foundation system and/or elevated floors is needed as part of the structural evaluation, the location and raw elevation data readings, including the location and elevation change at each floor type, should be clearly recorded on the plans so that the data can be adjusted and finalized into a topographic survey upon returning from the field.

7.4 SITE SAFETY

During the course of the site inspection, the professional should be cognizant of structural and non-structural conditions that may pose a safety hazard at the subject building and site. The professional must take appropriate action to protect life safety, including that of the public and the investigative team.

The professional should be familiar with and recognize safety postings from government agencies that may have been posted at the building prior to the arrival of the investigative team at the site. In addition, unsafe areas may have been identified by others or temporarily repaired prior to the arrival of the investigative team at the site. First and foremost, the professional should be familiar with indications of structural instability of the building. In addition to unsafe structural conditions, the professional must be aware of unsafe non-structural conditions.

7.4.1 Unsafe Structural Conditions

Hurricane-force winds and hurricane-related flooding may result in structural damage to buildings and create potentially unsafe structural conditions. Unsafe structural conditions posing an imminent threat to safety occur when the lateral and/or gravity load-resisting systems supporting the building have been compromised. Common unsafe structural conditions include: imminent collapse, permanent lateral deformation (i.e., racking), undermining, and scouring. The professional should also be cognizant of potential hazards associated with falling debris, including partially detached roof and siding panels, curtain wall assemblies, signage, and other exterior features.

To assist professionals in the safety evaluation of a building damaged by wind or flooding, a field manual, ATC-45 *Safety Evaluation of Buildings after Windstorms and Floods,* was prepared by the Applied Technology Council. ATC-45 provides categories that define the extent of threat to life-safety, as follows:

- **Inspected:** No apparent hazard found, although repairs may be required. Original lateral- and vertical-load capacity not significantly decreased. No restriction on use or occupancy.
- **Restricted Use:** Safety is questionable or hazardous conditions exist (or are believed to exist) that require restrictions of the occupancy or use of the building. Entry and use have been restricted as indicated on the placard. (Note: Further evaluation may result in the building being posted as either Inspected or Unsafe.)
- **Unsafe:** Extreme hazard or unsafe condition present. Significant risk of further damage or collapse exists. Unsafe for occupancy or entry, except as authorized by the local building department. (Note: Posting a building as Unsafe is not a demolition order.)

ATC-45 training may prove beneficial to the investigating professional in communicating the degree of an unsafe condition to the affected parties.

7.4.2 Unsafe Non-structural Conditions

Hurricanes may result in unsafe conditions that are non-structural in nature. These conditions may be present in mechanical, electrical, plumbing, and/or other building systems. Examples of non-structural unsafe conditions include: live electrical wires, gas or chemical leaks, friable asbestos release, etc. The professional should be cognizant of potential egress hazards, which include items that prevent occupants from exiting the building during an emergency. Egress hazards may include blocked exit paths, inoperable exit doors, compromised ramps, and blocked stairways.

7.4.3 Notification Process

Proper notification should include verbal communication of the location and nature of the unsafe condition to parties present at the site who may be in immediate danger. Additionally, unsafe conditions should be communicated in writing, to the building owner or owner's representative through the client of the investigating professional. The professional must maintain written records of all notices or other communication issued. In the event that the unsafe condition poses a significant threat to the public, the building is a critical infrastructure facility, or the professional is of the opinion that the building owner or designee does not intend to rectify the unsafe condition(s), the local building officials should be notified in writing.

7.5 TESTING

In addition to a visual evaluation, testing may be an important part of a field investigation for hurricane damage to a building. Testing is classified as either "destructive" or "non-destructive." When possible, non-destructive testing is preferable, as it does not cause damage to the building and does not require repair work to remediate damage or distress caused by the testing process. In conditions of severe damage to finishes and/or structural elements, it may be possible to perform needed destructive testing on components that would have required remediation, regardless of the testing performed. As mentioned earlier, destructive testing will generally require approval by the client and/or the building owner. While the decision to perform the testing is at the discretion of the investigating professional, some types of testing are very useful in evaluating buildings for hurricane damage.

7.5.1 Roof Surveys

Roofing damage to buildings due to hurricane-force winds is common. Damage to roofing can vary from impact from wind-borne debris (including gravel impact from roofs in the vicinity of the subject structure), to displacement of flashing or roofing materials, to displacement of all or portions of the roofing and decking. A visual roof condition survey, including photographic documentation, should precede any roof testing. The testing required will vary based on the roofing type and project requirements.

