EVALUATING STORM DAMAGE TO FLAT-ROOF ASSEMBLIES

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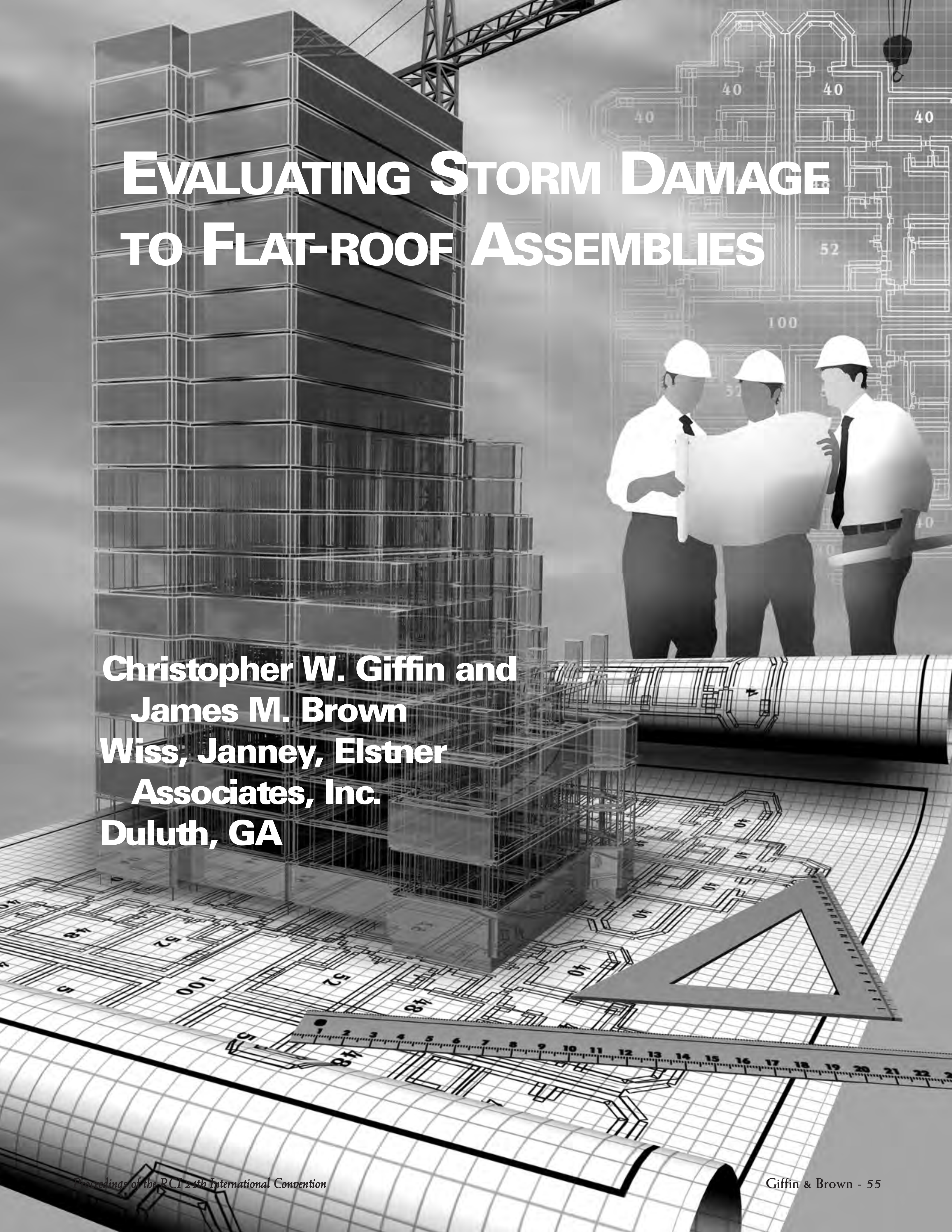

ABSTRACT

Roof systems are one of the most commonly damaged elements of the building envelope during natural disasters such as tornados and hurricanes. Determining if damage has occurred to a roof and the extent of the damage related to a storm event can be a difficult and controversial issue among building owners, professionals, and insurance companies. This paper will discuss how to utilize wind uplift field-testing procedures as a tool to assess and determine if an adhered roof system has failed from a storm event. The presentation will also review some of the tasks and procedures to follow when performing a detailed damage assessment. These tasks include collecting weather data, performing code research, documenting visual observations, and performing additional testing such as nondestructive testing (electrical capacitance meter, infrared imaging, etc.) and destructive test openings. Information gained from these tasks will assist in determining the existing conditions and the extent of damage from the storm event.

SPEAKERS

Christopher W. Giffin is a licensed architect specializing in the diagnosis and repair of building envelope problems. He has been involved with many roofing- and waterproofing-related projects having to do with both historic and contemporary structures. Notable projects include the Candler Building, the Grove Park Inn Resort & Spa, Chicago public schools, and U.S. Cellular Field. Giffin has performed numerous building envelope condition assessments and investigations, including storm damage assessments following hurricane and tornado events. He has also managed the design and construction period services for the installation of several new or renovated roofing and waterproofing systems.

James M. Brown is a licensed architect who has been involved with many specialized roofing- and waterproofing-related projects. He has experience with many different types of materials, including masonry, exterior insulation and finish systems (EIFS), and stucco. He has conducted building envelope condition assessments and storm damage assessments on several projects. He has also performed several different types of field tests for quality control purposes and for diagnosis purposes in investigations, including water testing, adhesion testing, and wind uplift testing.

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Evaluating Storm Damage to Flat-Roof Assemblies

INTRODUCTION

Roof systems are one of the most commonly damaged elements of the building envelope during natural disasters such as tornados and hurricanes. Determining if damage has occurred and the extent of the damage that may be related to the storm event can be difficult and controversial among building owners, professionals, and insurance companies. This paper will discuss how to utilize wind uplift field-testing procedures as a tool to assess and determine if an adhered roof system has failed from the storm event. The paper will also review some of the tasks and procedures to follow when performing a detailed damage assessment. These tasks include collecting weather data, performing code research, documenting visual observations, and performing additional testing such as nondestructive testing (electrical capacitance meter, infrared imaging, etc.) and destructive test openings. Information gained from these tasks will assist in determining the existing conditions and the extent of damage from the storm event.

After a major storm event, the condition of a roof system can be generally summarized as follows:

- The roof or building is at total loss. The roof is missing, or the building is damaged beyond repair.
- Some percentage of the roof is missing or a partial loss. Obvious visual dam age because of the storm has occurred.
- There is no readily apparent storm damage to the roof assembly.

For the first two conditions, evaluating storm damage to the roof system or determining what components have been affected due to the storm is generally evident. However, when it appears that there has been no discernable damage, and a claim has been made that the roof system has been compromised, determining if storm damage occurred and to what extent can often be contentious.

