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Roof Uplift Testing: Review of Applicable Standards and Industry Practice

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Today's Vision...Tomorrow's Reality

Abstract

Factory Mutual (FM) Global Insurance Company recommends that field uplift testing be conducted for most adhered roofing systems in the hurricane-prone regions of the United States and the Caribbean. Although this test procedure simulates the laboratory test, there is much controversy regarding the use of the test in the field and the variables that can affect test results. This presentation will explore the consultant's role in the selection of uplift testing protocols and testing procedures and help prepare participants to address the types of problems that can be encountered during the specification and field practices of roof uplift testing.

Speakers

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JERRY ABENDROTH and MATTHEW MCELVOGUE have performed ASTM and Factory Mutual wind uplift testing on various projects for the past ten years. This testing has included negative chamber testing and bonded uplift testing. During this same period, both men have conducted forensic investigations of hurricane-related roof damage throughout the Gulf Coast region. They have performed successful remediation designs of affected roof systems, including supplemental attachment of roof systems that did not meet the design standards.

Roof Uplift Testing: Review of Applicable Standards and Industry Practice

PURPOSE AND SCOPE

FM Global (FMG) recommends in its Property Loss Prevention Data Sheet 1-52 (Field Verification of Roof Wind Uplift Resistance) that field uplift testing or full-time roofing construction observation be conducted for most adhered roofing systems in the hurricane-prone regions of the United States and the Caribbean and locations where design wind speeds are equal to or greater than 100 mph. Although this test procedure is intended to simulate the laboratory test, there is much controversy regarding the use of the test in the field and the variables that can affect test results.

The following sections will explore the consultant's role in the selection of uplift testing protocols and testing procedures and will help prepare the reader to address the types of problems that can be encountered during the specification and field practices of roof uplift testing. Topics that will be addressed include applicable FMG and ASTM testing standards and common errors and challenges in specification and testing. Additionally, several case studies will be presented, as well as lessons learned, including successful and problematic roof uplift testing projects. Topics from these case studies include a selection of field uplift test pressures, and number and locations of uplift testing.

Tests Summary

FM Loss Prevention Data Sheet 1-52 provides for two methods of testing wind uplift resistance: the negative pressure test and the bonded pull test. The negative pressure test utilizes a 5-ft. x 5-ft. dome that is placed on the roofing membrane. Air is then pumped from the dome to create negative pressure (suction) to the roof membrane at an initial pressure of 15 pounds per square foot (psf); then the negative pressure is increased in increments of 7.5 psf, with each increment held for one minute. This process is continued until the design test pressure multiplied by a factor of safety (1.25 for the current version of the standard, 1.5 for previous versions) is reached within the dome or until failure occurs. A bar with a deflection gauge is positioned in the center of the chamber to measure deflection of the roof membrane. Because the test was initially performed using a durable skylight dome, this test process is sometimes referred to as the "bubble test." In recent years, test pressures have been increased substantially, requiring the use of negative pressure domes constructed of stronger materials.

A parallel test standard is the American Society for Testing and Material's (ASTM's) E907, *Standard Test Method for Field Testing Uplift Resistance of Adhered Membrane Roofing Systems*. The two tests are similar in that they use the same test apparatus and load application/cycling; however, there are some significant differences. With regard to chamber placement, FMG recommends that the chamber be placed "between roof supporting beams or joists (where practical). The exception is when testing roofs on pre-cast concrete roof decks, the test is to be located over the joints in the precast concrete deck." ASTM E907 does not include provisions or recommendations for placement relative to framing or joints, but does indicate that roof surface stiffness may be influenced by the roof deck and framing stiffness. In 2012, the ASTM E907 standard was withdrawn because it had not been updated as required by ASTM.

Another notable difference between the FMG and ASTM uplift tests is that the FMG 1-52 test requirements for allowable deflection are often more restrictive than ASTM E907. When using FMG 1-52 to test adhered membranes on wide rib steel deck, the maximum allowable roof surface deflections are ¼ in. for pressures up to 60 psf, ½ in. for pressures between 60 psf and 120 psf, and ¾ in. for pressures between 120 psf and 180 psf. The standard allows higher deflections for systems with intermediate or narrow-rib roof deck and for adhered roofing systems with mechanically attached insulation or thin cover boards. According to ASTM E907, up to 1 in. deflection is allowable at any test pressure.

