Guidelines for Wind Vulnerability Assessments of Existing Critical Facilities

FEMA P-2062 / September 2019

FEMA

Guidelines for Wind Vulnerability Assessments of Existing Critical Facilities

FEMA P-2062 / September 2019

FEMA

All photographs and figures used in this report were taken by FEMA or FEMA contractors or developed for this report unless stated otherwise.

For further information or clarification on items included in this manual, please contact the FEMA Building Science Helpline at FEMA-BuildingScienceHelp@fema.dhs.gov or (866) 927-2104.

Cover image shows the collapse of precast twin-tees over a fire station apparatus bay following the 2007 Greensburg Tornado in Kansas.

Acknowledgments

Authors and Key Contributors

Paul Beers, Glazing Consultants International, LLC

David T. Biggs, P.E., S.E., Biggs Consulting Engineering

Donald Champenois, P.E., AECOM

William L. Coulbourne, P.E., Coulbourne Consulting

Warren French, P.E., French Engineering

David K. Low, P.E., DK Low and Associates

John Scates, P.E., Scates, Inc.

Thomas Lee Smith, AIA, RRC, F.SEI, TLSmith Consulting Inc.

Reviewers and Contributors

Stuart Adams, E.I., CFM, Stantec

Erin Ashley, Ph.D., LEED AP, Atkins North America

Luis D. Aponte Bermúdez, Ph.D., P.E., Aponte Bermudez & Associates, LLC

Daniel Bass, RA, CFM, FEMA

David Conrad, P.E., Atkins North America

Anne D. Cope, Ph.D. P.E., Insurance Institute for Business & Home Safety

Lauren Finegan, P.E., PMP, Atkins North America

Jennifer Goldsmith-Grinspoon, FEMA

Victor Hare, P.E., FEMA

John Ingargiola, E.I., CFM, CBO, FEMA

David S. Johnston, Vinyl Siding Institute

Samantha N. Krautwurst, P.E., AECOM

Marc L. Levitan, Ph.D., NIST

Philip Line, P.E., American Wood Council

Kathryn Lipiecki, FEMA

J. Andrew Martin, CFM, FEMA

Glenn Overcash, P.E., AECOM

Manny A. Perotin, P.E., CFM, CDM Smith

Tim Reinhold, Ph.D., P.E. Stantec

Felix L. Rivera, P.E., Felix L. Rivera & Associates

Larissa Santoro, LEED AP, FEMA

Alan Springett, FEMA

Yana Tukvachinski, FEMA

Jonathan E. Westcott, P.E., FEMA

Technical Editing, Layout, and Illustration

Jennifer Sullivan, Atkins North America

PowerTrain, Inc.

Contents

List of Figures

List of Tables

Acronyms and Abbreviations

AAMA	American Architectural Manufacturers Association
ACI	American Concrete Institute
ANSI	American National Standards Institute
ASCE	American Society of Civil Engineers
ASTM	ASTM International
BOCA	Building Officials Code Association
C&C	components and cladding
CIB	International Council for Research and Innovation in Building and Construction
CMU	concrete masonry unit
DASMA	Door & Access Systems Manufacturers Association International
DEFS	direct-applied exterior finish systems
DX	direct expansion
EF	Enhanced Fujita
EIFS	exterior insulation and finish systems
EIMA	EIFS Industry Members Association
EOC	emergency operations center
FBC	Florida Building Code
FEMA	Federal Emergency Management Agency
F.S.	Factor of Safety
FM	FM Global
HVAC	heating, ventilation, and air conditioning
IBC	International Building Code
ICC	International Code Council
ICU	intensive care unit
IRC	International Residential Code
kV	kilovolt
LRFD	Load Resistance Factor Design
MAT	Mitigation Assessment Team
MBS	metal building system
MDE	moderate destructive evaluation
MDT	moderate destructive testing
MEPS	molded expanded polystyrene
mph	miles per hour
MRI	mean recurrence interval

MWFRS	main wind force resisting system
NCMA	National Concrete Masonry Association
NDE	nondestructive evaluation
NESC	National Electrical Safety Code
NFPA	National Fire Protection Association
NG	natural gas
NOAA	National Oceanic and Atmospheric Administration
NWS	National Weather Service
OSB	oriented strand board
PB	polymer-based
PCA	Portland Cement Association
PM	polymer-modified
psf	pound(s) per square foot
PV	photovoltaic
R	Resistance
RA	Recovery Advisory
RILEM	International Union of Laboratories and Experts in Construction Materials, Systems and Structures
RM-RC	reinforced masonry-reinforced concrete
SEAOC	Structural Engineering Association of California
SEI	Structural Engineering Institute
SPRI	Single Ply Roofing Industry
TAS	Testing Application Standard
TDS	Technical Data Sheet
TIA	Telecommunications Industry Association
TMS	The Masonry Society
URM	unreinforced masonry
VSI	Vinyl Siding Institute
WRB	weather-resistive barrier
WWPA	Western Wood Products Association
XEPS	extruded expanded polystyrene

Chapter 1: Introduction

Critical facilities are defined by the Federal Emergency Management Agency (FEMA) as buildings that are essential for the delivery of vital services or protection of a community. Critical facilities include emergency operations centers, healthcare facilities, police and fire stations, schools, and power stations. These facilities support critical community lifelines. These lifelines enable the continuous operation of critical business and government functions and are essential to human health and safety or economic security. Yet, despite the important functions these buildings serve, critical facilities are damaged frequently by high winds.

Winds with sufficient speed to damage weak critical facilities can occur anywhere in the United States and its territories. Even a well-designed, -constructed, and -maintained facility can be damaged in a wind event that exceeds the facility's design criteria. Fortunately, except in the case of tornado damage, it is rare for buildings to experience winds that exceed design levels. Most damage occurs because various building elements have limited wind resistance, resulting from inadequate design, poor installation, or material deterioration (FEMA 543, *Design Guide for Improving Critical Facility Safety from Flooding and High Winds* [FEMA 2007a]).

The normal operations of a critical facility can be interrupted by wind damage, including water leakage caused by wind damage and water infiltration due to wind-driven rain, and can require building occupants to evacuate.

If the vulnerabilities of a critical facility to wind damage are identified, they can be mitigated to avoid loss and disruption of services. However, thorough, peer-reviewed, or broadly accepted guidelines for conducting wind vulnerability assessments of critical facilities have not been available until the publication of this manual.

HURRICANE DAMAGE

Of all the storm types, a hurricane can devastate the largest geographical area and affect the largest number of people. It is, therefore, particularly important to perform vulnerability assessments of critical facilities in hurricane-prone regions.

MULTI-HAZARD DESIGN

This manual addresses the wind hazard. However, critical facilities can be damaged—and continuity of operations impaired—by other natural hazards such as flooding, seismic events, and wildfires. All natural hazards that could affect a facility should be considered and accounted for when assessing vulnerabilities.

This manual has been prepared to provide design professionals with guidelines for assessing the vulnerability of critical facilities to wind pressure, wind-borne debris, and wind-driven rain. The guidelines apply to critical facilities both within and outside hurricane-prone regions[1] and to critical facilities in tornado-prone regions. They are based on field observations and research conducted on a large number of buildings struck by hurricanes and tornadoes. The guidelines also are informed by a literature review and the recommendations of subject matter experts experienced in performing wind vulnerability assessments. See Section 1.2 for general information on tornadoes and Section 1.3 for general information on hurricanes.

If occupants intend to shelter-in-place in a facility during a hurricane, the vulnerability assessment should include a consideration of the hurricane safe room criteria in FEMA P-361, *Safe Rooms for Tornadoes and Hurricanes: Guidance for Community and Residential Safe Rooms* (FEMA 2015), and International Code Council (ICC) 500, *2014 Standard for the Design and Construction of Storm Shelters* (ICC 2014).[2]

A thorough wind vulnerability assessment is intended to identify all significant wind and wind-driven rain vulnerabilities (i.e., those vulnerabilities that could adversely affect building operations). The results of a thorough assessment can be used by building owners, design professionals, entities that award mitigation grants, and State, local, Tribal, and Territorial government agencies developing mitigation plans.

- **Building owners** will become aware of the vulnerability of their facilities to potential damage from wind. Based on the results of the assessment, the owner can budget for retrofit mitigation or construction of a new facility if the vulnerabilities are significant (see FEMA 2019). The building owner also will become aware of the risk from any identified vulnerabilities that are not mitigated, allowing for the development of a contingency plan for potential interruption of facility operations. Vulnerability assessments performed for a portfolio of buildings provide an owner with a comparison of wind mitigation issues across the portfolio.

- **Design professionals** involved in building renovations can use the information to guide discussions with the building owner about mitigation options.

  Design professionals also can use the guidelines after wind damage occurs. For example, if a portion of a wall

MITIGATION

Mitigation is defined as the effort to reduce loss of life and property by lessening the impact of disasters. Mitigating existing vulnerabilities can reduce or prevent the risk of damage. (FEMA 2018d).

1 Hurricane-prone regions are defined in ASCE 7-16, *Minimum Design Loads and Associated Criteria for Buildings and Other Structures* (ASCE 2017).

2 Though similar, there are important differences between safe rooms and storm shelters. While both must meet all ICC 500 requirements, safe rooms also meet the Recommended Criteria for safe rooms described in FEMA P-361; these criteria are more conservative than those presented in ICC 500 for storm shelters. The differences are explained at the beginning of each chapter of FEMA P-361 Part B and summarized in Table D-1 of Appendix D. If a safe room will be constructed with FEMA grant funds, the Recommended Criteria become requirements, in addition to the requirements for storm shelters in ICC 500. Although not required, a best practice is to apply FEMA safe room guidance to storm shelters.

or roof is damaged, the undamaged areas can be assessed to determine whether they are vulnerable to damage; and, if they are, the areas could be mitigated. On the building shown in **Figure 1-1**, a portion of brick veneer on one facade collapsed because of tie corrosion. If this corrosion occurred on the undamaged walls, it would be prudent to mitigate the tie corrosion on the undamaged walls instead of waiting for them to collapse during a future storm.

- **Entities that award grants for mitigating existing buildings** need thorough assessments before awarding funds to ensure that the proposed mitigation is technically feasible and effective and that the mitigation benefits equal or exceed their costs.
- **Agencies developing mitigation plans** can use the information from vulnerability assessments to identify and prioritize critical facilities for retrofit and include proposed mitigation in their plans.

Figure 1-1:
Brick veneer collapse due to tie corrosion. Hurricane Ivan (Florida, 2004) (FEMA 489)

1.1 Common Wind Vulnerabilities

Numerous wind damage investigations have revealed that the building elements most commonly damaged by high winds are:

- **Roof structure blow-off or collapse.** This type of failure typically occurs in buildings constructed before approximately 1990[3] or in buildings struck by a tornado (**Figure 1-2**).
- **Collapse of fire station apparatus bay doors in fire stations constructed before approximately 2000.**[4]
- **Glazing breakage from wind-borne debris generated by hurricanes or tornadoes.** At the hospital shown in **Figure 1-3**, 33 windows were broken, including windows in three of the eight intensive care unit (ICU) rooms and windows in other

3 These failures are related primarily to building codes and standards as well as design and construction practices of this era rather than to strength reduction from aging.

4 These failures are related primarily to building codes and standards as well as design and construction practices of this era rather than to strength reduction from aging.

patient rooms. Most of the glass breakage was caused by aggregate blown from the hospital's built-up roofs. The entire ICU had to be evacuated and was closed for about 2 weeks for repairs.

- **Roof coverings. Figure 1-4** shows a roof membrane that was detached by winds that were well below the basic (design) wind speed. **Figure 1-5** shows a single-ply membrane that detached from the roof of a hospital in Puerto Rico. The membrane was a re-cover over a bituminous membrane. After the single-ply membrane blew off, water breached the cap sheet during the hurricane. Roof coverings are the most commonly damaged building element.
- **Rooftop equipment**. Equipment that is blown off (**Figure 1-6**) frequently leaves openings in the roof and often punctures the roof covering.

Figure 1-2:
Much of the roof structure was blown off of this building. The steel roof deck was welded to steel joists that were supported by unreinforced concrete masonry unit (CMU)-bearing walls. The inset shows a large section of the roof assembly that was blown approximately 120 feet. The typical failure mode was uplifting of the joist bearing plates because the plate's studs were not grouted into the bond beam. There was no load path between the bond beam and the foundation. Hurricane Harvey (Texas, 2017) (FEMA P-2022)

Figure 1-3:
Wind-borne roof aggregate broke the glazing of this intensive care unit, requiring evacuation. Hurricane Charley (Florida, 2004) (FEMA 488)

Figure 1-4:
Detached roof membrane on a new police station.

Figure 1-5:
Detached roof membrane over hospital. Hurricane Maria (Puerto Rico, 2017) (FEMA P-2020)

Figure 1-6:
The heating, ventilation, and air conditioning (HVAC) unit in the foreground was not fastened to the curb. A substantial amount of water entered the police station where equipment was blown off. Lack of unit attachment is very easy to detect during a wind vulnerability assessment. Hurricane Michael (Florida, 2018)

1.2 Tornadoes

The National Weather Service (NWS) rates tornado severity according to six levels of observed damage on the Enhanced Fujita Scale (EF Scale). The scale ranges from EF0 to EF5. See **Table 1-1** for the wind speeds associated with the EF ratings. For more information on the EF Scale, see https://www.spc.noaa.gov/efscale/ef-scale.html and http://www.depts.ttu.edu/nwi/Pubs/EnhancedFujitaScale/EFScale.pdf.