It is often not feasible to test the entire roof surface, so testing is typically performed in sample areas. While the size of the sample area may vary at the discretion of the investigating professional, sample areas of approximately 100 square feet (one square of roofing) are most common. The number of sample areas and the location of sample areas should be determined to provide a representative sample of the roof. For a steep-sloped roof, testing is often performed in at least one sample area for each direction of roof slope.

7.5.1.1 Composition Shingle Roof

For composition shingle roofs, shingle adhesion surveys are useful for evaluation of wind damage. Shingle adhesion is evaluated by applying light upward pressure to the bottom lap of each shingle or shingle tab within the sample area. A shingle or shingle tab is considered to be partially un-adhered if the sealant strip has lost adhesion at less than half of the shingle or shingle tab, while the remaining portion of the shingle or shingle tab is still adhered. A shingle or shingle tab is considered to be fully un-adhered if the majority of the shingle or shingle tab (typically the entire shingle or shingle tab) can be lifted with light finger pressure. It is important to note that a lack of shingle adhesion can occur for many reasons unrelated to a hurricane.

The shingle adhesion survey should record the total number of shingles or shingle tabs and the number of partially and fully un-adhered shingles or shingle tabs, as well as the number of fractured or torn shingles or shingle tabs (flexural shingle distress). During the shingle adhesion survey, the professional should observe the condition of the sealant strips at un-adhered shingles for evidence of a previous seal and the pattern of dirt or debris, and should note the number of protruding roofing nails, especially for those occurring at sealant strips.

7.5.1.2 Low-Slope Roof

If the initial visual observation of a low-slope roof indicates suspected wind or debris impact damage, testing can be performed to establish the extent of damage. Typically, testing to establish the extent of hurricane damage to a low-slope roof consists of testing for moisture within the roof system or testing for detachment of the roof system from wind forces, or both. There are many types of low-slope roofing, and testing methods will vary depending on the particular roof system at the building being evaluated.

Many methods of non-destructive testing are available to determine moisture ingress, including infrared testing, nuclear testing, and surveying with a moisture meter. The validity of non-destructive testing for moisture ingress should be verified by selective destructive test cuts (or cores). During destructive testing, the insulation or substrate beneath the roofing should be measured for moisture with a pronged meter device for comparison with any prior moisture data obtained by non-destructive testing. If applicable, moisture content of wood framing should also be measured. Moisture measurements should be recorded for both the non-destructive and destructive portions of the testing (some non-destructive methods may be more "qualitative" than "quantitative" and, therefore, may not require specific numerical data). Visual observation and photographic documentation of the destructive test cores is also useful in evaluating the roof for moisture.

Testing to determine roof detachment or uplift will vary depending on the roof type. Uplift pressure testing should be performed in accordance with *Field Verification of Roof Wind Uplift Resistance* (FM 1-52) prepared by FM Global, to determine the extent of un-adhered membrane. This testing was developed for quality assurance evaluations of new roof systems and, therefore, the values from the testing should be considered in the proper perspective. For example, many older roof systems with weak substrates would not have passed this uplift standard even as first designed and installed.

For mechanically fastened low-slope roof systems, if visual evaluation indicates evidence of roof detachment, test cuts at fastener locations can be used for verification. The fastener locations should be observed for evidence of displacement during this destructive testing. The size and spacing of fasteners should be recorded to allow for additional analysis when applicable. The amount and location of test cores should be selected based on the nature of the investigation and should provide a representative sample of the roofing.

7.5.2 Plumbness Survey

Evaluation of wall plumbness and other elements throughout the building is useful if there is any question that the structure may be leaning (i.e., racking) due to hurricane-force winds. Plumbness surveys are commonly performed with a reliable digital level, although other methods may be used such as plumb bobs or laser surveying devices.

Measurements should be taken at multiple locations throughout the building as required by the geometry of the building and the nature of the investigation. Typically, the exterior corners of the building are included in the survey to evaluate the overall structural frame for any pattern of out-of-plumbness. Surveying doorways, windows, and openings in shear walls also provides useful information regarding the plumbness of the building.