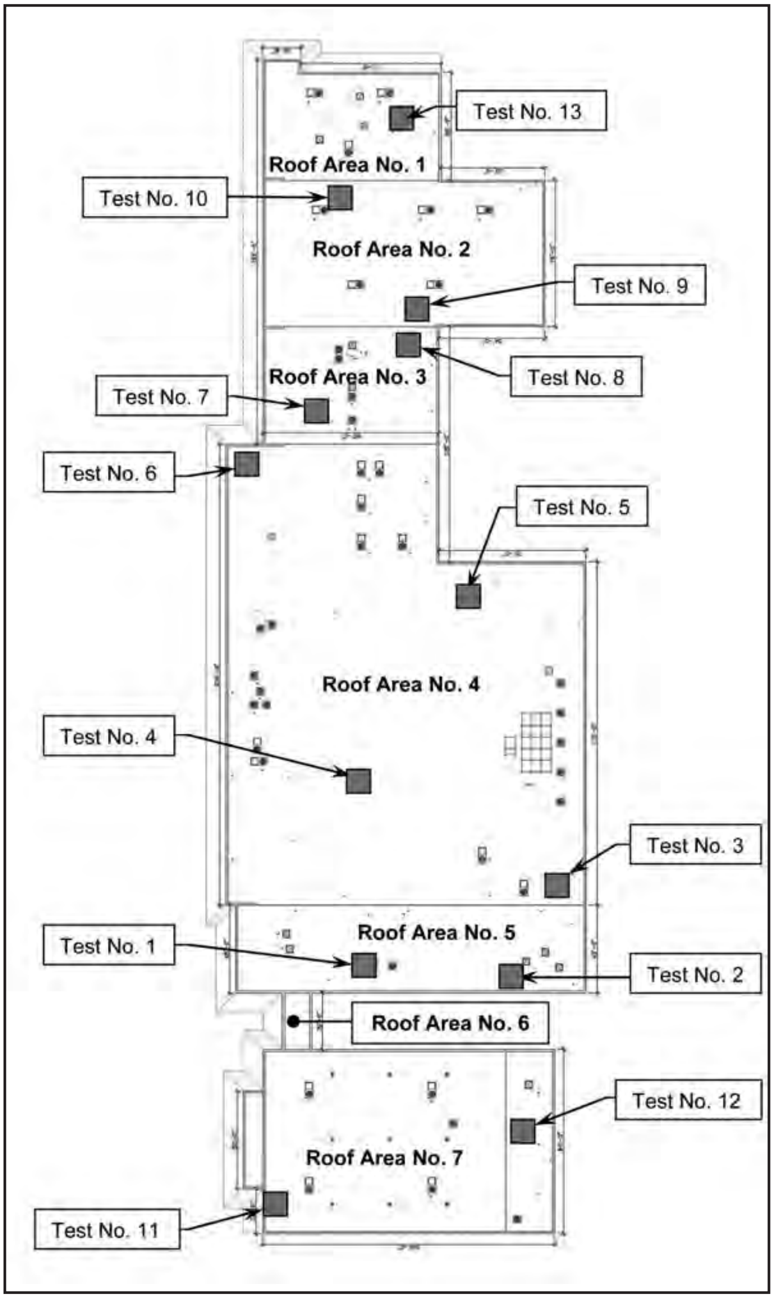

Figure 1 – Overall plan of roof area.

While in the United States, hurricanes and other severe storm events can occur anywhere along the Gulf or Atlantic coast, this paper will present experiences and observations made during numerous roof assessments following events that occurred in Florida in 2004 and 2005. The variety of construction types, evolving and changing building codes over the past decade, and the number of named storms during this period, resulted in several challenges in the assessment of storm damage to flat-roof assemblies.

HISTORY OF BUILDING

One part of assessing the roof system is acquiring any background information and historical records of the building and roof. This is important, as often the assessment involves evaluating or testing something that is old. Since the building codes have evolved to include more stringent wind speeds, newer roofs should be able to better withstand wind events and should perform better than a 25-year-old roof. Historical information may help to determine the existing condition of the roof prior to the storm event. Depending on the information available, it may help determine whether the roof can be repaired or if replacement is necessary. In addition, the information will aid in the visual observation portion of the assessment. If available, key information would include building orientation, the age of the building and the roof, the number of roofs, roof geometry, roof height, roof area, type of roof assembly, and the history of maintenance and repairs. Consideration should be given to any unique site conditions or building geometries that would create localized high-pressure zones, which may require closer evaluation.

Most of this information can be determined from the architectural drawings, previous assessment reports, contractor invoices from repairs, and from interviewing building owners or facility engineers. Some of this information can also be obtained or confirmed from the visual observations made during the assessment. Developing a roof plan that identifies the various roof areas, types of equipment, and other related components will be useful during the survey and testing portions of the assessment (*Figure 1*).

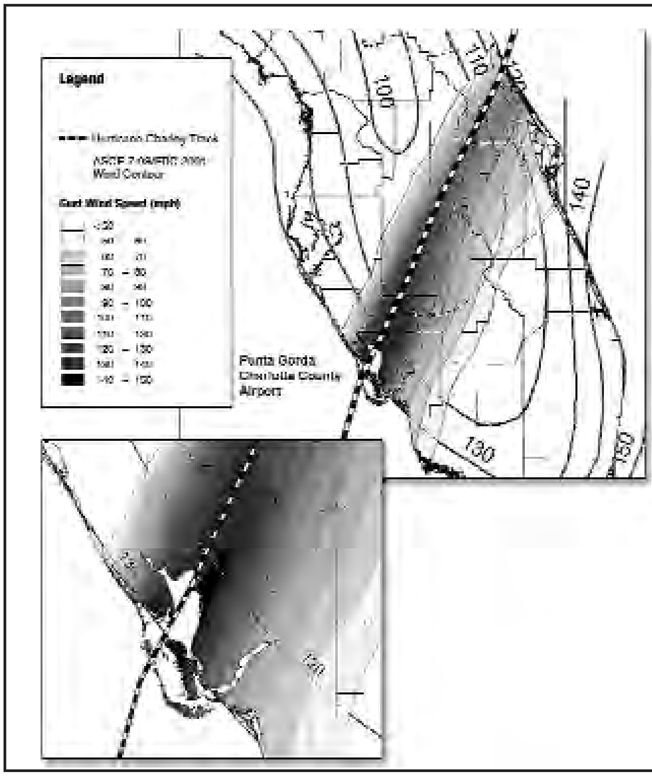

Figure 2 – Wind speeds as Hurricane Charlie crossed the Florida peninsula (image, courtesy FEMA).

Table 1. Common Form of Damage Based on Hurricane Category

Category	Wind Speed	Common Forms of Damage	Storm Surge
1	74 to 95 mph	Minimal damage, primarily to trees, foliage, shrubbery and unanchored mobile homes	4 to 5 ft above normal
2	96 to 110 mph	Moderate damage such as trees blown down, major damage to exposed mobile homes, and some damage to the building envelope such as roofs, doors, and windows	6 to 8 ft above normal
3	111 to 130 mph	Extensive damage such as large trees blown down, destroyed mobile homes, and some structural damage to roofs and small buildings	9 to 12 ft above normal
4	131 to 155 mph	Extreme damage such as large trees blown down, complete destruction of mobile homes, and extensive damage to roofs, doors, windows, and complete failure of roofs on small residences	13 to 18 ft above normal
5	Greater than 155 mph	Catastrophic damage such as complete failure of roofs on residences and industrial buildings, extensive damage to doors and windows, and some complete building failure	Greater than 19 ft above normal

WEATHER DATA

Acquiring weather data on the storm event can be helpful in determining storm-related damage. The purpose of gathering weather data is to understand the storm and its effects on the building. The data may not be available immediately after the storm. Over time, as more data are compiled and made available, the information can assist in analyzing and confirming field observations. The storm information generally provided consists of the hurricane category, wind speed, wind gust, location and path of the storm, location and path of tornados, hail, amount of rainfall, flooding, storm surge, and images of the storm and damage (*Figure 2*). The information is provided in various formats from charts, maps, illustrations, photographs, and

Figures 3 and 4 – Examples of natural weathering observed on a flat-roof system.

images. Storm-weather data can be collected from many sources and agencies. However, the most widely used agencies are the National Oceanic and Atmospheric Administration (NOAA), the National Weather Service (NWS), and the National Hurricane Center (NHC).