Table 1-1: Enhanced Fujita Scale

EF Number	Wind Speed
EF0	65-85 mph
EF1	86-110 mph
EF2	111-135 mph
EF3	136-165 mph
EF4	166-200 mph
EF5	>200 mph

SOURCE: NOAA (NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION)
Speeds are peak gust, Exposure C, 33 feet above grade
EF = Enhanced Fujita
mph = miles per hour

Based on data collected by the NWS, the median number of tornadoes in the United States in the years from 1990 to 2017 was 1,219 per year. The lowest number occurred in 2014 (886), and the highest number occurred in 2004 (1,817) (NOAA NWS 2017).

Tornado-related winds have a significantly lower probability of occurrence at a specific location than the high winds associated with meteorological events (frontal systems,

thunderstorms, and hurricane winds) that are responsible for basic wind speeds given in American Society of Civil Engineers (ASCE) 7, *Minimum Design Loads and Associated Criteria for Buildings and Other Structures* (2016 edition) (ASCE 7-16). The probability of tornado wind speeds is a function of the area that a tornado affects and the particular location. The probability of occurrence is a function of the area covered by a tornado and of the specific location. The probability of a site-specific EF0- to EF1-rated tornado strike in the central portion of the United States is on the order of a 4,000-year mean recurrence interval (MRI) (Ramsdell and Rishel 2007). In the areas of the United States where the risk of EF4- and EF5-rated tornadoes is greatest, the annual probabilities that a particular building will be affected by an EF4- or EF5-rated tornado is on the order of 10^{-7} (a 10,000,000-year MRI) (Ramsdell and Rishel 2007). Tornadoes in the Western States are rare, as illustrated by the NWS annual tornado maps for 1952 through 2011 at https://www.spc.noaa.gov/wcm/annualtornadomaps/.

1.2.1 Occupant Protection

Critical facility owners are recommended to hire a qualified architect or structural engineer familiar with tornado risk analysis to identify the best available refuge areas if the facility meets both of the following conditions:

- The facility is in an area where the wind speed is 200 mph or greater, in accordance with **Figure 1-7.**[5]
- The facility does not have a FEMA P-320-compliant or FEMA P-361-compliant safe room or ICC 500-compliant storm shelter and does not have access to such a safe room or storm shelter.

BEST AVAILABLE REFUGE AREAS

Best available refuge areas do not guarantee safety, but are the safest areas available for building occupants.

FEMA P-431, *Tornado Protection: Selecting Refuge Areas in Buildings* (FEMA 2009a) and FEMA's *Best Available Refuge Area Checklist* (FEMA 2017) provide guidance in identifying best available refuge areas.

5 To determine if a building site is located where the wind speed is 200 mph or greater, go to https://hazards.atcouncil.org/, enter the building address, and select "Tornado." A more conservative approach is to use 160 mph.

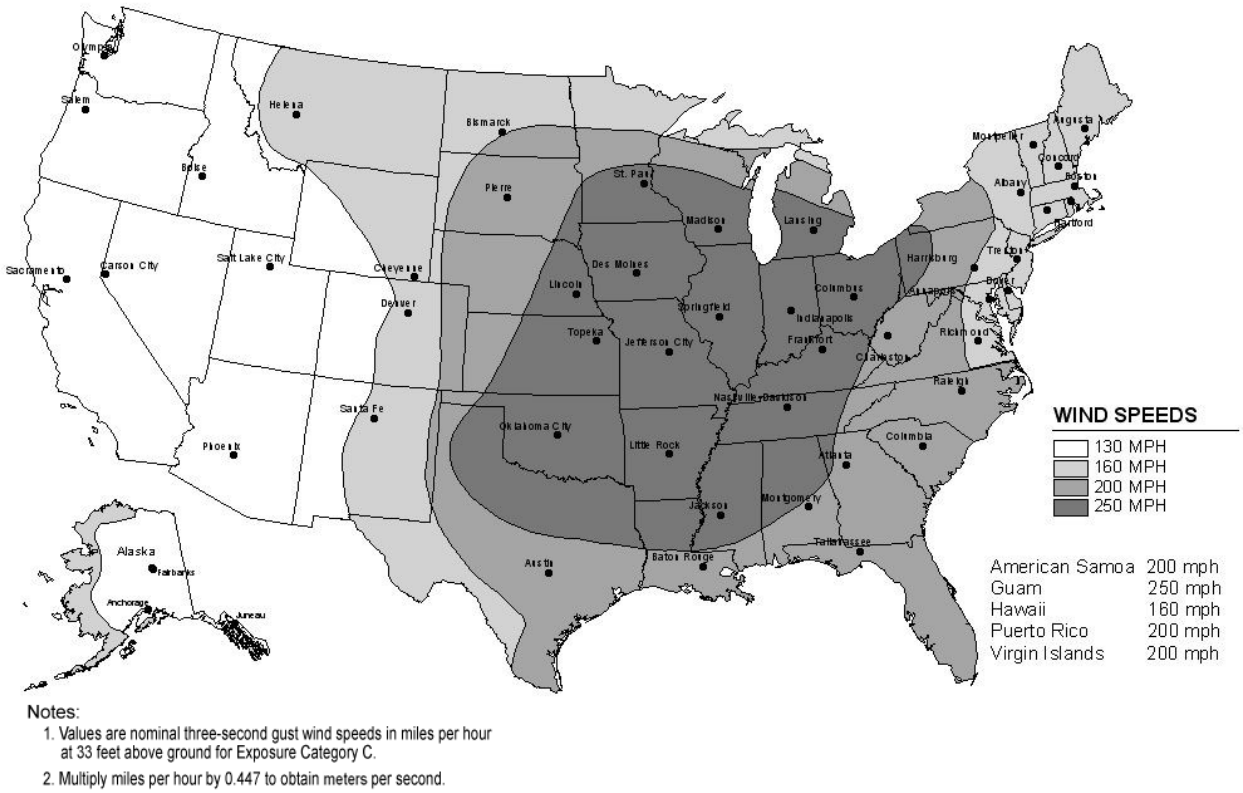


Figure 1-7: Safe room design wind speeds for tornadoes. SOURCE: ICC; USED WITH PERMISSION

1.2.2 Building Damage

Table 1-2 provides qualitative comparisons of main wind force resisting system (MWFRS) pressures derived from ASCE 7-16, and estimated pressures induced by EF1–EF4 tornadoes. Buildings that comply with the *International Building Code®* (IBC®) should exhibit good structural, door, and wall performance when struck by weak tornadoes (i.e., EF0 and EF1). However, damage investigations have indicated that tornado winds are more likely to generate more wind-borne debris compared to non-tornadic winds of the same speed. EF0- and EF1-rated tornadoes may generate wind-borne debris that can break unprotected glazing and puncture many types of door, wall, and roof assemblies, which can result in significant interior damage and disruption (**Figure 1-8**).

Figure 1-8:
Boarded-up windows in a school after the glazing was damaged extensively in an EF1 tornado. Ringgold Tornado (Georgia, 2011) (FEMA P-908)

Table 1-2: MWFRS Pressure Comparisons—Straight-Line Wind versus Tornado

Source of Wind Pressure	Roof Uplift Pressure	Wall Negative Pressure
ASCE 7-16, 115 mph	–30 psf	–22 psf
ASCE 7-16, 120 mph	–33 psf	–24 psf
ASCE 7-16, 180 mph	–74 psf	–55 psf
ASCE 7-16, 190 mph	–82 psf	–61 psf
EF0 (upper end of range) (85 mph)	–27 psf	–22 psf
EF1 (upper end of range) (110 mph)	–45 psf	–37 psf
EF2 (upper end of range) (135 mph)	–68 psf	–55 psf
EF3 (upper end of range) (165 mph)	–102 psf	–82 psf
EF4 (upper end of range) (200 mph)	–150 psf	–120 psf

Note: The above table is reproduced from ASCE 7-16, Table C26.14-3, with permission from ASCE.

The calculations are based on a 30-foot x 30-foot Risk Category II building with a mean roof height of 22 feet and a gable roof angle of 35 degrees sited in Exposure C. The ASCE 7-16 calculations assume an enclosed building. The tornado calculations assume partially enclosed conditions (caused by broken glazing) and a Tornado Factor based on tornado design considerations given in the ASCE 7-16 Commentary. Because of lack of field measurements of pressures and limited laboratory research, there is uncertainty in the calculation of tornado pressures.

As illustrated by **Table 1-2**, depending on a building's geographical location and Risk Category, EF2 and EF3 rated tornadoes produce wind pressures that range from below to above those derived from ASCE 7-16 for hurricane-prone regions. Hence, for buildings designed for wind pressure in accordance with ASCE 7-16, the performance of structural elements (i.e., MWFRS), doors, and walls in tornadoes will depend on the relationship between the tornado severity and the basic wind speed. For example, a building in Miami, Florida, is expected to have greater resistance to strong tornadoes (i.e., EF2 and EF3) than a building in Orlando, Florida, where the basic wind speed is lower than Miami's basic wind speed. However, wind-borne debris can break unprotected glazing and puncture many types of door, wall, and roof assemblies. Even if the glazing is protected from hurricane wind-borne debris, debris from an EF3 rated tornado may signficantly exceed the impact test criteria adopted for hurricane opening protection.

EF3 through EF5 rated tornadoes can produce wind pressures and wind-borne debris loads that are in excess of those derived from the highest design wind speeds for hurricane-prone areas and the wind-borne debris test standards for opening protection in hurricane-prone regions. Hence, if an EF4 or EF5 tornado passes over or near the facility, significant service disruption should be expected unless special design enhancements such as those recommended in Tornado Recovery Advisory 6 (FEMA RA6), *Critical Facilities Located in Tornado-Prone Regions: Recommendations for Architects and Engineers* (FEMA 2011a) have been implemented.

1.2.3 Continuity of Operations

Very few critical facilities are designed to remain operational if struck by a violent tornado (EF4 or EF5). Operations may be impacted even in lower-intensity events. If the facility must remain operational following a tornado event, it is recommended that the wind vulnerability assessment include a consideration of the continuity of operations recommendations in FEMA RA6 (FEMA 2011a).

1.3 Hurricanes

A hurricane is a system of spiraling winds converging with increasing speed toward the storm's center (the eye of the hurricane). Hurricanes form over warm ocean waters. The diameter of the storm varies and can be between 50 miles and 600 miles. A hurricane's forward movement (translational speed) can vary from approximately 5 mph to more than 25 mph. Besides being capable of delivering extremely strong winds for several hours and moderately strong winds for a day or more, many hurricanes also bring very heavy rainfall. Hurricanes also occasionally spawn tornadoes. The Saffir-Simpson Hurricane Scale (ASCE 7-16, Table C26.5-1) categorizes the intensity of hurricanes. The five-step scale ranges from Category 1 (the weakest) to Category 5 (the strongest). Hurricane-prone regions are defined in ASCE 7-16.

Of all the storm types, hurricanes have the greatest potential for devastating a large geographical area and, hence, affecting the greatest number of people. The terms "hurricane," "cyclone," and "typhoon" describe the same type of storm. The term used depends on the region of the world where the storm occurs.

If a building is intended to be occupied during a hurricane, it is recommended that best available refuge areas be identified in advance, in accordance with the recommendations given in Section 1.2.1.

1.4 Organization of the Manual

Section 4.1 lists several factors that can influence the vulnerability of structural elements. The listed factors can also influence the vulnerability of other building elements. Accordingly, it is recommended that Section 4.1 be reviewed prior to performing assessments identified in Chapters 5 and 6.

This manual is organized as follows:

Chapter 1—Purpose of the manual, building elements most commonly damaged by high wind, and background information on tornadoes and hurricanes

Chapter 2—The critical facilities that are recommended for assessment, qualifications of the assessment team, guidelines for assessing the building structure and envelope, and the components of the assessment process

Chapter 3—Guidelines for assessing the facility site

Chapter 4—Guidelines for assessing structural elements

Chapter 5—Guidelines for assessing the building envelope (exterior doors, exterior glazing and shutters, non-load-bearing walls, wall coverings, soffits, and roof systems) and exterior-mounted equipment (including roof- and ground-mounted equipment, including solar arrays)

Chapter 6—Guidelines for assessing a facility's ability to cope with the prolonged loss of municipal electricity, sewer, and water

Chapter 7—References and additional resources

Chapter 2: General Issues

Many building owners overestimate the wind and wind-driven rain resistance of their buildings and underestimate the amount of time it will take to make repairs to a damaged building or construct a new one. They also tend to underestimate the impact of wind and water damage on the continuity of building operations.

This lack of awareness may preclude building owners from mitigating their building's vulnerabilities. To understand a building's wind resistance, it is important to have a vulnerability assessment performed. A thorough wind vulnerability assessment is intended to identify all significant wind and wind-driven rain vulnerabilities (i.e., those vulnerabilities that could adversely affect building operations).

Figure 2-1: View of an occupied police station that collapsed during a hurricane. The building was not evacuated prior to landfall because the official in charge believed the building was safe. Hurricane Michael (Florida, 2018)

Figure 2-1 shows damage to a building that the official in charge believed was safe. The failures at this building illustrate the importance of performing a wind vulnerability assessment for buildings that will be occupied during a hurricane. If significant vulnerabilities exist, they should be mitigated, or else the vulnerable area(s) should not be occupied during a hurricane.