FMG 1-52 also provides a procedure for testing the roof system by bonding to the membrane surface and lifting to simulate negative pressure. The bonded uplift test utilizes two 2-ft. x 2-ft. pieces of plywood, which are fastened together to provide a stiff lifting platform for the roof membrane. The plywood is then adhered to the smooth roof surface with steep asphalt, cold adhesive, or another bonding material that is compatible with the roof system. After an appropriate curing period, the roof system is cut at the perimeter of the plywood. The attached plywood/roof assembly is then attached to a scale/tripod assembly, and upward force is applied in increments of 7.5 psf starting at 15 psf and held for one minute at each increment until 1.25 times the design pressure (or failure) is obtained. Probably the most significant difference between the standards is that FMG 1-52 is accepted by FMG for field-testing of roofing assemblies for buildings insured by FMG, where ASTM E907 is not.

ROOF UPLIFT DESIGN

Bernoulli Principle

In short, Bernoulli's Principle states that an increase in the velocity of a fluid (air, in the case of wind design) over an object is accompanied by a decrease in the surface pressure applied to that object. This basic principle has a wide range of applications throughout numerous industries, including piping systems, aeronautical design, and building enclosures. When the Bernoulli equation is applied to calculate pressure differentials between the roof system and the wind flow above it, the equation is narrowed down to the following equation, where ρ is the density of the fluid (air in this case) and v is the velocity (speed) of the fluid.

$$\Delta P = \frac{1}{2}\rho v_1^2$$

Table 2 in FMG 1-52, "Passing Uplift Test Pressures for Enclosed Low-Slope Buildings," lists critical test pressures associated with FMG roof wind ratings. This table provides negative pressure criteria for three sections of the roof (field, perimeter, corner).

These values are fundamentally developed from the parameters noted in Chapters 26 through 30 of the American Society of Civil Engineers (ASCE)/Structural Engineering Institute (SEI) Standard 7-10, Minimum Design Loads For Buildings and Other Structures. The ASCE 7-10 wind velocity pressure calculation has numerical multipliers KZ, Kzt, and Kd to account for the types of situations in which the equation may be applied. Earlier versions of the above-noted standard also included an importance factor "I," which was eliminated in the 2010 version through development of additional wind speed figures. The equation is below:

$$qz = 0.00256\, K_z\, K_{zt}\, K_d\, v^2\, (lb/ft^2)$$

As can be seen above, the velocity pressure equation in the ASCE 7 manual is derived from Bernoulli's Principle. Although this principle is used for various applications, it does have its limitations and restrictions. Therefore, various modifications and factors are employed to apply Bernoulli's basic principle to specific applications. In our world of roofing, the terrain, building height, safety factors, and air densities must all be accounted for in order to determine acceptable and sound pressures from which uplift wind ratings can be determined.

The FMG 1-52 test is intended to simulate the pressures derived from these equations applied to the roofing system. A pressure differential equal to what has been previously calculated and/or determined through methods in accordance with ASCE 7 or identified through FMG 1-52 (and associated standards) is created through the use of a vacuum. The pressure is held for a minute (Section 2.1.1.8 of FMG 1-52 2012), and if the roof holds per the parameters set forth in FMG 1-52 (discussed elsewhere), the specimen is deemed a pass.

FMG 1-52 FIELD VERFICATION OF ROOF UPLIFT RESISTANCE

FMG 1-52 Changes From February 2007 to April 2009 Standards

The version of FMG 1-52 issued in April of 2009 includes several significant changes from the previous version. The most significant change was that the test was not recommended for new roof systems that are mechanically attached to certain roof deck types. These roof deck types are steel (minimum 22 gauge), wood, cementitious wood fiber plank, and structural concrete (minimum 2500 psi).