Hurricanes are rated from 1 to 5 on the Saffir-Simpson Hurricane Scale (*Table 1*). The ratings are based on the hurricane's sustained wind speed. The sustained wind speed is the speed of the hurricane sustained over the water for one minute. The rating scale also relates to the type of potential property damage created by the storm. Category 1 and 2 hurricanes are dangerous, warrant preventive measures, and cause moderate damage. However, hurricanes reaching Category 3 and above are considered major hurricanes and have a greater potential for loss of life and severe property damage.

DEFINITION OF DAMAGE

When performing a storm damage assessment on an existing roof membrane, defining what is damaged can often be challenging. If the roof membrane, insulation, and structural deck are missing or sitting on the adjacent property, it is easy to determine that the storm event produced the damage. The failure mode that initiated the damage can be varied; nonetheless, the storm played a key role in producing the damage. On the other hand, when the existing flat-roof membrane is still intact and there is no obvious visible damage, determining if the roof is damaged is not as clear.

In order to determine if damage has occurred, the definition of "damage" must be considered. A proposed definition of damage for flat-roof assemblies might include the lack of functional integrity, lack of water tightness, or the reduction of the expected service life of the roofing material. Damage can also be classified into two categories: deterioration and damage from natural weathering, and storm damage. There are distinct differences between these two forms of damage, and they need to be considered and documented in the assessment.

Natural Weathering

Natural weathering of granule-surfaced modified-bitumen and built-up roof membranes includes uniform loss of granules, exposed reinforcing fabric, cracked and brittle membranes, blisters, ridges, and splits (*Figures 3* and *4*). Natural weathering can also be from entrapped water within the roof assembly. Generally, water entrapped within a roof system is the result of repeated water infiltration into the roof system that occurs over a long period of time. While storm damage from punctures can allow water into the roof system, the entrapped water is typically isolated to the point of the damage, unlike widespread areas of entrapped water from natural weathering. Over time, entrapped water within the roof system will decay the underlying materials and weaken the cohesive strength of the material, or loosen the bond or adhesion between the various materials.

Granule- and gravel-surfacing loss from natural weathering is generally uniform throughout the roof area. Storm damage to granule-surfaced modified bitumen- and gravel-surfaced, built-up roof membranes typically results in localized areas where the granules or gravel are missing, exposing the underlying bitumen, typically at the corners of the building.

Wrinkles and ridges of built-up roof membranes are a form of natural weathering where, over time, moisture absorption by the roofing felts and cyclic fatigue produce the observed wrinkles and ridges. Curled or improperly attached insulation boards can also, over time, telegraph through the roofing membrane as ridges or wrinkles.

Blisters are the result of a void that is created between the roofing plies, or between the roof membrane and the underlying insulation, and are formed when the roof membrane is installed. Over time, blisters grow in size from the evaporation of liquid water and expansion of water vapor in the blister. As the blisters grow, they impart more stress on the roof membrane and can result in splitting of seams or rupturing of felts, allowing more water over time to infiltrate into the roofing system.

Natural weathering of thermoplastic roof membranes can include plasticizer loss, membrane embrittlement, loss of reflectivity, and dirt accumulation. For thermoset membranes such as ballasted EPDM membranes, there is a tendency to shrink and pull away from the perimeter flashings.

Figure 5 – Example of storm damage to granule-surfaced modified-bitumen membrane from glass debris.

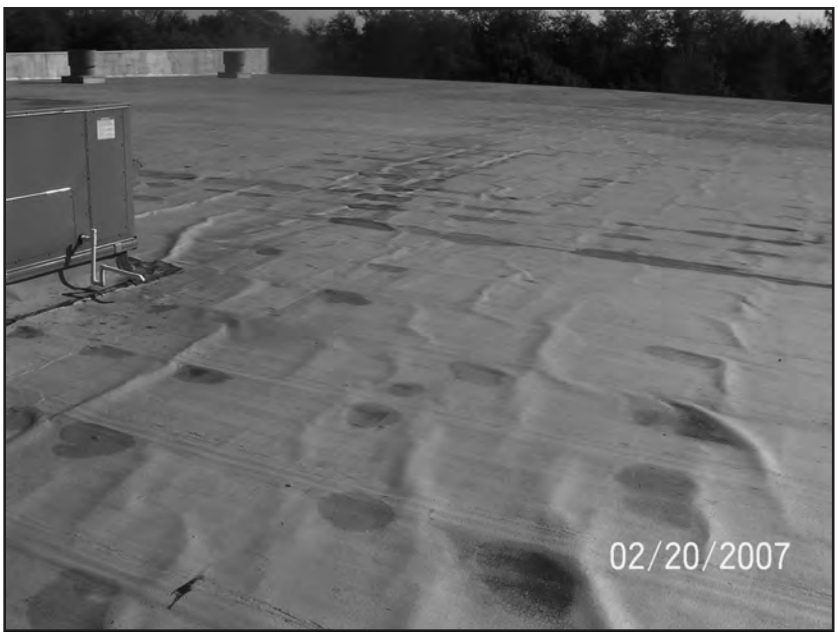

Figure 6 – Example of wind uplift damage to a portion of a smooth-surfaced modified-bitumen roof membrane.

Storm Damage

Storm damage to granule-surfaced modified bitumen and built-up roof membranes includes punctures and scrapes from foreign object impact, scoured and missing areas of granules or gravel surfacing, uplifted and detached roof membrane, broken and damaged roof insulation, and missing areas of the roof assembly (*Figure 5* and *6*). Storm damage to fully adhered thermoplastic and thermoset membranes can include punctures, cuts and tears, uplifted and detached roof membrane, broken and damaged roof insulation, and missing areas of the roof assembly.

Storm damage to the roof membrane is generally accompanied by damage to other items on the building or roof area. This might include damaged and blown-off sheetmetal copings, gutters, or fascias; dented or damaged rooftop mechanical units; or damaged or missing components of the exterior wall. Other indicators of storm-related damage and its intensity in the area can include fallen trees or light poles, broken windows and doors, or damaged signs and awnings.