This chapter includes:

- Discussion of the critical facilities that are recommended for wind vulnerability assessment
- Professional judgment and qualifications that an assessment team needs
- Resources that can be helpful when assessing the building structure and envelope
- Facility owner's performance expectations
- General description of the assessment process

2.1 Facilities Recommended for Assessment

A wind vulnerability assessment is recommended for all critical facilities that are more than 5 years old and for all facilities located in hurricane- or tornado-prone regions[6] regardless of age.

Critical facilities support many of a community's lifelines. Specifically, the critical facilities covered in this manual support the lifelines of safety and security; food, water, sheltering; health and medical; energy; and communications, as defined by FEMA.[7] These lifelines enable the continuous operation of critical business and government functions and are essential to human health and safety or economic security.

If a building owner has several facilities (such as school district buildings or a large hospital complex), budget constraints may prohibit timely evaluation of all the facilities. FEMA P-424, *Design Guide for Improving School Safety in Earthquakes, Floods, and High Winds* (FEMA 2010a) recommends prioritizing the assessments based on the owner's needs and perceived facility vulnerabilities. For example, schools that will be used as recovery centers after a hurricane and facilities constructed before the early 1990s are the types of facilities that normally would be evaluated first.

Mitigation is effective only if it includes all of the building elements/systems whose failure is likely to cause significant interruption of facility operations. To help ensure that all significant vulnerabilities to wind, wind-borne debris, and wind-driven rain are identified, the assessment includes site issues (e.g., egress [i.e., roads], collapse hazards [e.g., trees,

6 In this manual, "tornado-prone region" refers to any area in the United States where the wind speed is 200 mph or greater, in accordance with Figure 1-7.

7 See FEMA's Community Lifelines Implementation Toolkit at https://www.fema.gov/media-library/assets/documents/177222.

communications towers, poles], and rolling debris), the MWFRS, the building envelope, and exterior-mounted equipment. For buildings that need to be operational during or soon after a hurricane or other high-wind event, the assessment should include an evaluation of the facility's ability to maintain operations if municipal or other utility services (e.g., power, water, sewer, communications) are lost. For instance, the assessment should determine whether the facility has a water storage tank or well for backup water.

2.2 Assessment Team

A qualified team of architects and engineers should perform the assessment. Additionally, the design professionals performing the assessment should be experienced with the type of building element that is being evaluated. This experience is critical because accurately assessing the wind resistance of existing buildings is very difficult, in part because of a severe lack of field test methods and the difficulty in performing evaluations/inspections after construction. Good professional judgment is vital for a quality assessment.

2.3 General Guidelines for Assessing the Building Structure and Envelope

There are two ASCE publications that provide general guidelines for assessing the building structure and envelope:

- Structural Engineering Institute (SEI)/ASCE 11-99, *Guideline for Structural Condition Assessment* (SEI/ASCE 1999), is a general guideline for assessing the condition of the building structure (see Chapter 4). It includes buildings constructed of concrete, steel, masonry, and wood, or a combination of these materials.

  The recommended assessment procedure includes: reviewing available building documentation such as drawings and specifications; conducting a field investigation; and performing an analysis of the structural elements to compare expected loads with expected resistance. The analysis includes an investigation of the vertical and lateral load paths and the capacity of the elements of the paths to resist the loads expected when the performance level is met (see Section 2.4). However, there is no requirement in the SEI guideline to include the effects of high winds.

  Most of SEI/ASCE 11-99 deals with assessment techniques and issues relevant to the various materials that are covered. It is recommended that design professionals performing wind vulnerability assessments of structural elements be familiar with this guideline.

- SEI/ASCE 30-14, *Guideline for Condition Assessment of the Building Envelope* (SEI/ASCE 2014), is a general guideline for assessing the condition and performance of the building envelope (see Chapter 5). It includes information on professional service agreements, assessment procedures, evaluation of findings, and reporting. It is recommended that design professionals performing building envelope wind vulnerability assessments be familiar with this guideline.

2.4 Facility Owner's Performance Expectations

Before the assessment, the assessment team should meet with the facility owner to determine the desired building performance. The discussion should establish the acceptable level of risk, and hence the desired building performance level.

LIMITATIONS

The limitations of a vulnerability assessment should also be discussed with the owner (see Section 2.5.3).

Acceptable risk is the maximum level of damage from a realistic risk event scenario or probability that can be tolerated. Performance levels used in this manual are inversely related to four levels of anticipated damage to a building, contents, and occupants. These levels are:

ENHANCED PERFORMANCE

For enhanced building performance design guidance within and outside hurricane-prone regions, see FEMA P-424, 543, and 577. For enhanced performance design guidance in tornado-prone regions, see FEMA RA6 (FEMA 2011a).

- **Mild impact**. The facility has no damage or only minor damage and is operational.
- **Moderate impact**. The facility is damaged and needs some repair, but most or all of the facility is functional. A few injuries to occupants may be life-threatening, but injuries are generally moderate in nature and number. The likelihood of a single life lost is low, and the likelihood of multiple lives lost is very low. Moderate impact is illustrated by **Figure 1-1**, **Figure 1-4**, and **Figure 1-5**.
- **High impact**. The facility may be structurally damaged. Damage to non-structural components (e.g., building envelope, exterior-mounted equipment) is significant, and the cost of repair is also significant. Some or all of the facility may not be functional. If rain accompanies the windstorm or occurs prior to emergency repairs, water damage to the interior of the facility may preclude some or all of the facility from being occupied for several weeks or months. Injuries may be life-threatening and moderate in number. The likelihood of a single life lost is moderate, and the likelihood of multiple lives lost is low.

  High impact is illustrated by **Figure 1-3**, **Figure 1-6**, and **Figure 2-2**. At the six-story hospital shown in **Figure 2-2**, blow-off of metal wall panels on the elevator penthouse allowed water into the elevator equipment room, which destroyed the control

equipment. Because the elevators were not functioning, the top five floors had to be evacuated and could not be occupied until new elevator controls were installed.

Figure 2-2:
Reconstruction of the damaged walls of a hospital elevator penthouse. Hurricane Francis (Florida, 2004) (FEMA 577)

- **Severe impact**. The facility is severely damaged and may need to be demolished. Significant collapse may have occurred. Most or all of the facility may not be functional. In facilities without a safe room or storm shelter, injuries may be life-threatening and high in number. The likelihood of a single life lost is high, and the likelihood of multiple lives lost is moderate. Severe impact is illustrated by the cover photograph, **Figure 1-2**, and **Figure 2-1**.

The design professional should consider the code and standards on which the original design was based. This is because building codes and standards provide minimum design criteria and because the adequacy of requirements changes over time. A building that was code-compliant when it was constructed may not provide the level of performance that is now expected by the owner, either because the code was inadequate, the building components have deteriorated, or the building use has changed. Even facilities that comply with the latest edition of the IBC may not provide the level of performance expected by the owner since the IBC does not adequately address critical facilities in hurricane- and tornado-prone regions.[8]

2.5 Assessment Process

The assessment process consists of the following steps: (1) determine the performance expectations (Section 2.4), (2) perform a Level 1 assessment (Section 2.5.1), (3) perform a Level 2 assessment if appropriate (Section 2.5.1), (4) conduct the analysis (Section 2.5.2), (5) prepare a report (Section 2.5.3), and (6) prioritize any mitigation that is needed, based on the assessment results (Section 2.5.4).

8 For information on IBC limitations, see FEMA P-424, Section 6.1.4.2.

2.5.1 Level 1 and Level 2 Assessments

Two levels of assessment are provided for many of the building elements that are included in this manual. For some buildings, a Level 1 assessment is sufficient, but for other buildings, both levels are prudent. In general, a Level 2 assessment is recommended for buildings in locations where the current basic wind speed is greater than 120 mph.[9,10] A Level 2 assessment is costlier, but because more data are collected than in a Level 1 assessment, a Level 2 assessment has a smaller margin of error.

The elements of the two levels, as well as when a Level 2 assessment is needed, are as follows:

- **Level 1 assessment**. (1) Review historical information files (i.e., as-built drawings and specifications, submittals, previous leakage and repair reports); (2) discuss with personnel familiar with the building to determine whether it has leaks or has other known issues and obtain historical information that is not in the file; (3) conduct a field investigation; and (4) report findings. A written report normally is prepared prior to beginning a Level 2 assessment, but the initial report may be verbal. Written findings can be included in a final report that addresses both Level 1 and 2 assessments.

  The historical file review should consist of the following:

  - Check the original construction drawings and specifications to determine the original wind design criteria (i.e., specified design loads or design criteria such as basic wind speed, exposure, and importance factor).
  - If the original wind design criteria were not stipulated, determine which building code and edition the design and the wind load calculations were based on.
  - Calculate the loads based on the current edition of ASCE 7, and compare the original loads to the current loads. The comparison will allow for a qualitative assessment of the adequacy of the original loads versus the current loads.
  - Check the original specifications to determine whether system resistance ratings were specified (e.g., door, window, roof system ratings). If ratings were specified, compare them to the required ratings based on loads derived from the current edition of ASCE 7.

SAFETY

Appropriate safety precautions should be taken when performing field assessments.

9 The 120-mph basic wind speed is based on ASCE 7-16 Risk Category III and IV buildings. The selection of trigger speeds in this manual is based on peer-reviewed subject matter expert judgment.

10 To determine a building site's basic wind the speed, go to https://hazards.atcouncil.org/, enter the building address, and select "Wind"; then, select the speed associated with the building's Risk Category.

The Level 1 assessment should also address the general condition (i.e., remaining service life) and resistance of the various building elements and systems. If the assessment reveals that a building element or system is at or near the end of its useful service life, it should be scheduled for replacement as soon as possible. See FEMA P-424, FEMA 543, and FEMA 577, *Design Guide for Improving Hospital Safety in Earthquakes, Floods, and High Winds* (FEMA 2007b) for remedial work recommendations.

TEST CUT WARRANTY AND REPAIR

If a system is under warranty, notify the warrantor before performing destructive testing (test cuts) so that the warranty is not inadvertently voided; then, have the test cuts repaired by a contractor authorized by the warrantor.

- **Level 2 assessment**. For buildings in locations where the current basic wind speed is greater than 120 mph[11] and the Level 1 assessment reveals that a given system has several more years of useful service life, the assessment team should recommend performing a Level 2 assessment. A Level 2 assessment consists of destructive and/or nondestructive testing, as discussed in Chapters 4, 5, and 6.

2.5.2 Data Analysis

After the historical file has been reviewed and the calculations and field investigation have been completed, the data need to be analyzed in the context of the facility owner's desired building performance (see Section 2.4).

Although unlikely, the analysis may reveal that no remedial work is needed to meet the desired building performance. The analysis is more likely to reveal the need for minor or major remedial work or the need for a new facility. Each of these scenarios may include a residual risk that the facility owner considers acceptable because it is deemed too expensive to mitigate.

2.5.3 Assessment Findings Report

The assessment findings report should include the limitations of the assessment findings (see SEI/ASCE 30-14). An assessment that includes both levels has a smaller margin of error than a Level 1 assessment by itself, but the true vulnerability of a building may not be known until tested by an actual wind event. Field testing and the various field checks conducted during a vulnerability assessment are performed at discrete locations, so data on conditions and wind and water resistance are only obtained for the areas

LIMITATIONS

Although a thorough vulnerability assessment may not identify all significant wind vulnerabilities, the assessment should be able to identify vulnerabilities that can be mitigated before any significant wind damage occurs.

11 The 120-mph basic wind speed is based on ASCE 7-16, Risk Category III and IV buildings.

that are tested or checked. There is always the potential for an undetected anomaly that could allow wind damage or wind-driven rain infiltration.

A best practice is to develop contingency plans for interruption of facility operations in case wind damage or water leakage occurs. For example, a contingency plan should be available to the staff of a hospital that indicates where the staff and patients should be relocated within the facility if the roof begins to leak. Similarly, a contingency plan should include procedures for evacuating the entire facility before, during, or immediately after a hurricane or other high-wind event requiring its activation. The plan should account for the potential risks of evacuating a facility during a hurricane (though those risks may be lower than staying in a severely damaged facility). All contingency plans should clearly define activation trigger points that have been coordinated, prepared, and approved by leadership, as well as clear instructions of actions that should be taken by which staff and when.

The assessment findings report should:

- Contain a description of all tests performed.
- Document data obtained from historical information, interviews with facility personnel, and field investigation.
- Document needed information that was not obtained.
- Document assumptions.
- Describe the field testing.
- Identify the vulnerabilities that were found that are considered significant.
- Provide a prioritized list of general recommendations for mitigation or facility replacement (see Section 2.5.4).
- Recommend any needed further assessment.
- Recommend the building elements/systems that should be inspected regularly and at what interval (e.g., annual visual inspection of the roof and rooftop equipment).
- Recommend the building elements/systems that should be inspected following unusually high winds. For example, FEMA P-424, 543, and 577 recommend an inspection of the building envelope and rooftop equipment following actual wind speeds of 70 mph peak gust (Exposure C) or greater.
- Recommend which building elements/systems should have another thorough vulnerability assessment and when it should be conducted (e.g., assessment of the roof system in 5 years).

2.5.4 Prioritizing Mitigation of Identified Vulnerabilities

If significant vulnerabilities are identified, but funds are insufficient to mitigate all of them, the assessment team should prioritize the mitigation work. The following priorities, listed in descending order, are often appropriate, but should be tailored as needed:

- Structural elements and exterior walls (including glass curtainwalls) that have the potential to fail or collapse during wind speeds of 90 mph[12] peak gust (Exposure C) or less
- Building envelopes and exterior-mounted equipment that have the potential to blow off or collapse during actual wind speeds of 90 mph peak gust (Exposure C) or less

REMEDIAL WORK

If the vulnerability assessment reveals the need for remedial work, see FEMA P-424, 543, and 577.