Another modification provided in the April 2009 FMG 1-52 was to increase the allowable deflection for metal decks. For wide rib steel decks where the test pressure exceeded 60 psf, FMG allowed an additional ¼-in. deflection for each 60 psf increment of testing. If an intermediate or narrow rib deck was used, FMG allowed the deflection to be twice the previous limit up to a maximum of 1 in. deflection.

In addition, FMG recommended that all rooftop observers who were not directly involved with the test equipment should not stand directly adjacent to the test area during testing. Other changes to the standard included guidance for those conducting testing on how to interpret the results.

FMG 1-52 Changes From April 2009 to July 2012 Standards

One major theme in the changes from the 2009 to the 2012 standard is the distinction between "testing" and "field testing." This clear distinction is apparent in some of the items changed/added in the specification. First and foremost, the name of the standard has been revised to "Field Verification of Roof Wind Uplift Resistance" from the previous title of "Field Uplift Tests."

Along with other modifications, FMG has added a whole new method to predict wind uplift performance of an approved roof system (Roofnav assembly number, FMG Approval Report, etc.) without having to test the system itself. This method, "Visual Construction Observation," or VCO for short, is stipulated under section 3.5 of the 2012 FMG 1-52 standard. Under this provision, a third-party observer (VCO) must be present "full-time" during the installation of the roof system, and through daily report documentation and structured observation, the roof system may forgo wind uplift testing (bonded or negative uplift). Additionally, the standard specifies that the construction observer (CO) must not be a direct employee of the owner, design professional, or installing roof contractor to avoid potential conflicts of interest. The third-party CO is to verify the correct materials are being utilized, verify construction practices are in compliance with project documents, note any deficiencies in workmanship, and verify that all corrective measures are implemented per FMG and project document requirements.

Another modification involves test method recommendations. Previously, a statement existed in paragraph 2.1.1.3 of the 2009 FMG 1-52 that the bonded uplift test was not recommended where any type of mechanically fastened cover or insulation was used. However, in the 2012 FMG 1-52, Table 1, "Recommended Tests for Various Roof Systems," was added, and this table lists the applicability of the two test methods for various roofing types. See *Table 1.*

Type of Test or Analysis/Roof Type	MF SP, MF BUR[2], or MF ModBit[2] to Deck Other than LWIC	MF Sp[1], MF BUR[2], or ModBit[2] to LWIC	FA SP, BUR, or ModBit w/MF Insulation	FA BUR or ModBit w/FA Insulation	FA SP w/FA Insulation	Metal Roofs	Ballasted (See DS 1-29)
Negative Pressure Test	DNA	R1	R	R	R	DNA	DNA
Bonded Uplift Test	DNA	NR	NR	R	R	DNA	DNA

1. Fastener spacing does not exceed 2 ft. (0.6 m) in both directions.
2. Base sheet is mechanically attached, and upper plies are adhered.

MF – Mechanically fastened   R – recommended   FA – Fully adhered   NR – Not recommended
SP – Single-ply membrane   BUR – Built-up roof   ModBit – modified bitumen   DNA – Does not apply
Metal Roofs – Standing seam (concealed clip securement) or lap seam (through-fastened)

Table 1 – FMG 1-52 Table 1, Recommended Tests for Various Roof Systems.

Another modification involves the number of bonded uplift tests required. In conformance with the FMG 1-52 standard, a bonded uplift test utilizes a sample that is substantially smaller than that of the negative pressure test (4 sq. ft. instead of 25 sq. ft.). The 2012 FMG 1-52, paragraph 2.1.3.4, states, "Conduct four times as many bonded uplift tests (BPT) as recommended by Table 3, Figure 1 and Recommendation 2.1.9 to account for the smaller test sample area than that recommended for the negative pressure test (NPT). The four BPT samples should be prepared in close proximity to each other, taking into consideration that a complete cut needs to be made down to the top of the deck around the entire perimeter of the sample, and that bearing points are required for the tripod legs. This allows testing of the same approximate sample area as in the NPT, and minimizes the area requiring repair after." Although this paragraph states "...in close proximity to each other," FMG does not clearly indicate how far away samples must be tested. The above-referenced Table 3 is shown here in *Table 2*.