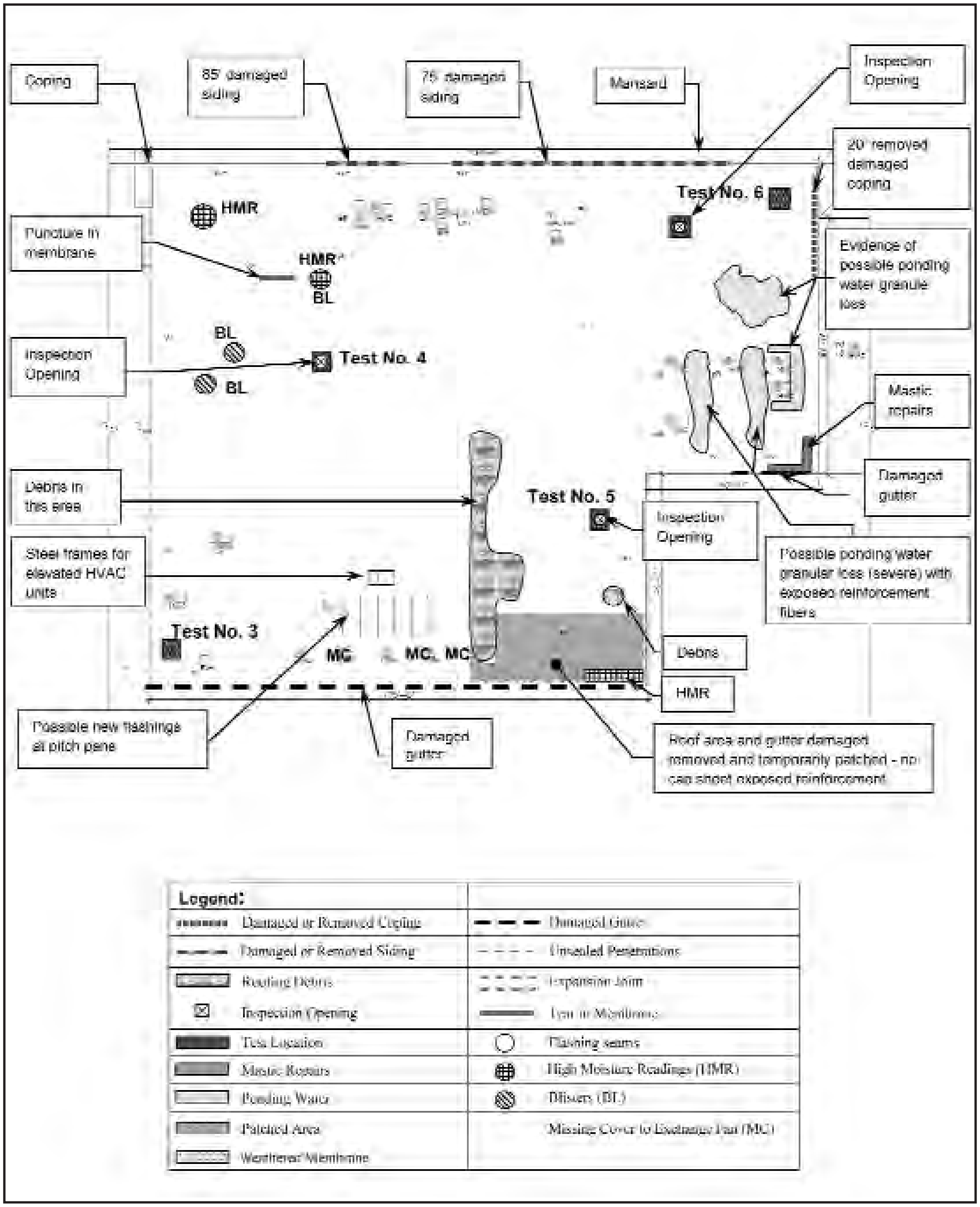

Figure 7 – Roof survey plan identifying locations of damage.

VISUAL OBSERVATIONS

After obtaining and reviewing the historical data, a visual survey of the building and the roof should be performed. The purpose of the survey is to identify, locate, and document any damage to the building and roof. These observations are critical in determining if the damage is a result of the storm event, natural weathering, or previous damage. If the damage is storm-related, the observations are important in determining if defective design or installation were a contributing factor to the loss. The visual survey is conducted in a manner similar to a normal roof maintenance inspection.

A roof plan should be used to illustrate the location of all the pertinent observations and damage. Use the most recent version of the roof plan. If a roof plan is not available, one should be drawn up while on the roof. The roof plan should be to scale and should illustrate the locations of different types of roof edges, roof equipment, penetrations, and accessories (*Figure 7*). Photographs of the observed conditions should be taken.

The survey should also include an inspection of the underside of the roof deck, exterior walls, and areas adjacent to the building prior to inspecting the roof. The underside of the roof may reveal signs of water intrusion, rust, dry rot, poor attachment, roof uplift, or other problems that may be the result of previous damage or the storm event. Special attention should be given to roof penetrations and along the perimeter of the exterior walls. If the visual damage to the roof membrane extends to the edge of the roof, thoroughly document the roof-edge detail. Determine the materials used along with the fastener types and their relative location and spacing. The observations should be noted and illustrated on the plan so they can be translated to the roof surface. The exterior walls may reveal signs of water staining, cracks, settlement, plumbness, movement, debris impact, and damage to drainage accessories such as downspouts, gutters, and scupper heads. When inspecting the exterior walls, observe and document the adjacent areas for storm surge and amount and type of debris. This is important to help understand the effects of the storm event.

The roof membrane and adjacent rooftop features or elements should be inspected for both natural weathering damage and storm damage. All deficiencies and defects should be noted on the roof plan. Note the general appearance and condition of the roof, and document the locations and frequency of the deficiencies and defects.

Natural weather damage items may include the following:

- Blisters.
- Membrane slippage.
- Fishmouths.
- Alligatoring of the flood coat.
- Splits.

Figure 8 – View of uplift test in progress.

- Ridges.
- Granule and gravel surfacing loss.
- Ponding water.

Storm damage items may include the following:

- Debris impact, resulting in punctures and scrapes in the membrane, which can allow water to infiltrate into the roof assembly.
- Hail impact damage, resulting in localized granule loss, which can lead to accelerated deterioration and aging of the roof membrane.
- Membrane bruising.
- Possible exposure of the roofing felts.
- Adhesion loss of the membrane to the substrate.
- Wind scouring, resulting in areas of missing granules or gravel surfacing, which can lead to accelerated deterioration and aging of the roof membrane and absorption of water at areas of exposed membrane.
- Areas of uplifted and detached roof membrane or substrate materials.

When performing the roof survey, the following are a few additional items to be aware of and to document as part of the storm damage assessment:

- Inspect the perimeter flashings for normal deterioration, granule loss, punctures, tears, open lap seams, wrinkles and ridges, and flashing attachment along the top edge, if any.
- Inspect embedded edge metal and gravel stops, as they can tear the membrane due to the differential thermal movement of the roof membrane and the embedded metal.
- Inspect the counterflashings for attachment, rusting, dents, bent sections, punctures, and open seams that may prevent the counterflashing from protecting the base flashings.
- Inspect the copings and cap flashings, as they protect the roofing and wall systems. Check for attachment, dents, rusting, punctures, and open seams. If water bypasses the coping and cap flashings it has a greater chance of infil-

trating the roof and wall system.

- Inspect penthouse and clerestory walls for deterioration, defects, and damage, as they can contribute to water infiltration and damage to the roof assembly.
- Inspect the flashings at all roof penetrations. Observe and note the conditions of the lap seams, membrane, seals or sealants, lead flashings, draw bands, and metal rain hoods. Note if the pourable sealer in the pitch pans is weathered, underpoured, or not adhered to the penetration substrate.
- Inspect the condition and attachment of any expansion joints. Ensure the expansion joint is free from defects and performs in a watertight manner.
- Survey the roof equipment. Note the condition of and attachment of the roof equipment, if any of the equipment is damaged or missing, and if the equipment rests directly on the roof.