TEMPORARY EVACUATION

If weak long-span roof structures, weak non-load-bearing walls, or weak glass curtainwalls are identified, FEMA P-424 recommends evacuating areas in the vicinity of the weak elements when winds above 60 mph peak gust are forecast in order to minimize the risk of injury and death.

Weak hurricanes and other weak storms are statistically more likely to occur at any given facility than strong hurricanes or other strong storms. Therefore, at some facilities (depending on their function) it may be appropriate to complete inexpensive remedial work first and more comprehensive/expensive work later. For example, if the roof deck, gutter, and rooftop equipment attachments on a school building are weak, but the roof system has another 5 years of useful service life, the gutter and equipment attachments could be strengthened immediately, and the roof deck attachment deficiency could be more economically addressed when the roof system is replaced.

However, if a roof over a hospital ICU has the same vulnerabilities, forgoing the roof system's remaining service life and proceeding immediately with reroofing and deck attachment strengthening would be prudent.

Scheduling mitigation retrofits can be prioritized based on a variety of factors including availability of funding, building function, and the likelihood of occupancy during a hurricane or other high-wind event. For instance, a school is not typically occupied during a hurricane (unless it is used as a shelter), and building damage during a hurricane would typically not pose a risk of occupant injury or death. In contrast, a hospital's ICU is likely to be occupied during a hurricane, so building damage could present a risk to occupants.

If an incremental retrofit is executed because there are insufficient funds for a full retrofit, it is important to select retrofit work that results in the desired performance and acceptable risk level, commensurate with available funds.

12 The 90 mph trigger is based on peer-reviewed subject matter expert judgment.

Chapter 3: Site Issues

The site issues that pertain to wind vulnerability are site egress (i.e., roads), collapse hazards (e.g., trees, communications towers, poles), and rolling debris.

In addition to considering structural elements and the building envelope, a complete review should also include an assessment of the site issues described in this chapter.

3.1 Site Egress

Having at least two routes of egress from a critical facility site is important, but particularly so for facilities in hurricane- or tornado-prone regions. One route could be blocked by trees, towers, or poles that have been blown down, by other debris that has been blown onto the road, or by flooding or landslides. While flood hazards and landslides are not the focus of this document, site egress may be blocked by water after a high-wind event that includes rain or storm surge.

The vulnerability assessment should identify the number of available means of site egress and likely vulnerabilities that could impair the use of each means of egress.

3.2 Collapse Hazards

Falling trees, towers, and poles (e.g., light fixture poles, flagpoles, power poles) can block egress roads and damage buildings, and may be referred to as collapse or laydown hazards.

At the nursing home shown in **Figure 3-1**, both of the site egress roads were blocked by fallen trees during a tornado. Residents were moved to portions of the building that were not badly damaged. Residents and staff were evacuated the next morning after one of the

Figure 3-1:
Both of the site egress roads were blocked by fallen trees. When this photograph was taken, the circled road had not been cleared. The other road (solid red arrow) had been cleared to evacuate the occupants. The yellow dotted arrow indicates where a tree fell on the roof (see Figure 3-2). Tuscaloosa Tornado (Alabama, 2011) (FEMA P-908)

roads had been cleared. The 68 residents and staff could not be evacuated immediately after the tornado passed because of the blockage.

Large trees, towers, and poles can crash through Metal Building Systems (formerly known as "pre-engineered metal buildings") and wood-frame construction (**Figure 3-2**) and can rupture roof coverings and break glazing. The vulnerability assessment should include whether the site has any trees with trunks larger than 6 inches in diameter, towers, or poles that could hit the building or block egress roads if they topple.

Figure 3-3 illustrates the collapse of large light fixture poles due to tube corrosion near the base plate. See Section 5.5.1.2 for information on the vulnerability assessment of light fixture poles.

Figure 3-2:
Tree-fall damage at the nursing home shown in Figure 3-1. Tuscaloosa Tornado (Alabama, 2011) (FEMA RA6)

Figure 3-3: Collapsed light fixtures at a hospital. The bottom of the tubes were severely corroded (see insets). Hurricane Ivan (Florida, 2004) (FEMA 489)

3.3 Rolling Debris

Rolling debris includes portable classroom buildings, large trash receptacles, construction trailers, and vehicles. Rolling debris can block egress roads and damage buildings, and it may or may not penetrate walls or cause walls to collapse, depending on the type of exterior wall and the momentum of the debris. **Figure 3-4** shows a portable classroom that became rolling debris and hit the main school building.

Figure 3-4:
Portable classroom that became rolling debris. Hurricane Marilyn (U.S. Virgin Islands, 1995) (FEMA P-424)

The assessment should include investigation of the adequacy of the anchorage of the buildings and other structures near the critical facility that are vulnerable to becoming rolling debris, such as sheds, portable classrooms, or large trash receptacles. The portable classroom in **Figure 3-5** is susceptible to becoming rolling debris because the metal straps that connect the building to the ground anchors are not taut. **Figure 3-6** shows a portable classroom that became airborne. While the classroom could have caused significant damage, it landed in a field, rather than on the nearby school.

Figure 3-5:
Portable classroom susceptible to being blown off the piers and to overturning (FEMA P-424)

Figure 3-6:
View of a destroyed portable classroom. Most of the ground anchor straps failed in tension. However, at least two anchors pulled out of the ground. Hurricane Michael (Florida, 2018)

Typically, large trash receptacles and vehicles become rolling debris only when struck by an EF3 to EF5 tornado.

3.4 Wind-borne Debris Potential

The assessment should consider nearby sources of debris that could become wind-borne during a high-wind event. Aggregate from the rooftops of nearby buildings (within 1,500 feet) or the building being evaluated can cause damage to glazing and other building elements. In addition to aggregate on the rooftops of buildings, tile from tiled roofs as well as lumberyards, outdoor storage facilities, gas station canopies, or other buildings may be a source of debris.

Chapter 4: Structural Elements

This chapter addresses the assessment of structural elements, which are collectively referred to as the MWFRS, and focuses on vertical and lateral load-carrying elements.

Vertical load-carrying elements include roof decks, roof framing system elements, overhangs and canopies, and vertical walls that must carry the loads to the foundation and into the ground. Lateral load-carrying elements include shear walls, moment frames, and bracing. ASCE 7 defines the MWFRS as "… an assemblage of structural elements assigned to provide support and stability for the overall building or other structure. The system generally receives wind loading from more than one surface" (ASCE 2017).

This chapter discusses: the factors of the MWFRS that determine its vulnerability to a high-wind event; wind loads on the MWFRS (demand); structural resistance to the loads (capacity), including vertical and lateral load paths; construction materials; and the common vulnerabilities of the construction materials. In addition, this chapter outlines a recommended assessment process, which includes identification of deficiencies or gaps between the environmental demands and structural capacity of the building.

4.1 Vulnerability Factors

The vulnerability of the MWFRS, or the building's load resistance capacity to a high-wind event, depends on the following factors:

- Age of the building
- Quality or robustness of the design
- Quality of construction
- Construction materials
- Building code used for design and construction
- MRI used in the design
- Condition (including material degradation) and level of maintenance
- Number of changes to the building frame since construction

Predicting wind load performance based on these vulnerability factors is extremely difficult, but it is possible to generalize typical performance, assuming a design-level wind event. **Table 4-1** illustrates the expected wind performance of a building based on vulnerability factors and a design-level wind event. The building factors in the table are intended to be combined across the columns to estimate a range of anticipated performance, meaning that it is possible to qualitatively evaluate a reinforced masonry–reinforced concrete (RM–RC) building built in 1980 to the Building Officials Code Administrators International (BOCA) codes. For example, a wood or unreinforced masonry (URM) building built prior to 1985 is likely to experience severe to catastrophic damage, with significant operational downtime.

Table 4-1 is intended to give some idea of the past performance issues from high-wind events and to capture most of those issues in one place. This can give a possible starting point in determining vulnerabilities to a high-wind event with minimal yet easy-to-find information.

4.2 MWFRS Loads

A vulnerability assessment of the MWFRS must focus on the quality and adequacy of the load paths (both vertical and lateral). Quality in this context refers to the completeness of the vertical and lateral paths from the point of wind interaction with the frame and the ground where the loads must be dissipated. Adequacy refers to the size or strength of the member and the connections between members (capacity) compared with the magnitude of the design loads (demand). Load paths that support gravity loads usually are not an issue in engineered buildings such as critical facilities, but these load paths also should be examined.

4.3 Structural Resistance

Resistance to expected wind pressures depends in part on the strength of the members and connections that make up a building and its envelope. The strength of members depends on their physical properties—namely, their mechanical properties, such as the section modulus (which depends on the dimensions and shape of the member), and their material properties, such as their allowable bending and shear stresses. See Section 4.4 for additional information about these factors.

The vulnerability assessment of a structural frame involves an investigation that compares the resistance of the structure (capacity) to the anticipated loads (demand). This is done at a whole building level as well as at an element level. Unused capacity is calculated as Capacity (C) – Demand (D) = Unused capacity (U). In addition, the ratio of demand to capacity (D/C) should be assessed. When the D/C ratio approaches or is greater than 1.0, the assessor should recommend mitigation measures that will ensure that the demand does not exceed the capacity. The acceptable D/C ratio depends on the MRI of the design event, how the facility is used, owner expectations of performance, and the other building factors noted in **Table 4-1**. The comparison of resistance to demand must be made on the same design basis using either Allowable Stress Design or Load Resistance Factor Design (LRFD).

Instructions for reading **Table 4-1**: Combine building factors, as relevant, to the structure under consideration in order to estimate expected wind performance. It is not recommended that the table be used to perform a detailed evaluation of a specific building; rather, it should be used as a tool when looking at a broad portfolio of buildings. **Table 4-1** is not read left to right; rather, the relevant building factors from each column are combined for a given structure to estimate wind performance. For example, a steel-frame building built prior to 1975, adhering to a building code in use at the time, could be expected to experience minimal to severe damage and have operational issues.

Table 4-1: Expected Wind Performance of a Building in a Design-Level Wind Event

Expected Wind Performance	Building Factor						
	Date of Construction	Quality of Design/ Construction	Building Materials	Building Code	MRI (in years)	Maintenance	Number of Changes*
• Catastrophic damage • Possible deaths • Significant operational downtime	1960–1975	Poor/Poor	Wood–URM	None	25–50	Poor	Many
• Severe damage • Injuries • Operational issues	1976–1985	Fair/Fair	Steel	ANSI Standards	75–100	Fair	Some
• Minimal damage • Operational issues	1986–2000	Average/ Average	Precast Concrete	ASCE 7 BOCA SBCCI UBC	125–500	Average	Few
• Minimal damage • No significant operational Issues	≥ 2001	Excellent/ Excellent	RM–RC	ASCE 7 IBC	> 1,700	Excellent	None

* Number of changes to the building frame since construction

ANSI = American National Standards Institute
ASCE = American Society of Civil Engineers
BOCA = Building Officials Code Administrators International
IBC = International Building Code
MRI = mean recurrence interval
RC = Reinforced concrete
RM = Reinforced masonry
SBCCI = Southern Building Code Congress International
UBC = Uniform Building Code
URM = unreinforced masonry

4.3.1 Vertical Load Paths

The recommended approach to a wind vulnerability assessment is to begin at the top of the building and follow the vertical load path, looking for weaknesses in the wind uplift load path. The most common weaknesses in vertical load paths and the assessment methods that can be used to identify them are listed in **Table 4-2**.

Table 4-2: Most Common Flaws in Vertical Load Paths and Methods of Assessment

Vertical Load Path	Assessment Method
Roof deck to roof framing connections	• In a Level 1 assessment, determine the expected uplift pressure on the roof deck. If a load path exists, the dead load of the roof deck and roof covering can be taken into consideration. Lightweight roof decks (such as steel, wood sheathing, lightweight insulating concrete over form deck, cementitious wood-fiber, and gypsum) are especially vulnerable to uplift forces during high-wind events, as shown in **Figure 4-1**, **Figure 4-2**, and **Figure 4-3**. • Calculate the wind pressure demand for each existing roof deck fastener (using components and cladding [C&C] external and internal pressure coefficients) and compare it to the capacity of the fastener. The D/C ratio should be ≤ 1.0. • In a Level 2 assessment, expose the roof deck to determine the exact type and spacing of fasteners, and possibly remove one or more fasteners to determine the exact fastener size and capacity.

Figure 4-1: School with steel roof deck blown off. Blow-off of older steel roof decks is common. Hurricane Michael (Florida, 2018)

Figure 4-2: Fire station apparatus bay with displaced cementitious wood-fiber roof deck panels. Hurricane Michael (Florida, 2018)

Figure 4-3: Military facility with poured gypsum roof deck blown off. Some of the bulb tees were also blown off. Tuscaloosa Tornado (Alabama, 2011)

Table 4-2: Most Common Flaws in Vertical Load Paths and Methods of Assessment (cont.)