Revisions also include calculation of the required pressure for the uplift tests (bonded or negative). Previously, paragraph 2.1.1.8 of the standard indicated the use of a safety factor of 1.5 with the design pressure to achieve the "passing uplift test pressure." The 2012 FMG 1-52, paragraph 2.1.1.8, now specifies a factor of safety of 1.25.

Some additional failure criteria have also been addressed in section 2.1.2.7. If the cover board is observed to crease below design pressure (factor of safety of 1.0), it is indicative of a failure with the cover board (crack formation). The standard also has provided some illustrative examples (photographs) in the new 2012 standard.

Roof Area (A, ft^2, or m^2)	Minimum No. of Tests
A ≤ 10,000 (1,000)	3 (1 F, 1 P, 1 C)
10,000 (1,000) ≤ A ≤ 60,000 (6,000)	5 (2 F, 2 P, 1 C)
A > 60,000 (6,000) or multiple adjoining roof areas	See Section 2.1.1.9 and Figure 1

F = Field of roof P = Perimeter of roof C = Corner of roof

Table 2 – FMG Table 3, Minimum Number of Negative Pressure Tests.

Examples of Field Uplift Testing Vs. Actual Performance

Following Hurricanes Katrina (2005) and Ike (2008), several testing agencies used wind uplift testing to determine the viability of existing roof systems. The author observed one test conducted on a 25- to 30-year-old roof system that had been mopped directly to lightweight insulating concrete. The roof system had withstood the hurricane with little gravel ballast displacement (scour) and little water penetration into the building; however, it could not pass the FMG 1-52 test. Therefore, while it did not meet the FMG 1-52 deflection criteria, it was able to survive a major hurricane with minimal damage to the roofing system.

In another example, a 25-year-old built-up roof system that had a partial blow-off during a hurricane event was tested to a FMG 1-90 Wind Rating. The roof consisted of a three-ply built-up system over tapered perlite insulation. All layers had been mopped in steep asphalt. The remaining sections of the roof system passed the FMG 1-52 test, even after adjacent sections of the roofing system had blown off during the hurricane. In this case, although the roof system passed the field uplift tests, large roof areas failed during a hurricane.

NRCA Articles

It is important to consider input from all sources when evaluating testing procedures and protocols. For this reason, organizations such as ASTM utilize committees for development and maintenance of test standards. These committees generally consist of a broad range of members, including manufacturers, contractors, design professionals, and subject matter experts. The National Roofing Contractors Association (NRCA) is the largest membership organization for roofing contractors. This organization provides valuable feedback to a wide variety of concerns as they affect the roofing industry (safety, building codes, product usage, and testing, just to name a few).

In December 2008, the NRCA published an article in its *Professional Roofing* magazine entitled "Experiences With FMG Global Guidelines: Concerns Regarding FM Global Field Uplift Testing Guidelines Persist." In the article, Associate Executive Director of Technical Services Mark Graham listed the results of a survey conducted by NRCA regarding FMG 1-52 testing. The scope of the survey is listed below:

"NRCA received reports for more than 8,000 roofing projects. Compliance with FM Global guidelines was reported to be specified in about 26 percent of those projects. FM Global was reported to be the property insurer in about 3 percent of those projects."

The following feedback was received:

- Roof systems passed the field uplift tests only about 55 percent of the time.
- Sometimes reports were issued that did not provide proper information about the pass or failure of the roof system.
- Several respondents stated that "FM Global required field uplift tests to be conducted on existing roof systems (including one that has been in place for more than 23 years), apparently as a condition of FM Global's insurance renewal process."

Graham concluded this section of the article with the following statement:

> Although the survey results are not statistically representative [n]or significant of the overall U.S. roofing industry, the information provides a clear basis for roofing professionals' continuing concerns with FMG Global guidelines.

Graham concludes the article thus:

> Given the results of NRCA's survey, clearly it is time for FM Global to re-evaluate its reliance on field uplift testing as a post-construction, quality-assurance measure.
>
> NRCA maintains—as it has for years—the most effective means of ensuring the quality of low-slope roof system application is by the continuous visual monitoring of the application process at the time of roof system installation.