FIELD UPLIFT TESTING

Three standardized roof uplift tests exist. They are as follows:

- ASTM E907, Standard Test Method for Field Testing Uplift Resistance of Adhered Membrane Roofing Assemblies.
- FM Global Property Loss Prevention Data Sheet, Field Uplift Test 1-52.
- Florida Building Code, Test Protocol HVHZ Testing Application Standard (TAS) 124.

Each of these tests generally outlines similar procedures to determine the uplift resistance of an adhered roof membrane with either a negative pressure bell chamber or a bonded pull test. When performing uplift tests in a storm damage assessment, the bell chamber test is typically more practical and efficient to perform. These test methods are intended to be used as a measure of the uplift resistance of the roofing system. The tests apply to roof systems with or without rigid board insulation or base plies, which are either adhered or mechanically fastened, and fully adhered membranes.

The uplift test is performed by creating a controlled negative pressure on top of the roof surface by means of a fitted plastic chamber with a pressure-measuring device and vacuum equipment (*Figure 8*). A 5-ft x 5-ft square plastic chamber is placed over a deflection bar with a dial indicator attached. The perimeter of the chamber is then temporarily sealed to the roof surface. The dial indicator is positioned so that the tip of the dial indicator is in contact with the roof membrane near the center of the test area. A pressure-measuring device (manometer) and the vacuum equipment are attached to the holes provided in the chamber. The vacuum equipment is activated and adjusted to regulate the negative pressure in the chamber to specified levels. According to the test procedures, a negative pressure of 15 lbs per sq ft (psf) is created in

Table 2. Uplift Test Results at Various Pressures

	15 psf Uplift		22.5 psf Uplift		30 psf Uplift		45 psf Uplift			
Test No.	Gauge at 0 Seconds (in.)	Gauge at 60 seconds (in.)	Gauge at 0 Seconds (in.)	Gauge at 60 seconds (in.)	Gauge at 0 Seconds (in.)	Gauge at 60 seconds (in.)	Gauge at 0 Seconds (in.)	Gauge at 60 seconds (in.)	Total Deflection at 45 psf (in.)	Comments
1	0.0000	0.0569	0.1156	0.1208	0.1900	0.2222	0.3570	0.3985	**0.3985**	
2	0.0000	0.3980	0.5390	0.5630	0.6730	0.7000	0.9687	1.0640	**1.0640**	
3	0.0000	0.3100	0.0407	0.1052	0.1370	0.1471	0.2140	0.2864	**0.2864**	
4	0.0000	0.5420	0.5776	0.8571	0.9730	1.1390	1.3600	1.6445	**1.6445**	
5	0.0000	0.1365	0.1836	0.1933	0.2309	0.2449	0.3042	0.3918	**0.3918**	
6	0.0000	0.0388	0.0401	0.0490	0.0501	0.0629	0.0668	0.1156	**0.1156**	
7	0.0000	0.1320	0.2430	0.3123	0.3196	0.3564	0.3759	0.4722	**0.4722**	
8	0.0027	0.6684	0.6684	0.9839	1.0724	1.7510	1.2390	1.3706	**1.3679**	
9	0.0000	0.2561	0.3740	0.4064	0.5098	0.7889	0.9648	1.1248	**1.1248**	
10	0.0038	0.4021	0.4595	0.6711	0.7920	0.8044	0.9960	1.0354	**1.0316**	
11	0.0096	0.0162	0.0206	0.0236	0.0276	0.0286	0.0355	0.0381	**0.0285**	
12	0.0000	0.0089	0.0089	0.0093	0.0123	0.0138	0.0214	0.0214	**0.0214**	
13	0.0120	1.2768	1.2768	1.4450	1.4450	1.5938	1.5938	1.5940	**1.5820**	Movement occurred instantaneously to 1.25" and gauges peaked at 1.5940 in.
14	0.0020	0.2344	0.2590	0.2657	0.2981	0.3017	0.5946	0.6246	**0.6226**	
15	0.0000	0.4472	0.5075	0.5961	0.6184	0.6445	0.7900	1.0119	**1.0119**	
16	0.0030	0.0335	0.0450	0.0471	0.0585	0.0616	0.1007	0.1041	**0.1011**	
17	0.0050	0.4784	0.6190	0.6648	0.8252	0.8494	1.0750	1.2450	**1.2400**	Sudden jump during 45 psf - fastener pop

Table 3. Weather Data During Uplift Test

Test Number	Wind Speed (mph)	Air Temperature (°F)	Roof Surface Temperature (°F)	Relative Humidity (%)	Barometric Pressure (inHg)	Heat Index
1	4.0	83.5	96.0	70.9	30.05	
2	2.0	88.6	100.5	58.0	30.07	
3	4.5	86.6	97.0	65.7	30.06	96.1
4	4.0	86.0	95.2	57.0	30.05	
5	5.5	84.0	96.0	63.0	30.04	91.9
6	4.5	88.0	98.2	55.9	30.05	94.7
7	5.9	88.9	100.7	50.2	30.06	97.3
8	2.5	88.9	102.5	52.0	30.05	97.6
9	3.8	88.8	99.3	55.4	30.05	95.4
10	1.8	88.5	98.5	55.0	30.03	95.7
11	1.5	85.2	94.0	62.6	30.04	
12	2.1	82.4	94.6	66.0	30.05	
13	10.0	85.0	99.7	68.5	30.04	
14	10.0	85.0	100.3	68.5	30.05	
15	5.0	90.0	105.0	56.0	30.05	
16	5.0	90.0	104.4	56.0	30.05	
17	4.2	90.0	105.8	55.0	30.05	

the chamber and held for one minute. The negative pressure in the chamber is then raised in increments of 7.5 psf and held for one minute at each increment. The maximum negative pressure we created in the chamber was typically 45 psf. The deflection of the roof membrane is measured at the beginning and end of each increment (*Table 2*). In addition, the air temperature, roof temperature, relative humidity, barometric pressure, and wind speed were recorded for each test location (*Table 3*).

The test methods state how many uplift tests should be performed given the size of the roof area. Typically, a minimum of four tests should be performed, with one additional test for every 10,000 sq ft. The selection of the test area should be made carefully. Locations where tests should be performed are adjacent to visibly damaged areas, corner conditions, perimeter or edge conditions, and interior field conditions.

According to ASTM 907 and TAS 124, failure of the roof membrane occurs when the roof is uplifted 1 inch or a sudden ballooning occurs. FM 1-52 classifies failure when a quarter inch of roof deflection is achieved. Depending on the deck type, insulation, or membrane system, this amount of deflection may be too limiting. Therefore, during our assessment, we generally use the 1-in failure classification. In addition, the standards state that the uplift tests are to be performed when the roof surface temperature is between 40°F and 100°F.

One of the problems that can be encountered when performing the uplift test is obtaining false results. One of the issues that can be frequently encountered is that the placement of the chamber over insulation joints or between fasteners can potentially skew the results. If the chamber is placed over steel joists or at a beam location, a stiffer roof assembly will be tested compared to placement of the chamber between a series of joists. When performing these types of tests for quality assurance purposes, factors such as these can be important to know if a roof system passes or fails. However, when performing an uplift test during a storm damage assessment to determine if damage may exist, the low pressures typically needed to determine if a roof is damaged or not are generally not affected by some of these other conditions.