Plumbness measurements should be recorded including the location of the measurement, the plumbness value (typically expressed as an angle or amount of out-of-plumbness over a measured distance), and the direction of lean, if any. It is often useful to record the plumbness measurements on building plans as described in Section 7.3.3.

It may also be useful to extend the survey to other buildings or structural elements at the site, such as small storage buildings and columns at shed roofs. Since these elements typically have less bracing than a building, they may clearly indicate lack of racking, or if there is racking, may provide clues as to the racking pattern consistent with wind forces. Since out-of-plumbness of walls is commonly due to as-built construction deficiencies and other causes unrelated to the storm event under investigation, it is important to compare the patterns of distress at brittle wall finishes in order to see if there is a correlation indicative of racking or out-of-plumbness due to lateral forces from the storm.

Plumbness measurements may also be useful for the evaluation of elevated buildings, such as those with piers or pilings beneath the first floor. A representative number of the piers/pilings should be measured for plumbness, generally in the two primary directions outlining the building's perimeter.

7.5.3 Foundation Elevation Survey

If the building has distress to interior and exterior finishes, such as fractures or separations in the exterior veneer or interior walls and ceilings, a relative elevation survey of the foundation is useful to evaluate the levelness of the foundation for differential foundation movement. This data can be used to correlate with the observed distress to determine the likely cause of distress. Relative foundation elevation surveys are especially useful in areas prone to differential soil movement, such as from expansive soils.

A manometer or hydrostatic altimeter (i.e., a corded liquid- or gas- type level) is typically the most useful tool for surveying buildings with interior demising walls. In some cases, such as warehouses or buildings with large open floor spaces, another surveying device, such as a self-leveling rotary laser level may be preferable.

The purpose of a foundation elevation survey is to document the levelness of distressed areas in addition to the overall levelness of the building's floor, thereby allowing assessment of any differential foundation movement from the horizontal plane. Foundation elevation surveys are not usually referenced to a permanent benchmark or datum elevation, although one may be used if available.

Survey points should be taken throughout the building on a grid. While the grid may vary depending on the project, a grid of 8 feet to 10 feet is typically sufficient. Consideration should be given to floor finishes and areas with sloped floor finishes (such as residential garages), and measurements should allow for adjustment of the elevation data back to the horizontal plane. Data from the foundation elevation survey can be recorded on graphic distress maps, as described in Section 7.3.3.

7.5.4 Moisture Damage Survey

A non-destructive survey with a moisture meter can be performed throughout the building to determine moisture damage to interior finishes. The validity of moisture measurements may be verified by further measurement with a pronged moisture measurement device or by destructive testing. For an accurate determination of moisture ingress at the building, the limitations of the measurement device must be considered, as must the conditions at the site. The location of the moisture meter and the moisture value data can be recorded on the graphic distress maps, as described in Section 7.3.3.

If indoor air quality is a concern due to exposure to water damage, fungal growth or other contaminants, it is recommended that a certified industrial hygienist test the building.

7.6 CONCLUSION

A field investigation is an important part of any forensic investigation of a hurricane damaged structure. Since some of the field evidence is perishable, there is a significant benefit to conducting the field investigation as soon as possible after the storm event. A good field investigation will provide valuable information for determining the nature and extent of damage, and the causes of the damage.

7.7 REFERENCES

Applied Technology Council. 2004. ATC-45 *Field Manual: Safety Evaluation of Buildings after Windstorms and Floods.* Applied Technology Council: Redwood City, CA.

DeLeon, M., and Pietrasik, P (2009). Assessing Wind Damage to Asphalt Roof Shingles. American Society of Civil Engineers (ASCE), ASCE 5th Forensics Conference: Forensic Engineering 2009 Pathology of the Built Environment. Proceedings of the Fifth Congress of Forensic Engineering, Washington D.C., November 11-14, 2009.

FM Global. FM Global Property Loss Prevention Data Sheets July 2012. Field Verification of Roof Wind Uplift Resistance (FM 1 – 52).

Lee, K., Caffey, J., and Killian, D. (2009). Structural Evaluation Procedures and Case Studies of Damage Related to Wind Storms, Tornadoes and Hurricanes. American Society of Civil Engineers (ASCE), ASCE 5th Forensics Conference: Forensic

Engineering 2009 Pathology of the Built Environment. Proceedings of the Fifth Congress of Forensic Engineering, Washington D.C., November 11-14, 2009.