In a follow-up article issued in July 2009, Graham evaluates recent changes to the FM 1-52 test and adds the following remarks concerning NRCA's position regarding testing.

> NRCA continues to strongly oppose field uplift testing, such as FM 1-52, as a measure of quality assurance for low-slope roof system application. The test method's variability and lack of repeatability and operator sensitivity, as well as lack of correlation between such test data and FM Global's laboratory-derived approval classifications, make data and results from FMG 1-52 testing noncredible.
>
> Some of FM 1-52's latest revisions indicate FM Global is beginning to recognize roof deck deflection's influence on FMG 1-52's test results. Because a roof deck's design, installation and deflection are not controlled by the roof system applicator, this further indicates FMG 1-52 is not appropriate as a roof application quality assurance measure.
>
> Also, FM Global's recommendation that there be no movement near the test apparatus between the time the deflection gauge is zeroed out and when the test is complete is not feasible with some of the equipment and procedures used during the tests.
>
> NRCA maintains—as it has for years—the most effective way to ensure the quality of a low-slope roof system application is continuous visual monitoring of the application process during roof system installation.

We certainly would agree that a sound quality assurance program with aggressive field quality control is the best method to limit potential deficiencies in the installed roof system that can lead to catastrophic failures during high-wind events. In fact, FMG has included verbiage to recognize full-time monitoring of roof installation in lieu of field testing. However, monies for continuous monitoring of roof system installation are rarely allocated with project budgets or set aside by building owners. Owners typically make statements such as professional general contractors and subcontractors are hired to install the work per the contract documents, and the owners should not have to expend additional monies to ensure that the job is done right.

The following section includes five case studies that include field uplift testing as an evaluation measure, construction compliance quality control measure, or both. Following the case studies, conclusions regarding the authors' opinions related to the use of field uplift testing are presented.

CASE STUDIES

Case Study 1

Building Type: Hotel/Hospitality
Location: West Texas
Roof Age: 1-2 years
Roof Deck: Metal deck
Roof Construction: Multiple layers of polyisocyanurate insulation
¼ in. glass-mat, water-resistant, gypsum cover board
60-mil EPDM fully adhered roof system
Roof Height: 165 feet
Roof Uplift Pressures (Design):

Field	41.64
Perimeter	65.35
Corner	89.60

During the spring of 2012, the Lubbock, TX, area experienced a high-wind event that was typical for the area. Regional weather reporting stations recorded maximum wind gusts of 63 miles per hour over several hours during daylight hours. During the wind event, the southwest corner of roof system ballooned, causing a substantial portion of the roof to be dislodged and damaged.

The roof manufacturer was contacted to repair the roof system under the terms of the warranty. The warranty issued by the manufacturer included language that listed 55 mph as the maximum "warranted" wind speed for the roof system. The roof manufacturer denied the repair claim.

The insurance company for the hotel hired several engineering firms to investigate the mode (or modes) of failure of the roof system. After removing the temporary EPDM membrane over the damaged area, the engineers and consultants observed the elements of the damaged roof system. These observations provided a basis for discussion and conclusions. After visual observations, FMG 1-52 testing was performed at six locations. Results are shown in *Table 3*.

Findings and Testing Applicability

Test cuts were made at all test locations. At each location, delamination was observed within the gypsum cover board; and at all locations, the delamination extended beyond the test cut. Delamination was observed immediately below the cover board top facer, within the matrix of the cover board gypsum core, and immediately above the cover board bottom facer. No delamination was observed between the EPDM sheet and the cover board top facer, between the cover board bottom facer and the insulation, between layers of insulation, or between the insulation and the concrete deck. As the field tests showed that many locations failed at approximately half of design pressures, and the failure occurred within the plane of the cover board, it was determined that a material failure, not an installation failure, was responsible for the partial roof failure.

In this case, the consistent failure of the roof system, often at or near half of the design values, along with visual confirmation of the failure mode, accurately reflected the cause of the roof failure and the fact that the roof system was never capable of withstanding design wind loads. Therefore, roof uplift testing provided a reliable predictor of roof performance.