These applied pressures are often well below the design uplift pressures for the building, since only the weight of the roof materials needs to be overcome by the negative uplift force. Therefore, for the purposes of assessing whether uplift damage has occurred to a roof-membrane assembly, the initial negative load of only 15 psf will likely be an indicator whether the roof system is adhered. If the roof surface is not adhered, 15 psf of uplift pressure will normally exceed 1 inch. If a roof membrane resists a negative pressure for some period then fails at some higher negative pressures, the roof membrane was initially adhered, not damaged from the storm, and failed due to the negative pressures applied during the test.

Uplift Test Pressures

ASTM E907 states the negative pressure in the test chamber shall be increased "until the agreed-upon pressure is reached." During the course of damage assessments, determining what the agreed-upon pressure is can be difficult. For the purposes of assessing if damage has occurred, a maximum negative pressure of 45 psf is often sufficient. The selection of this test pressure was based upon the rationale that if a fully adhered roof membrane was uplifted and damaged during a storm event, the roof would no longer be adhered to the substrate, and little negative pressure would be needed to overcome the weight of the roof materials and lift them above the 1-in failure distance.

Some testing agencies, owners, or contractors may elect to use uplift pressures calculated using the latest building-code requirements. Several problems become apparent when using these uplift pressures to measure hurricane damage and define what constitutes failure of the test. The age of the roof on the building needs to be considered. If a roof system is 20 years old, the design pressures at the time the roof was installed were likely less than those used by today's building code. Over the past 10 to 15 years, the wind velocities and gust coefficients have increased in each building-code revision to better reflect the forces that actually occur during a hurricane. The weather data obtained from the storm event could also be used to calculate what the likely uplift forces might have been at the time of the storm. This could then be compared to the original design pressures, as well as the uplift testing results.

In south Florida, for example, if the roof assembly was installed in 1996, the design wind speed was 110 mph. However, if the same roof were installed using the current building code, the design wind speed would be 140 mph. This results in a significantly higher uplift pressure applied to the building. Using the current building-code design pressures to determine if damage has occurred or if an existing building can meet these requirements is an inappropriate use of the code. One cannot expect a roof that was installed several years ago, using lower design pressures, to be able to resist the higher, modern, building-code design pressures. In our opinion, this does not meet the definition of storm damage.

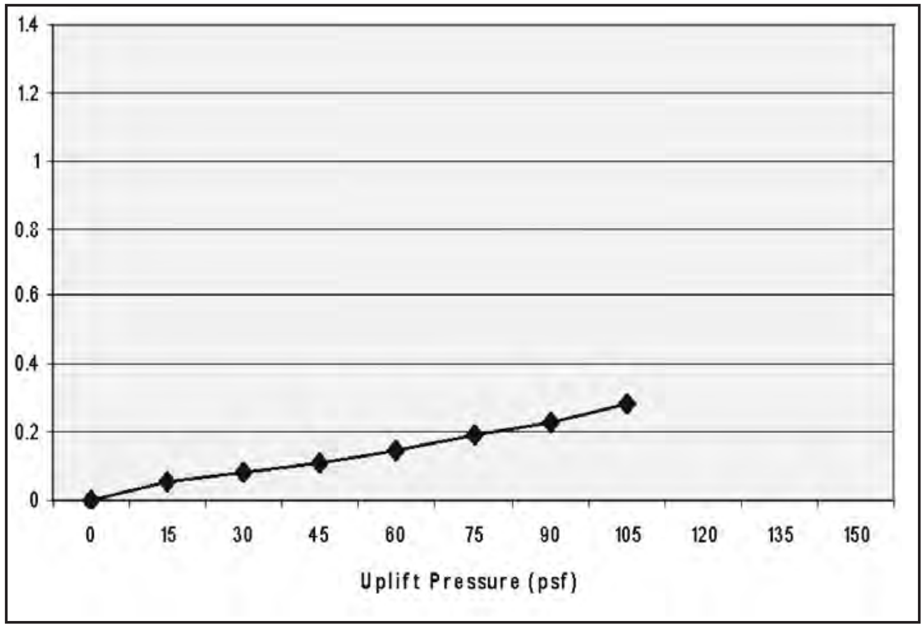

Figure 9 – Diagram Type 1 where the roof is well adhered during the uplift test.

Definition of Failure

The uplift test procedure outlined in ASTM E907 can be used on an existing roof assembly to determine if storm damage occurred. Similar tests are also outlined in FM Global 1-52 and TAS 124. When utilizing these tests on existing roof assemblies, a thorough understanding of the roof composition and existing conditions and the negative pressures that will be applied need to be fully evaluated. ASTM E907 states in paragraph 9.1, "Most roof systems subjected to a negative pressure will exhibit an upward deflection that will increase as the negative pressure increases. Poorly adhered systems will exhibit relatively large increases in upward deflections with relatively small increases in applied pressure. For roof systems that are well adhered, the increase in deflection will be gradual and at a relatively constant rate up to a point at or near failure. When failure occurs due to lack of adhesive or cohesive resistance of the roof system, there will be a sudden increase in the upward deflection." In addition, according to the ASTM E907 test method, failure during the test also occurs when the deflection of the roof membrane exceeds 1 inch, even if no sudden increase occurs. FM Global 1-52 limits the maximum deflection to 1/4 inch. However, for light-gauge metal deck and bar-joist roof systems, the maximum limit for deflection of 1 inch is more common and would provide a more reasonable measure of storm damage during these types of assessments.

During the test, the deflection is measured at each negative pressure increment. If these two variables are plotted on a chart, a stress/strain diagram can be drawn illustrating the relationship of deflection to applied load on the roof assembly. Based upon our uplift testing experiences and ASTM definitions, four general types of stress/strain diagrams can be developed.

The first type of diagram illustrates a roof that performs well during the uplift test. This is indicated by a shallow sloping line that gradually increases in deflection as the negative pressure is applied (*Figure 9*). The deflection of the roof also does not exceed 1 inch during the pressure increments. This test demonstrates that the roof assembly was well adhered and attached to the structure prior to the start of the test and remained attached upon completion of the test. As a result, the tested roof membrane was not uplifted by a storm event.

The second type of diagram is an increasingly steeper curve, or an exponential type of curve where the line starts out on a shallow slope, then increases during each pressure increment (*Figure 10*). This would indicate that the roof assembly resisted the initial negative loads applied, then progressively delaminated cohesively or adhesively as the pressures increased. The deflection recorded at the end of the test may or may not have exceeded 1 inch. With this diagram, there is no clear spike or sudden increase in the deflection as the pressure increases. This test demonstrates that the roof assembly was well adhered and attached to the structure prior to the start of the test and failed during the test, if the deflection exceeded 1 inch. As a result, the test also indicates the tested roof membrane was not uplifted by a storm event.