Vertical Load Path	Assessment Method
Roof framing to exterior wall connections	• Determine the expected uplift force (demand) at the end of the roof framing member that is attached to the exterior wall or wall framing. This force is developed from appropriate roof-uplift pressures. When a load path exists, reductions in the expected uplift force from the dead load of the roof system can be considered. • The capacity of the connection between the roof framing member and the exterior wall must be greater than the wind uplift force on the connection. The connection could be: – Bolted if steel members. – Welded if the roof frame is steel and the wall is masonry or concrete, including precast concrete panels, with steel plates to receive the roof member. – Welded if the roof is precast concrete with embedded steel plates and the walls are concrete with steel plates used to receive the roof member. – Steel reinforcing bars if both the roof and walls are poured concrete. – Connected with a mechanical connector if the roof framing is wood. See **Figure 4-4** for a wood-to-wood framing system connector. • In a Level 2 assessment, include the use of borescopes or x-ray technology to determine the presence of embedded steel plates; presence, size, and quality of welds; and connections of steel reinforcing bars. See **Figure 4-5** for failed welds that connected a joist to a bearing plate.

Figure 4-4: Connector used in wood-to-wood framing system

Figure 4-5: Failed welds (to left of each parallel line) that connected a joist to a bearing plate. The weld quality was marginal. Hurricane Harvey (Texas, 2017)

Table 4-2: Most Common Flaws in Vertical Load Paths and Methods of Assessment (cont.)

Vertical Load Path	Assessment Method
Resistance of roof framing to upward bending, placing tension members (e.g., bottom chords of trusses) into compression	• Determine the uplift force (demand) on the entire roof framing member (e.g., truss, beam, girder) using the MWFRS uplift pressures and roof member tributary area. • For trusses, using methods of structural analysis, determine the compressive stresses that uplift loads impose on the truss members and determine the risk of buckling. The resistance to buckling must be greater than the compression forces in the truss members. For beams, the capacity of the member to resist bending or excessive deflection must be greater than the force (demand).
Connections of appurtenances such as canopies and overhangs to the frame	• Determine the uplift and downward forces (demands) on the canopy or overhang because either the canopy or overhang can control the design. Calculation methods for determining demand are in ASCE 7 and the Wind Design Manual Based on the 2018 IBC and ASCE/SEI 7-16 Examples for Wind Forces on Buildings and Solar Photovoltaic Systems (SEAOC 2018). System capacity is likely to be governed by the connection of the canopy or overhang to the building frame. • Free standing canopies are likely to fail if the roof deck comes off or the vertical canopy columns are pulled from the base plate due to failing anchor bolts • The resistance to failure typically is provided by: – The connection between the canopy or overhang and the exterior wall – The element from which the canopy is hung – Additional braces, if any, such as knee braces or struts supporting the outer edges of the canopy to the exterior wall – The bolts securing the canopy, with the most likely failure mode occurring in either a pullout or shearing of the bolts
Connections between walls and foundations	• Review the notes or details on drawings to determine the capacity of the connections between walls and foundations since these connections usually are not visible. There are many possible material combinations for wall-to-foundation connections, including masonry walls to concrete foundations, precast concrete walls to concrete foundations, steel-framed walls and columns to concrete footings, and wood posts to concrete footings. The three primary connection methods are: – Reinforcing steel placed in the concrete foundation and spliced to reinforcing steel in the wall. No steel or short splices indicate a probable deficiency in capacity. – Steel plates embedded in both the wall and the concrete foundation. The connection is made by welding the plates together. Weld size and length are indicators of connection capacity, but this type of connection is nearly impossible to see in the field.

Table 4-2: Most Common Flaws in Vertical Load Paths and Methods of Assessment (cont.)

Vertical Load Path	Assessment Method	
Connections between walls and foundations	– Columns attached to footings with bolts. The capacity of the connection is based on the size and number of bolts and on the embedment depth of the bolts into the concrete. Size and number might be visible, but embedment depth usually is not visible. **Figure 4-6** illustrates a failed column base plate with an embedded anchor bolt. The bolt was extruded from the concrete. Use of headed anchor bolts is preferred for greater resistance. • In a Level 2 assessment, include the use of borescopes or x-ray technology to determine the: presence of embedded steel plates; presence and size of welds; and connections of steel reinforcing bars.	 Figure 4-6: Failed column base plate with an embedded anchor bolt. Joplin Tornado (Missouri, 2011) (FEMA P-908)

Table 4-2: Most Common Flaws in Vertical Load Paths and Methods of Assessment (concluded)

Vertical Load Path	Assessment Method
Connections between beams (including masonry bond beams) and beam supports (see **Figure 4-7** of a bond beam not secured to the supporting load-bearing CMU wall)	• Use structural drawings for the assessment since this area of the structure is not visible • Review the notes about reinforcement in the bond beams and how the bond beams are to be tied to the wall of the MWFRS. See **Figure 4-7**. A lack of notes about the vertical tie between the steel in the bond beam and the wall may be an indication of a lack of attention to the details of the beam and wall reinforcing. – For Level 2 assessments, use either a metal detector or an x-ray imaging process, if possible, to see both the locations of steel reinforcing and perhaps get an indication of the size of the steel. This nondestructive examination method should be done to determine average spacing and size of steel with some certainty.

Figure 4-7: Masonry bond beam not secured to the MWFRS. Tuscaloosa Tornado (Alabama, 2011)

C = Capacity
C&C = Components and cladding
CMU = Concrete masonry unit
D = Demand
MWFRS = Main wind force resisting system
SEAOC = Structural Engineering Association of California

4.3.2 Lateral Load Paths

The most common weaknesses in lateral load paths and the assessment methods that can be used to identify them are listed in **Table 4-3**.

Table 4-3: Most Common Flaws in Lateral Load Paths and Methods of Assessment

Lateral Load Path	Assessment Method
Large distances between shear walls	Many older building codes contain limited prescriptive designs on the spacing of shear-resistant elements within structures for wind. The lateral load or shear may be distributed into walls or may be resisted by moment frames or braced frames. • Determine the lateral wind load (demand) that must be resisted at each level of the building (knowing that the load accumulates as the analysis progresses toward the ground), and then assign the shear loads to either walls or frames. • Determine the adequacy of the shear transfer members that carry lateral load from roof or floor diaphragms to shear walls. • Determine the adequacy of diaphragms and diaphragm chords and collectors in the MWFRS. • Determine the shear capacity of the assigned walls or frames, including their anchorage. Capacity must be greater than the lateral load demand. • For RM or concrete shear walls, capacity is provided by reinforcing steel in the walls and in the connections of the walls to the vertical frame, including the foundation. • A Level 2 assessment of shear wall capacity for RM or concrete requires x-ray technology or a similar method of determining the extent of steel reinforcement in the walls and the number and size of bars at the wall/floor or foundation connection.
Inadequate resistance to wind pressures	• Determine whether the roof structure (including the deck) is strong enough and attached well enough to resist all applied wind pressures. In wind-borne debris regions, wind pressures should be determined using the internal pressure coefficient (GCpi) for a partially enclosed building, unless all glazing is resistant to or protected from wind-borne debris and the walls are adequate to resist wind pressures and debris without breaching the building envelope sufficiently to create a partially enclosed building.
Inadequate shear resistance of light frame walls and unreinforced masonry walls	• Determine whether light frame walls (wood, steel, URM) are attached to a building frame adequately to resist racking when subjected to lateral loads. The APA—The Engineered Wood Association has tables with required wall material thicknesses and fastener schedules for various shear loads (in pounds per linear foot of wall) for wood walls. Steel siding and fasteners need to be evaluated for capacity, which is primarily shear resistance of the fasteners. URM is unlikely to be sufficiently strong to resist any lateral load and should be considered inadequate for shear resistance. • Determining capacity for lateral resistance is highly variable and may depend solely on performance metrics. Ultimate capacity is to resist being pushed over or racking to the point of diminished operations. However, there may be some lower level of capacity that should not be exceeded so the building can be easily repaired or continue to operate. In these cases, D/C will be much less than 1.0.

RM = reinforced masonry; URM = unreinforced masonry

Table 4-3: Most Common Flaws in Lateral Load Paths and Methods of Assessment (concluded)

Lateral Load Path	Assessment Method
Inadequate tension resistance at the ends of openings in shear walls	• Determine the distribution of lateral loads along the base of the shear walls for resistance of the horizontal loads and the tension capacity in anchors that are installed at the ends of openings in the shear wall. Inadequate capacity of these tension restraints allows the shear wall to displace vertically as well as laterally at the top of the wall (racking). It is nearly impossible to determine the resistance capacity of these tension restraints except by a review of the drawings. The tension resistance usually is provided by reinforcing steel embedded in masonry or concrete walls and by mechanical connectors if the walls are steel-framed or wood-framed. Level 2 assessments may require the use of x-ray technology to determine the presence of the tension resistance at the end of the shear walls. This technology still may not be definitive in finding the sizes of the tension restraints.
Inadequate horizontal diaphragm capacity at the roof or floor level of light frame buildings	• Determine the lateral load distribution from the roof and floor diaphragms into shear walls. A weakness (lack of capacity) in the horizontal diaphragm does not allow the lateral load to be distributed to the shear walls and eventually to the ground. The most likely failure in a diaphragm occurs at the roof level since the floors are usually concrete in a critical facility and are sufficiently robust. The roof deck in light frame buildings (as previously described) could be a steel deck attached to steel framing with screws or arc spot ("puddle") welds or wood sheathing attached to either a steel- or wood-framed roof system, gypsum roof deck, lightweight insulating concrete, or cementitious wood-fiber deck. The weakness (lack of capacity) in the diaphragm most likely occurs in the attachment of the fasteners of the roof deck or diaphragm to the framing (i.e., an insufficient number of fasteners, inadequate fastener size, poor welds, lack of adequate fastener depth into the framing member, or corrosion). This possible failure mode can be checked if access to the bottom of the roof framing can be provided. See Section 5.4.2 for information on taking roof cuts to evaluate deck integrity and connections.
Lateral resistance provided by moment frames or bracing	• For moment frames, lateral resistance is provided by strength and stiffness (capacity) of the vertical members of the moment frame and in the moment capacity of the connection between the verticals and the foundation and the verticals and the horizontal connecting member. • For braced frames, lateral resistance is provided by the tension capacity of the brace in the tension direction and the resistance to buckling like a column in the compression direction. The connections of the brace to the vertical elements also must be checked to ensure that the demand is less than the capacity. • For both moment frames and braced frames, these elements may not be easily observed, so borescopes or x-ray technology may be required to determine the presence of these elements. These bracing elements should be reviewed from the structural drawings, if available. • For roof framing in particular, additional weight caused by piping, ductwork, or other non-structural elements should be included in the structural analysis of possible failures or reduced resistance.

RM = reinforced masonry; URM = unreinforced masonry

4.4 Construction Materials

Construction materials used in the structural frame and their condition at the time of a high-wind event have a significant effect on the performance of the frame during these events. Performance is affected by age and the condition of the material. Some materials may be in poor condition from previous events and, if so, this information is important in determining the potential vulnerability.

The potential issues to investigate are:

- **Concrete:** Investigate cracks, spalling, evidence of corroded reinforcing steel, and water penetration into the concrete.
  - **Cracks** are not all the same. Some are from normal shrinkage of the concrete and usually occur shortly after original installation and do not increase in size. The primary crack issues to investigate are those caused by differential or abnormal building settlement; by a stress differential in the structure caused by a failure in load-carrying capacity of part of the structure; or by internal stresses such as those induced by temperature differences.
  - **Spalling** is the deterioration of the concrete surface. Concrete can spall in small pieces or large sections. Spalling can be caused by chemical attack on the surface of the concrete; by a lack of bonding of the concrete elements, such as the concrete aggregate; or from corrosion of the reinforcing steel inside the concrete element (e.g., beam, column).
  - **Corroded reinforcing steel** increases in volume as it corrodes. The diameter increase forces the concrete covering the steel to crack and/or spall off the concrete surface. Most corrosion of reinforcing steel begins at a crack or small opening in the concrete element. Corrosion staining of the concrete may not always be visible at the surface.
  - **Water or moisture that penetrates a concrete element** follows a travel path to the inside of the element. The path is usually a crack in the surface that could be the result of poor bonding of the steel and the concrete. The water or moisture travels along the path in the steel until it is trapped at a place that allows the water to collect, causing the steel to corrode and eventually causing spalling from the corrosion.
- **Steel:** Investigate corrosion, cracked welds, bent flanges or webs of steel beams, and sagging roof and floor joists. **Figure 4-8** shows end-wall failure in a relatively new metal building system (MBS).

Figure 4-8: End-wall failure in a relatively new MBS. MBSs are used for many critical facilities. Hurricane Michael (Florida, 2018)

- **Corrosion** can reduce the strength of the steel member. Surface rust is not an indicator of loss of strength, but corrosion that has caused deterioration of the member is an indicator of loss of strength (capacity). The capacity of the corroded member for wind loads should be checked.
- **Cracked welds** are an indicator of capacity loss for the connection and are cause for serious examination and notifying an owner. Loads are transmitted from members through connections. A cracked weld and the resulting loss in connector capacity should be checked against the wind load demand that the connection is expected to transmit. Arc spot welds of steel roof decks have experienced a substantial number of failures. These welds can be x-rayed to help determine the capacity of those welds. The seriousness of the hazard caused by failed connections (welds) in the MWFRS cannot be overstated.
- **Bent flanges** on beams can be an indicator of reduced bending or compression capacity.
- **Sagging joists** in the roof or floor system indicate excessive load in the past or an excessive span.