Test Number	Test Pressure (psf)	Deflection (inches)	Comments
Test 1 (Corner)	37.5	0.26*	
Test 2 (Corner)	45.0	Ballooned	Failed 29 seconds into test cycle
Test 3 (Perimeter)	30.0	0.33*	
Test 4 (Perimeter)	37.5	Ballooned	Failed 14 seconds into test cycle
Test 5 (Corner)	52.5	Ballooned	Failed 21 seconds into test cycle
Test 6 (Field)	37.5	Ballooned	Failed 20 seconds into test cycle

* = Exceeds allowable deflection

Table 3 – Test results summary.

Case Study 2

Building Type: Hospital/Medical Center
Location: Mobile, Alabama
Roof Age: 25-30 years
Roof Deck: 1-in. corrugated metal pan deck
Roof Construction: Lightweight insulating concrete
Coal tar pitch roof with aggregate
Roof Height: 20 ft.
Roof Uplift Pressures: Not available

On August 29, 2005, Hurricane Katrina struck the Gulf Coast of the United States. The storm made landfall as a Category 3 rating on the Saffir-Simpson Hurricane Scale. According to the National Weather Service, the storm brought sustained winds up to 150 miles per hour and stretched some 400 miles across. Because of the power of the storm, widespread damage and flooding occurred in Louisiana, Mississippi, and Alabama. Experts estimate that Katrina caused more than $100 billion in damage.

Roof systems from the Superdome in New Orleans to hospitals on the Alabama gulf coast were damaged from the exposure to high winds from the storm. Building owners in many sectors employed the use of FMG 1-52 testing to determine if their roof systems would still perform adequately during high-wind events.

A hospital owner in Alabama hired an engineering firm to perform testing on all of the hospital roofs and the adjoining building roofs. The roof targeted in this Case Study was 25-30 years old. After discussions with several professionals regarding the efficacy of the uplift tests, the testing firm decided to proceed with the testing with the knowledge that the roof system was not designed and installed to FMG requirements. Tests in conformance with FMG 1-52 were conducted at five locations on the approximately 30,000-square-foot roof.

Findings and Testing Applicability

Although the intent was to perform the tests in conformance with FMG 1-90 rating, all five tests failed at pressures between one-fourth and one-half of the applicable test pressures. Test cuts were made at all test locations. At each location, the test cut revealed that the pitch built-up roof assembly was attached to the lightweight insulating concrete with minimal fasteners or with no fasteners at all. The aged roof system withstood the force of a major hurricane and exhibited few signs of distress. Roof system performance under FMG 1-52 testing in this instance did not correlate with the roof system's performance during a major wind storm.

Case Study 3

Building Type: Manufacturing Facility
Location: Houston, Texas
Roof Age: New construction
Roof Deck: 22-gauge metal deck
Roof Construction: 2½ in. polyisocyanurate insulation
½ in. high-density gypsum cover board
60-mil PVC membrane, fully adhered
Roof Height: Varied from 22 to 46 ft.
Roof Uplift Pressures (Test):
Passing uplift test pressures provided by FMG for each roof location

	Building 1	Building 2	Building 3
Field	56 psf	56 psf	56 psf
Perimeter	80 psf	80 psf	74 psf
Corner	120 psf	120 psf	110 psf

The manufacturing facility was owned by an international firm that was insured by FMG. During the design process, the general contractor and subcontractors were informed that FMG would provide design comments and follow-up site visits during construction. Testing in conformance with FMG 1-52 was included in the roofing specification, and knowledge of the testing was transmitted to the general contractor and subcontractor at several preconstruction meetings. The roofing subcontractor acknowledged the testing criteria, even stating that he had installed roofs where the FMG testing protocols had been used and that he had not had problems with those roof applications.