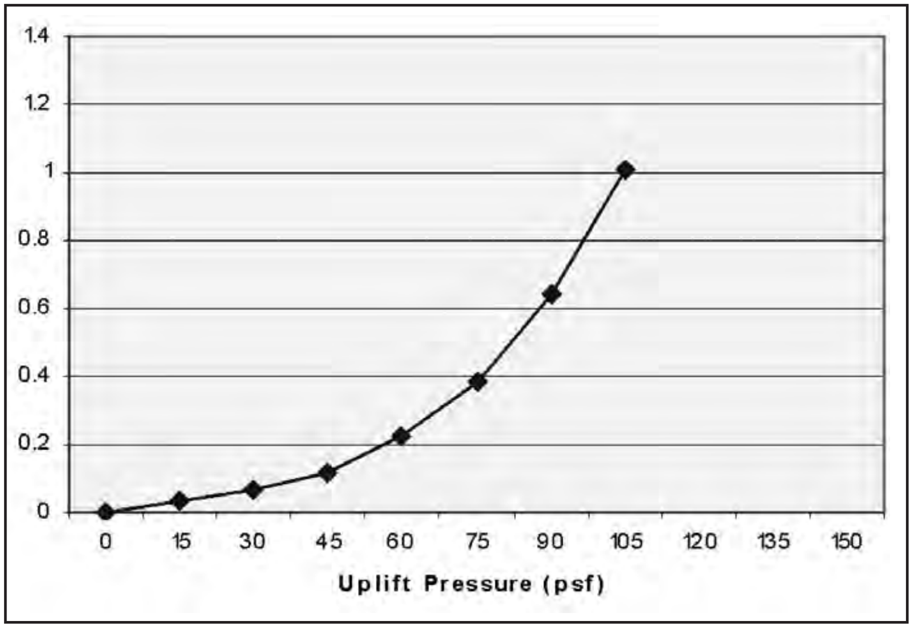

Figure 10 – Diagram Type 2 where the roof progressively fails during the uplift test.

The third type of diagram would be one that initially starts out with a shallow line similar to the first graph, and then jumps steeply upward within one pressure increment (*Figure 11*). This type of diagram would indicate the roof assembly was well adhered during the initial loadings, then failed suddenly – either cohesively or adhesively – during the test and was no longer attached. Often, the deflection recorded with this type of diagram would exceed 1 inch. This test demonstrates that the tested roof assembly was well adhered and attached to the structure prior to the start of the test, and failed during the test. As a result, the test also indicates that the roof area was not uplifted by a storm event.

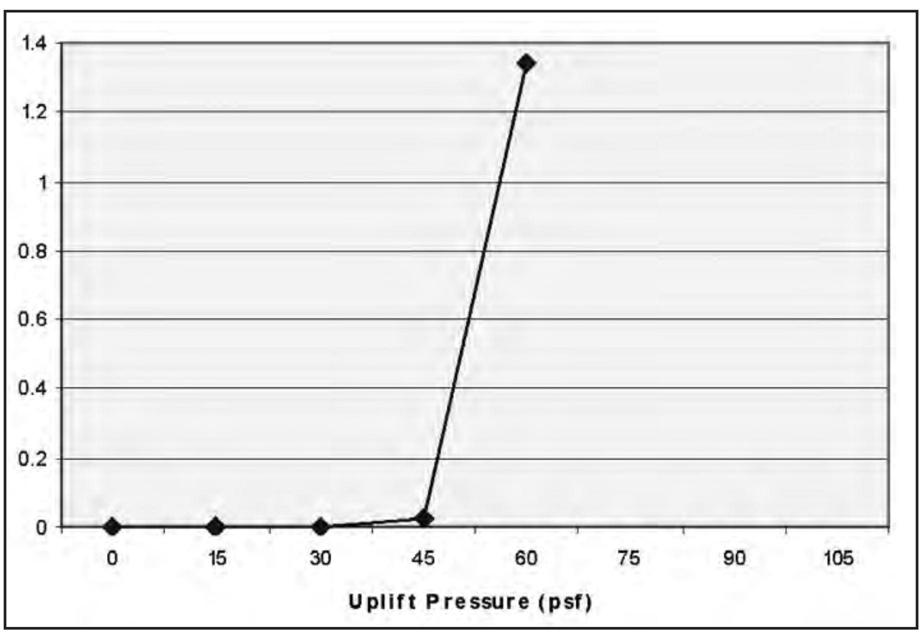

Figure 11 – Diagram Type 3 where the roof suddenly fails at a high load.

The fourth type of diagram is one that jumps steeply upward within the first pressure increment (*Figure 12*). This type of diagram would indicate the roof assembly was not attached, as it could not resist any load. Often, the deflection exceeds 1 inch within the initial 15-psf negative loading. This type of diagram might indicate that the roof was uplifted and damaged during a storm event. It is important to note that further investigation

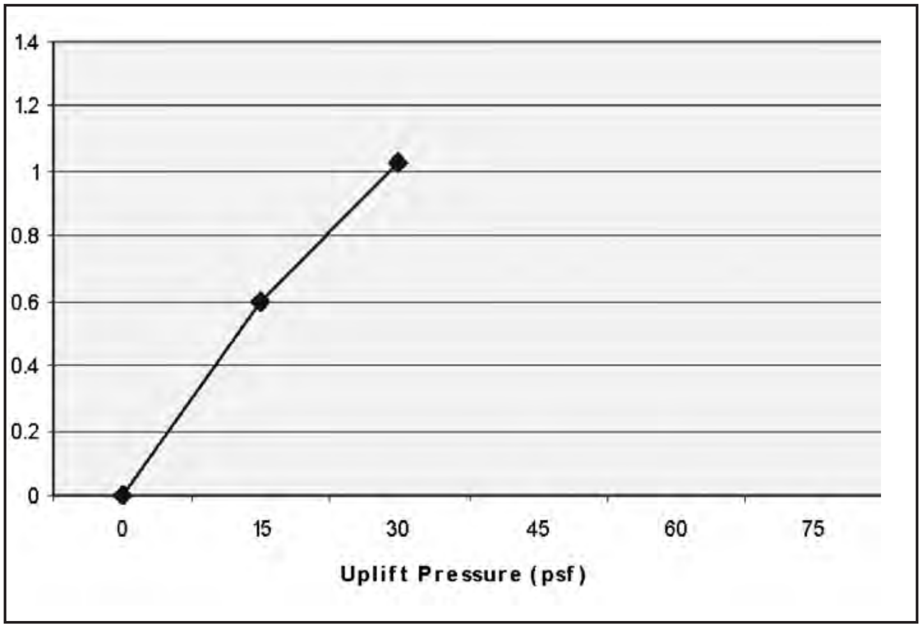

Figure 12 – Diagram Type 4 where the roof membrane is not adhered.

and analysis are required to determine the failure plane within the roof assembly and the condition of the installed materials. This is often done with inspection openings at the test location to identify why and how the roof failed the test. The delamination and failure of the roof could be the result of installation problems, wet materials, natural weathering, or from storm damage.

The fourth type of diagram is the only one of the four mentioned where actual storm damage might have been detected. Inspection openings are required to verify the test results and to confirm if the lack of uplift resistance was from storm damage. The other three stress/strain diagrams indicate that the roof assembly was not damaged as a result of a storm. When a roof membrane is subjected to the negative pressures exerted on it by the effects of a storm, the roof materials will either resist the pressures or fail and become detached from the substrate. When roof assemblies are uplifted to the point of failure during a storm event, the effects are immediate and irreversible. The roof system is then no longer attached, and thus cannot withstand any future applied load, either from wind or during subsequent roof-uplift testing. Therefore, if a roof assembly has been uplifted and damaged during a storm event, it will not resist much negative applied load, and large initial deflections will occur when tested.