- **Masonry:** Investigate cracks, shrinkage, or separation in the masonry; bowing; the presence of reinforcement in contraction or expansion joints; and veneer backing. See Sections 5.3.1 and 5.3.2 for details on assessing masonry veneer and non-load-bearing masonry.
  - **Cracks** in the mortar joints may be from normal shrinkage of the mortar or more severe distress caused by differential or abnormal building settlement. Severe stress differential in a structure also is likely to damage the masonry unit (not just to follow the mortar joints) if the differential is caused by a failure in load-carrying capacity of part of the structure or by internal stresses such as those induced by temperature differences.

- **Shrinkage or separation** of masonry units indicates a lack of continuity in the load path for unreinforced masonry. Shrinkage is most likely to occur at the mortar joints and can be caused by the normal drying of the mortar. A separation between different walls or masonry elements that should be tied together to allow for load transfer indicates a possible lack of reinforcing at the intersection and, thus, a possible lack of capacity in transferring load along the load path.
- **Bowing** of a masonry wall indicates either excessive load or a wall section (thickness) that is not adequate for either the vertical or horizontal load demand (or both). Refer to Section 5.3.1.5 for assessment considerations. The amount of bowing is important to determine, and any out-of-plane deflection of more than ¼ inch to ¾ inch in 8 feet of height should be highlighted in a mitigation report.
- **Expansion and contraction joints** occur at some interval in long masonry walls to allow the masonry to expand and contract without damaging the walls or any interior elements. In high-wind locations, these joints might have some reinforcement that is sleeved to allow for horizontal movement, but that prevents any out-of-plane differential movement. These joints should be checked for the presence of the reinforcement. The reinforcement in bond beams that form the chords of diaphragms must be continuous without any slip mechanism.
- **Veneer backing** (discussed here as masonry, but which also could be wood) can provide both vertical and lateral support to masonry veneer. This surface is unlikely to be observable from the exterior, but it could be partially viewed from the interior. The assessment issues of cracking and bowing as they relate to vertical and lateral load-carrying capacity are important for veneer backing.

- **Wood:** Investigate deterioration and damage of roof, wall, and floor systems as well as evidence of cracked wood members or twisting or warping of members.
  - **Deterioration/wood decay** can occur anywhere that wood may be subject to moisture or wood-destroying insects, such as termites. Deterioration by fungi can occur when the moisture content of the wood exceeds 19 percent for an extended period, which can easily occur if a leak allows water into the wood framing. If the wood later dries, fungi may remain as spores until moisture levels activate the fungi again.
  - **Sagging** in the roof or floor system indicates excessive load in the past or an excessive span, which may reduce the capacity of the members to resist the design loads.

- **Cracked** members indicate that wood has dried out, become brittle, or received stress in the length of the member along the grain of the wood. Cracking (splitting along the grain of the wood) can reduce both the compression and bending strength of the member.
- **Twisting/warping** sets up an induced torsion in the wood member, which may affect its load-carrying capacity.

4.5 Assessment of Structural Elements

In addition to performing a Level 1 or Level 2 field assessment as previously described, the assessment team can perform an assessment of structural elements remotely. Assessing the vulnerability of the structural frame to determine whether wind load demand (D) is less than capacity (C) can be accomplished in numerous ways. The recommended process is as follows:

1. Determine the design wind speed or the wind speed assumed in determining an acceptable level of performance.
2. Develop a table of wind pressures on the various elements of the MWFRS. These pressures should be LRFD (ultimate) level pressures representing the expected demand on the building elements (frame and connections).
3. Determine a series of critical vertical and lateral load-carrying elements for which a wind load capacity will be calculated.
4. Calculate the expected ultimate capacity of the elements selected in Step 3. The capacities should be modified from an ultimate capacity when new—based on age, condition, quality of design and construction, materials, and flaws—as discussed above for both vertical and lateral load paths. The difficulty with revising the capacities based on these conditions (e.g., age) is that there is little research to use as a basis for making judgments about the levels of reduction in capacity that may be appropriate.
5. Determine the D/C ratio for each selected element.
6. For each element where $D/C > 1.0$, propose a method for increasing resistance.
7. For each element where $D/C \gg 1.0$, propose an immediate improvement in resistance to reduce the possibility of severe damage, lengthy operational downtime, or death or injury of occupants if a high-wind event that causes structural failure occurs.

Chapter 5: Building Envelope and Exterior Equipment

This chapter addresses the assessment of the building envelope and exterior-mounted equipment for vulnerability to wind, wind-borne debris, and wind-driven rain. The building envelope consists of exterior doors, glazing, non-load-bearing walls, wall coverings, soffits, and roof systems. Exterior-mounted equipment includes roof- and ground-mounted equipment, including solar arrays.

5.1 Doors: Personnel Doors, Sectional Doors, and Rolling Doors

This section addresses solid personnel doors, sectional (garage) doors, and rolling doors. For glazed personnel doors and glazed vision panels in doors, see Section 5.2.

5.1.1 Personnel Doors

Failure of personnel doors is uncommon. Personnel doors can fail because of over-pressurization or from the failure of the door latch or hinges from impact by wind-borne debris (**Figure 5-1**).

5.1.1.1 Level 1 Assessment

The following steps are recommended as part of a Level 1 assessment of personnel doors:

Figure 5-1:
Hinge screws pulled out of the door frame at a fire station. Hurricane Charley (Florida, 2004)

- Determine whether there is a door assembly wind-pressure rating label on the door or frame. If the label is not present, check the historical file to determine whether the assembly was rated. If the assembly was rated, compare the rating with the design wind load based on the current edition of ASCE 7.
- Remove at least one hinge and one strike-plate fastener to determine fastener type and size. Compare the installed fasteners to the type and size of fasteners used in an assembly capable of meeting the design load based on the current edition of ASCE 7.
- Determine how far the latch extends into the frame. Compare this dimension with the throw of an assembly that can meet the current design wind load.

ATTACHING DOORS

For design guidance on door frame attachment, see the American Architectural Manufacturers Association (AAMA) TIR-A14 (AAMA 2010).

For a methodology to confirm that an anchorage system provides load resistance with an appropriate safety factor to meet project requirements, see AAMA 2501. Both documents are available for purchase from the AAMA (https://aamanet.org).

- If the door has horizontal exit hardware, determine whether an assembly with this type of hardware (versus hardware with top and bottom vertical rods) can meet the current design wind load.
- If the frame fasteners are visible, evaluate the frame attachment.
- For wind-driven rain: Check for the presence and adequacy (i.e., type and condition) of weatherstripping. See FEMA P-424 for various types of weatherstripping. Also, check the adequacy of the sealant/flashing between the door frame and the wall.
- For wind-borne debris: For buildings in hurricane-prone regions, where the current basic wind speed is greater than 135 mph[12]—except for schools[13]—determine whether the door was tested for resistance to wind-borne debris

TESTING FOR WIND-BORNE DEBRIS RESISTANCE

Neither IBC nor ASCE 7 require doors without glazing to be tested for wind-borne debris resistance. However, FEMA 543 and 577 recommend test missile "E" (as defined in ASTM E1996-17, *Standard Specification for Performance of Exterior Windows, Curtain Walls, Doors, and Impact Protective Systems Impacted by Windborne Debris in Hurricanes*) for critical facilities other than schools.

12 The 135-mph basic wind speed is based on ASCE 7-16, Risk Category III and IV buildings.

13 The reasons for the school exception are: (1) the probability of significant wind-borne debris damage to solid doors is relatively low, (2) schools typically are not occupied during a hurricane (unless used as a hurricane evacuation shelter), and (3) schools typically are not needed immediately after a hurricane (unless used as a congregate shelter for survivors whose homes are uninhabitable or inaccessible). If a school is to be used as an evacuation shelter, see Chapter 1.

according to ASTM International. (ASTM) E1886-13a, *Standard Test Method for Performance of Exterior Windows, Curtain Walls, Doors, and Impact Protective Systems Impacted by Missile(s) and Exposed to Cyclic Pressure Differentials* (ASTM E1886), or Florida Building Code (FBC) Testing Application Standard (TAS) 201/203 (FBC 2017c; FBC 2017d).

See Section 5.2 for glazed personnel doors and vision panels in doors.

5.1.1.2 Level 2 Assessment

If the Level 1 assessment reveals that the door assembly has several more years of useful service life, and the building is located in a region where the current basic wind speed is greater than 120 mph,[14] a Level 2 assessment is recommended. The following steps are recommended as part of a Level 2 assessment:

- If the door frame fasteners are concealed, use a borescope or perform destructive observations to determine how the frame is attached to the building.
- Compare the attachment strength to the design load based on the current edition of ASCE 7.

5.1.2 Sectional and Rolling Doors

This section addresses sectional and rolling door assemblies. There is only one level of assessment.

5.1.2.1 Sectional Doors

Sectional doors are constructed of wide slabs (sections) that are joined with hinges. When the door is opened (moved upward to an overhead location), the outside edges of the sections are guided by rollers that follow a track. The sections typically require some reinforcement. The reinforcements and their attachments to the sections are important parts of the door strength and must be examined in detail in a vulnerability assessment.

The most common type of reinforcement is horizontal struts (u-bars) on the interior face of the door. Sometimes less apparent reinforcement is used, such as reinforcement inside the sections. Struts can vary in size, metal thickness, and material strength. The attachment of the struts to the door—specifically, the locations and number of screws—is of interest. Additional reinforcement may take the form of more screws, longer or stronger roller stems, additional end hinges, or additional vertical stiles.

A less common type of reinforcement in sectional doors is vertical posts. The posts span from the floor to the header along the width of the span, generally at the center of the opening and/or to either side of center. Posts generally are limited to doors no taller than 8

14 The 120-mph basic wind speed is based on ASCE 7-16, Risk Category III and IV buildings.

feet (Door & Access Systems Manufacturers Association International [DASMA] Technical Data Sheet [TDS] 153 [DASMA 2013a]).

5.1.2.2 Rolling Doors and Rolling Sheet Doors

Rolling doors have a curtain of interlocked horizontal slats or a continuous corrugated sheet of metal. Both types of doors are opened when the curtain is pulled up out of the opening and coiled around a pipe or barrel. The edges of the curtain are constrained in vertical guides.

WIND LOAD RATING

Wind-Rated Door: Door that carries a wind load rating.

Unrated Door: Door that is not constructed to withstand any particular wind pressure.

Narrower rolling doors may have adequate resistance to wind loads because of the stiffness of the slats or curtain alone, but wider rolling doors have windlocks (**Figure 5-2**) at the edges of the curtain that hook onto the guides to keep the curtain from deflecting or bowing far enough to pull out of the guides.

From a distance, the difference between a wind-rated rolling door and an unrated door may not be apparent because reinforcement features are almost hidden.

Figure 5-2:
Slats with continuous endlocks and windlocks. The upward wings blocking the slats from sliding apart are endlocks. The tabs that are centered and facing down are windlocks that engage the rolling door guides for wind-rated doors.

5.1.2.3 Assessment of Sectional and Rolling Doors

The assessment of sectional and rolling doors should include an evaluation of whether the door operates smoothly without binding or interference. Doors also should be checked for common wear items, including loose or missing fasteners, cracks in metal components, and, in sectional doors, roller wear.

See DASMA TDS 151 and DASMA TDS 181 for inspection guidelines of sectional and rolling doors, including safety considerations.

The assessment of sectional and rolling doors for resistance to wind loads, wind-borne debris, and wind-driven rain infiltration is discussed below.

Wind Load

The first step in assessing a sectional or rolling door for wind load is to determine the door's wind load rating, and the first step in determining the rating is to identify the manufacturer and obtain the door specifications. There is no standard construction for sectional or rolling doors because manufacturers develop and prove their own designs.

Manufacturers commonly label wind-rated doors with the pressure rating. If present, the label provides a starting point to locate the design documents because it usually includes the manufacturer's name and references the wind load construction drawing. The drawing is needed to compare the design to the actual as-built construction. If the pressure rating label is absent, the manufacturer's name may be on the lock escutcheon plate, hinges or other hardware, or warning labels.

There is no field test method for wind pressure or wind-borne debris resistance of sectional or rolling doors. Verification of the installation is accomplished by comparing the door wind load construction drawing to the installed product. It is important to look at every detail of the wind load drawing. Typically, these drawings do not detail the complete door design but only highlight the additional nonstandard features that are required to meet the desired wind load rating. Every detail should be considered important, including the number of screws and thickness of the metal.

The door must be kept closed during a wind load event. To accomplish this, doors typically have a simple lock or an electric operator. The installed condition of the lock or electric operator should be checked against the manufacturer's recommendations, particularly on manually operated wide doors, which may require lock engagement into both side tracks of the door.

The attachment of the door to the building also should be checked. An inadequately secured door will not achieve its wind load rating even when properly reinforced if the door cannot transfer the load to the building through a reliable connection (see **Figure 5-3**, **Figure 5-4,** and **Figure 5-5**). The rolling door in **Figure 5-3** was attached with expansion bolts into concrete. The concrete spalled at the bolt locations, which was attributed to inadequate edge distance. In **Figure 5-4**, the frame of the sectional door was adequately attached to the 2 x 6 nailer, but the nailer was inadequately attached to the wall. Most manufacturers provide guidelines for attachment, and DASMA has generic jamb attachment guidelines for general use (see DASMA TDS 161 and DASMA TDS 156). **Figure 5-5** shows rolling door failures caused by inadequate wind resistance of rough opening members.