Findings and Test Applicability

Upon completion of the field testing, approximately one-third of the test locations failed. Test cuts were taken at these locations to determine the mode of failure. In most instances, it appeared that bonding adhesive was installed properly. At several locations, dry-lay sheets were discovered. From these test cuts it was determined that the bonding adhesive had been applied in the proper amounts; however, they had not been installed in the window of time while the adhesive was still "sticky." At other locations, the adhesive appeared to have not been installed in a sufficient amount to provide for proper adhesion. In these areas, the PVC sheet easily peeled back from the cover board beyond the test cut area.

The engineering firm, with assistance from the manufacturer, conducted additional test cuts to determine the extent of the problem. After additional mapping of each roof, it was determined that the problem areas could be isolated and effectively repaired. The manufacturer provided a fastener layout that required the roofing subcontractor to install fasteners well beyond the problem areas to ensure that the problem areas did not experience tributary problems. After the installation of the additional fasteners, an overlay of new PVC sheet was installed, totally adhered to the fasteners and existing PVC material.

In this case, the performance criteria and the metrics required to determine performance criteria were clearly stated, and a system capable of meeting the criteria was specified. Through field uplift testing, construction deficiencies associated with failure of the roof system below threshold amounts were discovered. However, through study of the test results and a rational approach to evaluating the roof system, deficient areas were isolated and reasonable remediation was performed. Without field uplift testing, construction deficiencies may not have been discovered until a major wind event occurred, and a reasonable approach to remediation of the newly installed roof system likely would not have been achieved.

Case Study 4

Building Type: Medical
Location: Houston
Roof Age: New construction
Roof Deck: Concrete, 22-ga. metal deck
Roof Construction: Multi layers of polyiso insulation
½ in. Dens Deck, water-resistant, gypsum coverboard
60-mil TPO fully adhered roof system
Roof Height: Varies
Passing Uplift Test Pressures:

Field	56.25
Perimeter	93.75
Corner	140.63

Passing Uplift Test Pressures (ASTM E907-96 Test):

Field	90
Perimeter	150
Corner	225

Field uplift tests were performed on the above-noted hospital in Houston, Texas. Four original locations were to be tested; however, after initial failures, two additional test locations (two perimeter locations: Test Specimens 4 and 6) were performed, for a total of six test locations.

Initially, the tests were performed in accordance with ASTM E907-96. Field test pressures, determined by ASCE 7, were provided by the design team. After two of the initial four tests failed, the prescribed deflection limit of 1 in., the consultant calculated test pressures as required by FMG 1-52/1-28. Although the resulting test pressures were less than that provided by the design team, one of the two additional tests performed failed performance requirements under FMG 1-52. Therefore, the roof assemblies did not meet required performance specified by the design team or the alternative FMG 1-52 standard. See results in *Table 4*.

Findings and Test Applicability

Following testing, roof cuts and selective roofing demolition were performed at failed test locations and other roof perimeter and corner conditions. Observations of the roof cuts and at demolished conditions indicated inconsistent and inaccurate spacing between roofing system adhesive ribbons. The spacing of the ribbon adhesive was generally greater than what is required and not in accordance with the roofing manufacturer's instructions for the perimeter and corner zones of the specified roof assembly.

As a result of the insufficient adhesion of the roofing components, the roofing assembly was generally unable to meet the ASTM 907 or FMG 1-52 roof uplift performance criteria.

Based on the consistent correlation between the failed test results and locations where construction deficiencies were observed, field uplift testing served to provide an accurate measure of roof construction compliance.

Case Study 5

Building Type: Medical professional building
Location: Houston, Texas
Roof Age: 1 year
Roof Deck: Concrete over metal deck
Roof Construction: Multiple layers of polyiso insulation
½ in. water-resistant gypsum coverboard
Two-ply modified bitumen roof system
Roof Height: 115 feet
Passing Uplift Test Pressures (Design & Test):

Field	90
Perimeter	105
Corner	135

According to the National Hurricane Center's January 23, 2009, report, Hurricane Ike made landfall in Texas on September 13 with recorded sustained winds of 95 mph. The huge storm knocked out power to the Houston-Galveston area for over three weeks, causing billions of dollars in damage. The hospitals in the region were subjected to the force of this storm, and many roofs were damaged or destroyed as the result of the wind uplift forces associated with it.