As stated in ASTM E907, poorly adhered roof systems or roof systems that have been damaged or uplifted by a storm event exhibit relatively large increases in upward deflection with relatively small increases in applied pressures. These applied pressures are often well below the design-uplift pressures for the building, since only the weight of the roof materials needs to be overcome by the negative uplift force. Therefore, for the purposes of assessing whether uplift damage has occurred to a roof-membrane assembly, the initial negative load of only 15 psf will likely be an indicator of whether the roof system is adhered. If a roof membrane resists a negative pressure for some period, then fails at some higher negative pressures, the roof membrane was initially adhered and not damaged from the storm, and failed due to the negative pressures applied during the test. This would correspond to diagrams one, two, and three. In addition, when evaluating an older roof system, the uplift tests might also indicate the existing roofs do not meet the current building code uplift requirements, but this is not damage from a storm event.

NONDESTRUCTION EVALUATION METHODS

The three main nondestructive tests for evaluating the presence of moisture within a roof assembly are infrared thermography, electrical capacitance, and nuclear detection. Depending on the type of roof assembly being evaluated, each of these tests has advantages and disadvantages that need to be considered in the evaluation process. Performing these types of tests can be of assistance in determining the extent of entrapped water within a roof assembly. By themselves, these tests may not be able to identify if the entrapped water is a direct result of the storm, only that water is entrapped in the assembly.

If a corner or section of the roof has been damaged, the nondestructive tests could be performed on the intact adjacent roof areas to determine if water exists in the roof that likely occurred as a result of the storm. Conversely, if no apparent roof damage can be identified, yet there are a number of natural weathering-related conditions present, along with areas of entrapped water, it is possible the entrapped water is a result of damage due to natural weathering and has been entrapped in the roof for a significant amount of time. It is also possible that the effects of long-term entrapped moisture can influence the bond of the roof membrane to the underlying insulation, which can be misinterpreted as storm damage. The combination of the visual observations, uplift testing, and inspection openings can then be used to help determine if these areas have been damaged by the storm.

INSPECTION OPENINGS

When performing an evaluation of storm damage on a flat-roof assembly, inspection openings can provide critical clues into whether the roof system has incurred roof damage. Upon completion of the uplift test where the roof assembly has exceeded the 1-in failure deflection criteria, an inspection opening should be made. It should also be noted at what pressure the 1-in failure occurred and what type of roof uplift curve was generated, as this can provide clues to the mode of failure.

The inspection openings should be approximately the same size as the uplift chamber or 5 ft x 5 ft. An inspection opening of this size will generally allow for examination and determination of many conditions, including

- The existing roof materials and their condition.
- The amount and spacing of insulation fasteners.
- Types of fastener plates.
- The location of board joints.
- The amount of adhesive used and its coverage area.
- The presence of moisture in the roof system.

The mode of failure should be determined in the inspection opening, and this information can be used to determine if the results of the uplift testing curve are in agreement with the inspection openings. This would confirm if the uplift test damaged the roof assembly, or if the roof was damaged as a result of the storm event. This information can also be used to compare the estimated uplift forces that may have occurred during the event. In addition to the inspection openings at the uplift test location, inspection openings taken in an adjacent or nearby roof area would further support the results of the uplift test and observations of the inspection opening at the chamber.

BUILDING CODE SUMMARY

Researching and interpreting the relevant building codes is essential in determining the possible repair methods for storm-damaged roof areas. In this instance, the applicable building codes are the current building codes at the time of the event and not the building codes used or defined during the design and construction of the building. In some cases, more than one code may be applicable to the building. Be sure to check for both state and local codes and to follow the most stringent applicable code, ensuring all of the amendments and supplements have been collected. Building codes have an evolving language, and the amendments and supplements may contain changes to the originally issued code that can affect the repair method on the building.

A thorough review of the code is also needed to determine the classification of, or the level of work to be performed. For example, if using the Florida Building Code, the classification of the work and the level of alteration or combinations of levels must be selected prior to determining the subsequent applicable provisions. Work on existing buildings, including roofing-related work, can be classified as either Repairs, Alteration – Level 1; Alteration – Level 2; or Alteration – Level 3. Each classification has distinct requirements and parameters.

CONCLUSIONS

When performing a storm-damage assessment on an existing flat-roof assembly, the following are some of the tasks that could be performed so that a full and accurate assessment can be made:

- Determine the history and background of the building and roof construction.
- Obtain the weather data surrounding the storm event.
- Determine what damage has resulted from natural weathering and what damage has occurred from the storm event.
- Conduct a visual survey of the roof and surrounding building elements.
- Conduct a wind uplift testing of the roof system to determine the uplift resistance of the system.
- Conduct nondestructive moisture surveys to document entrapped water in the system.
- Make roof inspection openings to determine the mode of failure and type of damage in the roof system
- Determine the applicable code requirements for repair or replacement of a damaged roof section.

Each of these tasks in the storm-damage assessment can provide vital information in helping to determine the extent of storm damage. Depending on the roof assembly and potential issues being evaluated, a thorough storm-damage assessment will often require performing many, if not all, of these tasks. The observations and findings, after each task, need to be compared against the observations and findings from the other tasks to ensure they complement and support the overall assessment of the roof condition. Simply performing a visual inspection, making inspection openings, or conducting a series of uplift tests alone may not yield enough information to make a full and accurate assessment.

Wind uplift testing may be necessary to determine if the storm event damaged the attachment of the roof membrane or insulation to the substrate, which would otherwise be missed if a visual survey of the roof were performed. Uplift testing can be effectively used as an evaluation tool but will need to be used in conjunction with inspection openings. Many underlying conditions may affect the results of uplift testing, such as the placement of the chamber over insulation joints, fasteners, steel joists, or beams. These factors can influence the stiffness of the roof assembly. Therefore, it is important to perform an inspection opening after an uplift test to document these underlying conditions. The inspection openings are also useful for determining the existing roof materials and their condition and the mode of failure from the uplift test, if any.

Establishing the definition of failure and performing uplift testing to agreed-upon test pressures is essential in storm-damage assessments. Performing the uplift test pressures on the roof membrane up to the design pressures or even to failure is often not necessary to determine if the roof membrane has been uplifted or damaged by the storm. The uplift testing can be performed in incremental pressures to determine if the roof membrane is adhered to the substrate. Typically, incremental pressures of 15 psf, 22.5 psf, 30 psf, and 45 psf will provide enough information on the current performance of the roof membrane (without ultimately damaging the roof at the test area) to determine if storm damage has occurred. Entering the uplift test results into a chart and graphically illustrating the stress/strain diagram will also provide a good indication if the roof is damaged. High deflection of the roof membrane at low pressures will indicate the roof has been previously uplifted and damaged from the storm. Conversely, low deflection of the roof membrane at low pressures and incrementally increasing pressures will indicate the roof is adhered and was not damaged by uplift from the storm.

The current standardized uplift tests limit the testing to when the roof-surface temperature is between 40°F and 100°F. Depending on the time of the year when the assessments are being performed, this limitation can be difficult to work around. During our own assessments in Florida during August, it was not uncommon for the roof surface temperature to be over 100°F by 10 a.m. The use of portable canopies and tents can be strategically utilized to shade the test area and keep the surface of the roof cool during the test. However, the industry should perhaps consider studying this temperature limitation, as storm events and high winds can occur abruptly when the surface temperatures of the roof are outside of this temperature range. The roof system should still be expected to perform at the same level, no matter if the temperature is 35°F or 135°F.

Once the storm-damage assessment is made and the quantity of storm damage is determined, an estimate of the costs associated with repairing the damage is often required, particularly when the extent of the damage is in dispute.

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