Figure 5-3:
Failure of a rolling door at a courthouse due to inadequate edge distance of the frame's expansion bolts. Hurricane Charley (Florida, 2004) (FEMA 488)

Figure 5-4:
Failure of a fire station sectional door due to inadequate attachment of the nailer to the wall. Hurricane Charley (Florida, 2004)

Figure 5-5:
View of rolling door failures caused by inadequate wind resistance of rough opening members. The solid red and dotted orange arrows indicate failed rough opening jamb and header framing members. The dashed green arrow indicates a missing rough opening jamb member at an adjacent door. Hurricane Michael (Florida, 2018)

An alternative to contacting the manufacturer is to check the database of wind load door designs maintained by Florida and Texas. See Product Approval page at https://www.floridabuilding.org/pr/pr_app_srch.aspx for Florida and www.tdi.texas.gov/wind/prod/ for Texas.

Wind-borne Debris

The assessment of a sectional or rolling door should include whether the door has been tested for resistance to wind-borne debris if the building is located in a hurricane-prone region where the basic wind speed is greater than 135 mph.[15] This determination is not needed for schools.[16] If a door has been tested for resistance to wind-borne debris, the sectional and rolling door industry typically cites test method ANSI/DASMA 115 on the label. Alternate test methods include ASTM E1886 and FBC TAS 201/203. Since the 2005 edition of ANSI/DASMA 115, test missile "D" (as defined in ASTM E1996-17) has been used by default. See text box in Section 5.1.1.1 about test missile "E."

Wind-Driven Rain Infiltration

Sectional and rolling doors typically are not designed to be leak-free. It should be assumed that wind-driven rain will penetrate the door unless otherwise indicated, which may represent a vulnerability to the building depending on whether the interior area affected can withstand penetration by wind-driven rain. Sectional and rolling doors are used commonly at loading docks or at fire stations, where entry of water at the frame or threshold is not an issue.

5.2 Exterior Glazing and Shutters

This section addresses exterior glazing, such as fixed and operable windows (including jalousie windows), skylights, glass doors and door vision panels, and impact-resistant systems, such as shutters or screens.

The assessor must have knowledge of industry standards, manufacturers, system designs, and current building code requirements to perform the assessment. If design criteria differ from code requirements, the assessor must determine what the criteria are. The design criteria that are important in windows, skylights, glazed doors, and shutters are resistance to wind loads, wind-borne debris, and water leakage.

15 The 135-mph basic wind speed is based on ASCE 7-16, Risk Category III and IV buildings.

16 The reasons for the school exception are: (1) the probability of significant wind-borne debris damage to solid doors is relatively low, (2) schools typically are not occupied during a hurricane (unless used as a hurricane evacuation shelter), and (3) schools typically are not needed immediately after a hurricane (unless used as a congregate shelter for survivors whose homes are uninhabitable or inaccessible). If a school is to be used as an evacuation shelter, see Chapter 1.

5.2.1 Glazed Assemblies

This section addresses fixed and operable glazing, including windows, skylights, glass doors, door vision panels, and jalousie windows (for solid doors, see Section 5.1). Reference Section 5.3 for a discussion on corner wind zones, which are subject to higher wind pressures than other portions of walls.

An assessment of exterior glazing for vulnerability to wind includes the glass (or metal, when considering operable window assemblies), framing systems, and anchors. As part of the assessment, the assessor should determine the type of framing and glass (or metal), manufacturer, assembly performance criteria, age and condition of assemblies, and current performance reliability.

5.2.1.1 Level 1 Assessment

A Level 1 assessment of exterior glazing is nondestructive and includes research, information gathering, and observations. The following tasks comprise a Level 1 assessment, provided the needed information is available:

- **Review project design documents.** Original project design documents establish the age of the building. A full set of project documents often contains specifications for performance criteria. Project documents can be useful in helping to identify the manufacturer. Details such as how the assemblies are anchored to the structure and anchor substrates also can be determined. Any information contained on the drawings must be verified in the field because changes are sometimes made during construction.
- **Review original construction submittal documents**, including shop drawings, engineering calculations, test reports, product approval documents, manufacturers' literature, and any other submittals if they exist. Unfortunately, more often than not, this information either never existed or has been lost. If these documents are available, they may provide enough information to avoid a Level 2 assessment.
- **Determine the age of the assemblies**. Judgment must be made as to whether the windows, skylights, and glazed doors are original to the building. If original project documents are not available, public records (such as building code permits and tax assessments) often can be used to determine the age of the building and its windows, skylights, and glazed doors.
- **Review repair and maintenance records** to help determine the service history and condition of the assemblies. If the property has been affected by any windstorms, the records may contain repair information. Depending on the age of an assembly, maintaining items such as weatherstripping, sealants, and hardware can extend the useful life and provide for better long-term performance.

- **Review reports of any performance-related issues**, such as water intrusion, to gain insight into the past and current performance of assemblies and to try to ascertain whether past performance issues were one-time events associated with a severe wind event or are a chronic problem.
- **Research weather records and historical weather data** for the area during the life of the building to determine whether the assemblies have been through any severe wind events that may have exceeded the design capabilities. This information is useful in predicting future performance because even discrete windstorm damage can affect the wind resistance of assemblies.
- **Interview building occupants** for reliable information about the service history of the building or any prior or current performance problems, such as water leakage. When speaking with building occupants, try to glean the facts and not their opinions because they usually are not glazing experts.
- **Conduct a site inspection** to determine through observation the condition of the assemblies. Sometimes research and interviews provide little information, and the site inspection is the only option for estimating performance data and current reliability. The exterior glazing should be carefully examined during the site inspection. Framing should be checked for material composition, profile measurements, condition of framing joints, evidence of construction defects, signs of wind damage, aging, and corrosion. **Figure 5-6** through **Figure 5-20** show typical examples of wind damage.

Figure 5-6: Discrete windstorm damage: Frame rotation at a window meeting rail

Figure 5-7: Discrete windstorm damage: Deflection at sliding door panel legs

Figure 5-8: Discrete windstorm damage: Frame rotation at sliding door bottom rail

Figure 5-9: Discrete windstorm damage: Frame movement at the right jamb of window

Figure 5-10: Discrete windstorm damage: Water damage at lower right corner of window

Figure 5-11: Discrete windstorm damage: Frame movement at the head

Figure 5-12: Windstorm damage: Water damage and corrosion at lower left corner of window

Figure 5-13: Windstorm damage: Frame rotation at a window meeting rail

Figure 5-14: Windstorm damage: Deflection at sliding door panel legs

Figure 5-15: Windstorm damage: Water damage and corrosion at bottom rail of window

Figure 5-16: Windstorm damage: Frame rotation at sliding door top rail

Figure 5-17: Windstorm damage: Frame rotation at a window bottom rail

Figure 5-18: Windstorm damage: Frame separation at a window meeting rail

Figure 5-19: Windstorm damage: Frame movement at the left jamb of window

Figure 5-20:
Windstorm damage: Frame movement at the right jamb of window

- **Identify the type and treatment of the glass.** The glass may have a label (also called "bug") that can help identify the type and treatment (**Figure 5-21**).
- **Determine whether the glass is laminated or insulated, and determine the thickness of each ply**. Glass thickness tools can be used to make these determinations.
- **Document anchor type, size, location, and condition**.
- **Determine the condition of sealants and weatherstripping** to help predict current air and water infiltration performance.
- **Check the interior finishes** around windows and skylights for evidence of water intrusion. The severity of any evidence of water leakage can be a predictor of whether the leakage is isolated or chronic. Document all observations during the site inspection with field notes and photographs. See **Figure 5-22** to **Figure 5-28**.

Figure 5-21: Typical glass label

Figure 5-22: Water damage (bottom left corner of door)

Figure 5-23: Water damage (bottom left corner of window)

Figure 5-24: Water damage (bottom right corner of window)

Figure 5-25: Water damage (bottom center of window)

Figure 5-26: Water damage (bottom right corner of window)

Figure 5-27: Water damage (top center of window)

Figure 5-28: Water damage (bottom left corner of window)

- If the manufacturer was not identified during the review of the project records, **check the framing for the manufacturer's logo**. The glass fabricator, which may be identified on a glass label, is not normally the same as the window, skylight, or door manufacturer. Unfortunately, most manufacturers of older assemblies are no longer in business.
- **Check for labels that may contain performance data**. Some labels are part of an industry association certification program. The AAMA sponsors a window certification program that requires a label on every window (**Figure 5-29**).[17] The performance data on the label can be reconciled with industry standards for the relevant timeframe to determine the performance criteria required for certification.

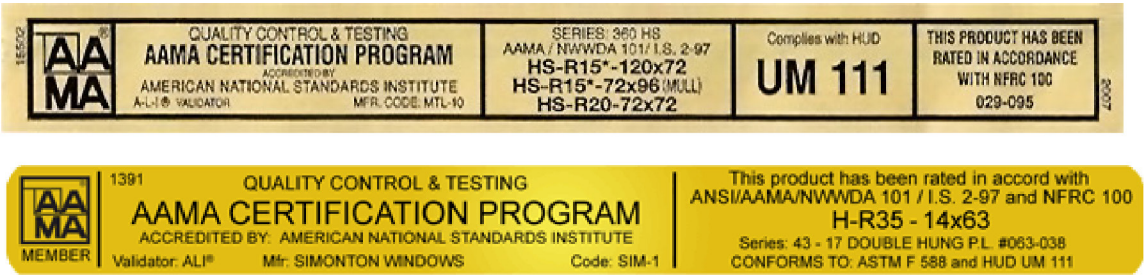


Figure 5-29: Typical AAMA labels

Miami-Dade County Product Control[18] and the Florida Building Commission[19] also have product approval programs, and product information can be obtained from them. If there is no label, sometimes hardware items have logos that indicate the manufacturer. See **Figure 5-30** to **Figure 5-32**.

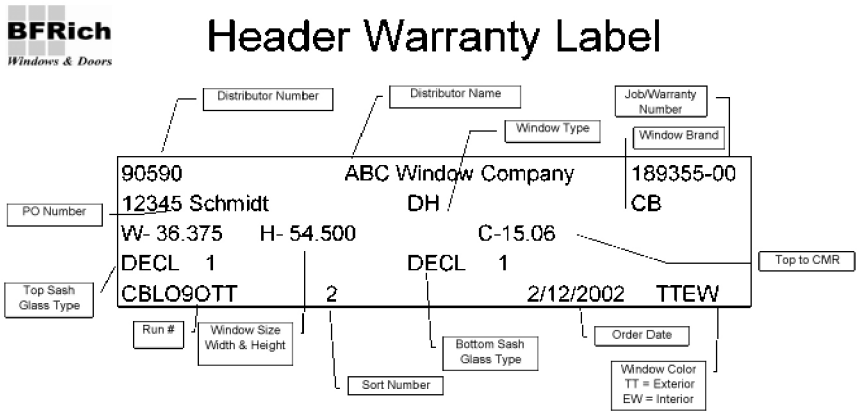


Figure 5-30: Typical manufacturer label

17 AAMA certification program information is available at https://aamanet.org.

18 More information is available at http://www.miamidade.gov/building/product-control.asp.

19 More information is available at https://www.floridabuilding.org.

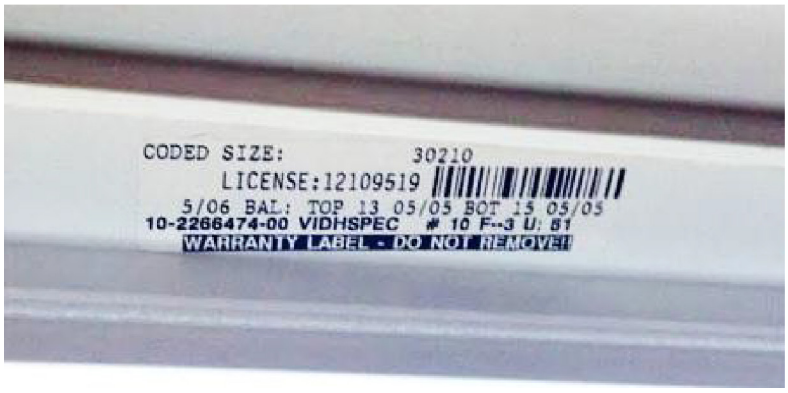


Figure 5-31:
Typical manufacturer label on head of window

Figure 5-32:
Manufacturer's logo on window hardware

- **Locate manufacturer's specifications and performance data** by doing research. If the manufacturer is identified and the age of the product is determined, performance criteria may be available from the manufacturer. If the manufacturer is no longer in business, review industry association certification records, such as AAMA.

- For buildings in hurricane-prone regions where the basic wind speed is greater than 135 mph,[20] **if the glazing is not protected with shutters, determine whether the glazing assembly was tested for resistance to wind-borne debris** via ASTM E1886 or FBC TAS 201/203, using test missile "D" or test missile "E."[21] If the glazing is protected with shutters, see Section 5.2.2.

TEST MISSILES

FEMA P-424 recommends test missile "D" (as defined in ASTM E1996-17) for schools located where the basic wind speed is less than 175 mph. Test missile "E" is recommended where the basic wind speed is 175 mph or greater.

FEMA 543 and 577 recommend test missile "E" for critical facilities other than schools.

20 The 135-mph basic wind speed is based on ASCE 7-16, Risk Category III and IV buildings.

21 Per the exception in ASCE 7-16, when the glazing is located more than 60 feet above the ground and more than 30 feet above aggregate surfaced roofs located within 1,500 feet of the building, the glazing typically would be deemed to not be vulnerable to breakage.