Test Number	Test Pressure (psf)	Deflection (inches)	Comments
Test 1 (Field)	90	0.1	Passed
Test 2 (Perimeter)	150	1.03	Failed at test pressure of 75 psf
Test 3 (Field)	90	0.08	Passed
Test 4 (Perimeter)	150	1.15	Failed at test pressure of 60 psf
Test 5 (Corner)	225	1.56	Failed at test pressure of 105 psf
Test 6 (Perimeter)	150	.09	Passed

* = Exceeds allowable deflection

Table 4 – Test results summary.

On one of the newer hospital buildings, a roof system that had been in service for less than a year failed in several large areas. A decision was made to replace the roof while keeping the building in service. A contractor was chosen, and a new two-ply modified bitumen roof was installed. After installation of the roof system, loose areas (bulged and debonded) were observed throughout the roof areas. After contacting the general contractor, roofing subcontractor, and the manufacturer, eight FMG 1-52 negative-pressure field uplift tests were performed. The tests failed at very low pressures (30% or less of design/test pressure). Test cuts were taken at all eight test locations, and delamination was observed at either the cover board or polyisocyanurate insulation facers.

After the test report was issued, the roofing contractor and manufacturer asked for permission to conduct bonded-pull testing. The owner voiced objection, but agreed to the testing procedure. A testing agency was chosen and the tests were conducted. *Table 5* is representative of their findings.

The bonded uplift tests did not correlate to the chamber testing conducted several weeks earlier. After further review of the test results, it was determined that the testing agency did not conduct the test using the correct pressures. Rather than using a test pressure for a 2- x 2-ft. sample, they instead used pressures associated with a 1-sq.-ft. area. Therefore, the resulting test method subjected the test specimens to approximately one-fourth of the required uplift force. The test results were not valid.

Another testing agency was commissioned to perform the bonded pull testing. In the second instance, the results of the bonded pull tests closely mirrored those of the dome tests. Presented with the results of the second, valid, bonded pull tests, the roofing subcontractor and manufacturer, with the roof consultant, prepared a plan to add securement to the roof system.

Test Applicability

After missteps with the initial bonded pull testing, subsequent bonded pull testing correlated with the initial negative pressure uplift testing and deficiencies observed in the roof system. Therefore, both test methods provided reliable confirmation that the roof assemblies did not posses the specified uplift resistance.

Test Number	Temperature °F	Lbs. of Pressure	Pass/Fail
1 (Perimeter)	75	134	Pass
2 (Perimeter)	74	105	Pass
3 (Field)	80.8	90	Pass
4 (Field)	54.8	90	Pass
5 (Field)	53.9	90	Pass
6 (Field)	60	90	Pass
7 (Field)	62.5	90	Pass

Table 5 – Bonded uplift test results summary.

CONCLUSIONS

As with any testing, field uplift tests must be conducted in a manner that follows the parameters set forth in the specifications or test protocol. Common sense must be used in the selection of the test areas, performance of the testing, and in the interpretation and use of the results. Specifications for new roof systems should include the type of testing, test pressures, locations and numbers of tests, and any other relevant information so that the contractor can develop a comprehensive plan for installation of a successful roofing system. Roof monitoring during construction is an important element of a successful roofing installation. However, despite concerns with field uplift testing, uplift testing is a viable tool to help determine a roof system's ability to withstand potential wind events.

As noted in the sections above, the use of field uplift testing to determine the acceptability of an older existing roof system where clear performance criteria has not been established and agreed to by all parties should not be performed unless a sound methodology such as comparative testing (determining if roof performance is consistent across all areas of the roof) is established. For applicable existing roof system projects, bonded pull tests should provide comparable results to negative pressure testing, provided sufficient sampling is performed. The selection of the test method and target/passing test pressures for the roof system should be decided based on all of the pertinent criteria, including applicability of the test with the type of roof system constructed, potential damage to the roof, and number of tests that should be performed. Finally, unless full-time monitoring of roof systems can be performed, roof uplift testing should be considered a useful tool in new roof construction quality assurance programs and the evaluation of recently completed roofing projects.