Damaging wind-borne debris has been documented to occur inland of the wind-borne debris region defined in ASCE 7-16 (**Figure 5-33**). Depending on how critical the facility is that is being evaluated and whether there is a nearby debris source such as trees or weak buildings, it may be prudent to use a speed as low as 120 mph[22] in lieu of the 135-mph trigger speed given above.

Figure 5-33: View of an emergency operations center (EOC) (left) that was struck by wind-borne debris from a weak building (yellow dotted oval). The debris had sufficient momentum to damage metal wall panels. Although the building was well inland of the wind-borne debris region, the glazing was protected by shutters. The hurricane's estimated wind speed at this location was 117 mph. Hurricane Michael (Florida, 2018)

JALOUSIE WINDOWS

The Level 1 assessment also is appropriate for jalousie windows. Jalousie windows contain panels (louvers) made of metal, glass, or wood that can be opened or tilted to control airflow. This type of window is common in schools and other residential and nonresidential buildings in Puerto Rico, the U.S. Virgin Islands, and other areas with warm or tropical climates. Jalousie windows have also been observed at offices and labs at potable water treatment plants and wastewater treatment facilities in Puerto Rico.

Jalousies are very susceptible to wind-driven rain, even when the louvers are undamaged. Common metal jalousie louvers may be undamaged by low-momentum debris, but they can be easily breached by wind-borne debris that is common during strong hurricanes.

Metal jalousie window struck by wind-borne debris. Hurricane Irma (U.S. Virgin Islands, 2017)

22 The 120-mph basic wind speed is based on ASCE 7-16, Risk Category III and IV buildings.

Upon completion of the Level 1 assessment, prepare a report to summarize the investigation and findings. The report should include:

- A description of all tasks performed
- A list of all materials that were reviewed
- Any unsuccessful attempts to glean information
- Any needed information that was not obtained
- Any assumptions
- Any performance data that were obtained
- Information on the manufacturer, framing type, glass type and treatment, anchors, type of operation, and hardware for any investigated windows and skylights
- The site inspection
- A description of the methodology and sampling procedure used
- Photos of all observations with descriptive captions and arrows, if needed (**Figure 5-34** to **Figure 5-40**)
- A summary of the findings and recommendations for further assessment, if any

Figure 5-34:
Example of a typical report photo with caption and arrow

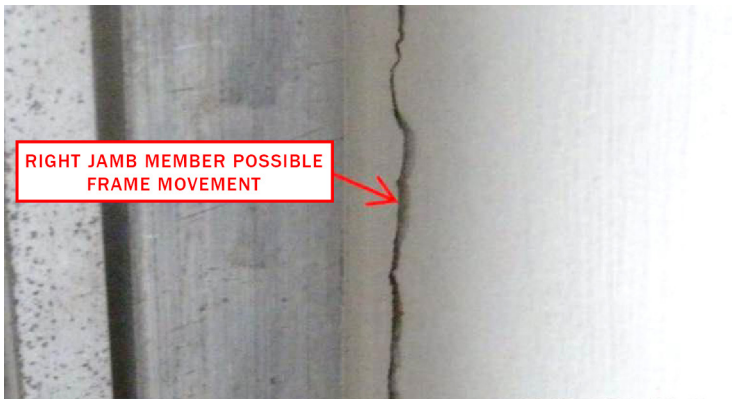


Figure 5-35:
Example of a typical report photo with caption and arrow

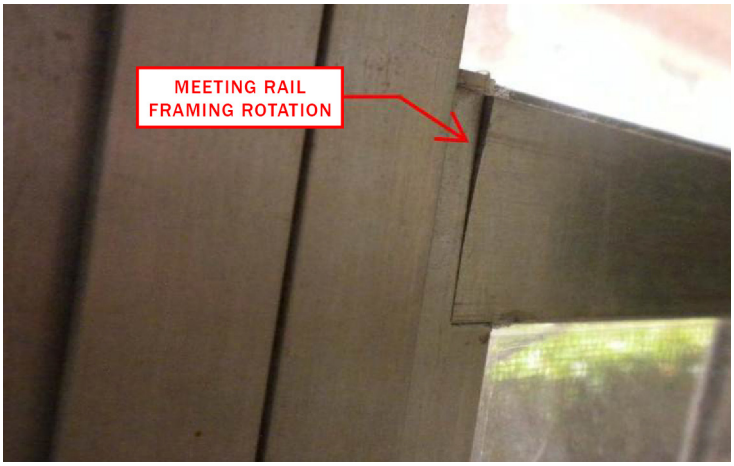


Figure 5-36:
Example of a typical report photo with caption and arrow

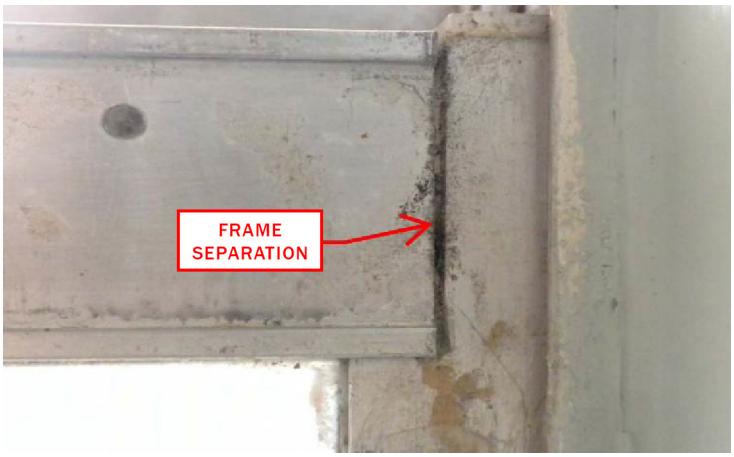


Figure 5-37:
Example of a typical report photo with caption and arrow

Figure 5-38:
Example of a typical report photo with caption and arrows

Figure 5-39:
Example of a typical report photo with caption and arrow

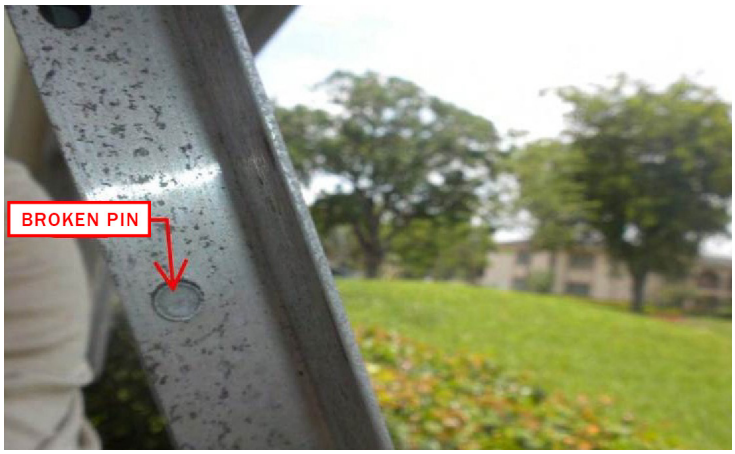


Figure 5-40:
Example of a typical report photo with caption and arrow

5.2.1.2 Level 2 Assessment

If the information obtained during the Level 1 assessment was sufficient to predict current assembly performance or compliance with design criteria, no further assessment is necessary. A Level 2 assessment is recommended if:

- The Level 1 assessment revealed that the glazing system has several more years of useful service life, and the building is located where the basic wind speed is greater than 120 mph.[23]
- The Level 1 assessment did not produce all the information needed.
- The assumptions drawn from the Level 1 assessment need to be confirmed.

A Level 2 assessment may include the field testing, destructive analysis, and theoretical analysis that is described as follows:

- **Conduct field air and water infiltration tests** to confirm current field performance. ASTM E1105-00, *Standard Test Method for Field Determination of Water Penetration of Installed Exterior Windows, Skylights, Doors, and Curtain Walls, by Uniform or Cyclic Static Air Pressure Difference* (ASTM 2015a), is the industry standard for field water infiltration testing. The test involves constructing an air chamber across the inside of the assembly[24] and vacuuming air from it at a specified rate, while applying water across the outside face from a uniform spray grid (see **Figure 5-41** to **Figure 5-46**). The test simulates the conditions of wind-driven rain.

Figure 5-41:
Water infiltration field testing (interior air chamber)

23 The 120-mph basic wind speed is based on ASCE 7-16, Risk Category III and IV buildings.

24 The method also allows for an exterior air chamber with positive pressure in lieu of the interior chamber. The test results are the same for either setup.

Figure 5-42:
Water infiltration field testing (water leakage at lower right corner)

Figure 5-43:
Water infiltration field testing (interior air chamber)

Figure 5-44:
Water infiltration field testing (water leakage at bottom of window frame, solid red arrow)

Figure 5-45:
Water infiltration field testing (spray rack configuration)

Figure 5-46:
Water infiltration field testing (exterior air chamber)

AAMA 502-12 (AAMA 2012a) and AAMA 503-14 (AAMA 2014) provide guidance for setting up the test and specifying proper test pressures. ASTM E2128-17, *Standard Guide for Evaluating Water Leakage of Building Walls* (ASTM 2017e) also can provide guidance for how to investigate water leakage issues. ASTM E783-02(2018), *Standard Test Method for Field Measurement of Air Leakage Through Installed Exterior Windows and Doors* (ASTM 2002) can be used to measure field air infiltration. Field air and water testing can be very complex. The test must be set up properly to yield useful results. Isolation testing is often necessary to determine whether water entry is occurring through a window or skylight or from an adjacent wall or roof areas (**Figure 5-47** to **Figure 5-49**).

Personnel and agencies experienced with field air and water infiltration testing should be used. Rogue tests, such as smoke pencils, or applying water from a garden hose or pressure washer will not provide reliable or repeatable data and may result in improper conclusions.

Figure 5-47:
Water infiltration field testing (isolation)

Figure 5-48:
Water infiltration field testing (isolation)

Figure 5-49:
Water infiltration field testing (isolation)

- **Remove or partially disassemble typical assemblies**. Partial disassembly can be used to confirm framing section properties and glass type and thickness. It also can allow for observations of concealed conditions and anchors. Full removal of an assembly allows for inspection of anchor conditions and anchor substrates along with determining whether there is hidden water damage inside the wall cavity.
- **Analyze anchors and fasteners**. This can be a critical determinant of predicted assembly performance. Anchors and fasteners can deteriorate over time and lose effectiveness. If they no longer are performing as designed, assemblies can fail (blow out) during severe windstorms.

- **Review anchor substrates**. This is also important for predicting installed assembly performance. Older systems were designed to lower standards than current code requirements. Sometimes the anchor substrate does not have sufficient holding strength for the anchors to perform as designed, which can result in failures during severe windstorms.
- **Conduct theoretical engineering analysis** to develop performance criteria for existing assemblies when data are not available otherwise. Detailed framing dimensions and section properties must be determined in the field along with glass type, treatment, and thickness; anchor type and size; and anchor substrate information.

At completion of the Level 2 assessment, a supplemental report should be prepared and should include:

- A description of any additional investigation and testing that was performed. Field water infiltration test methods have specific reporting requirements.[25]
- A summary of the results of the field water infiltration tests and the full test report attached as an Exhibit. Any information obtained about anchors and anchor substrates should be included.
- Detailed observations with photographs of partial disassembly or removal of assemblies.
- Theoretical calculations, if any.
- A summary of the conclusions and the complete calculations attached as an Exhibit.
- A summary of the combined findings of the Level 1 and Level 2 assessments and, if possible, a prediction of future performance of the installed assemblies.

5.2.2 Impact-Resistant Systems

This section addresses impact-resistant systems, including shutters and permanently mounted screens. These systems are installed to fit over glazed openings to protect the openings during a high-wind event, such as a hurricane (**Figure 5-50**).

25 See Section 13 of ASTM E 1105-00.

Figure 5-50:
Metal shutters at this fire station (blue arrows) protected the building from wind-borne debris. (Puerto Rico, 2017) (FEMA P-2020)

For shutter assemblies, there is only one level of assessment. If the glazing is protected by shutters, the following steps are recommended:

- **Determine whether the shutter assembly was tested for resistance to wind-borne debris** via ASTM E1886 or FBC TAS 201/203 using test missile "D" or "E." Shutter labels often do not indicate testing information. In these instances, a label may indicate the manufacturer. If so, contact the manufacturer and inquire about testing, or check with the building owner to see if they have shutter data.
- **Verify that shutter assemblies can be successfully deployed**. For roll-down and accordion shutters, verify that the shutters can be fully closed. Assess whether there are any obstructions to the deployment of installed systems. Examples of obstructions could be window air conditioning units or decorative finishes (see **Figure 5-51**). For panel shutters, verify that the building owner knows where the panels and attachment hardware are stored.
- **Ensure that the impact-resistant system was properly installed**, according to manufacturer standards, and has been maintained. In particular, ensure that shutters on track systems are secured appropriately to their tracks (**Figure 5-51**).
- **Check the attachment of the shutter frame or track to the building**. Evaluate whether the type, size, and spacing of fasteners are adequate to keep the shutter assembly from blowing away during design wind conditions.
- **Check for corrosion or other deterioration** of the shutter frame or track, fasteners, and the shutter itself (**Figure 5-52**).

Figure 5-51:
Successes and problems related to installation of shutter systems over glazed doors and windows at this health center, including a shutter system properly installed (green dashed arrow), a shutter system with a track missing at a glazed door (solid red arrow), a window air conditioning unit preventing a shutter being deployed (orange dotted arrow), and a pair of glazed doors without glazing protection (yellow double arrow) (Puerto Rico, 2017) (FEMA P-2020)

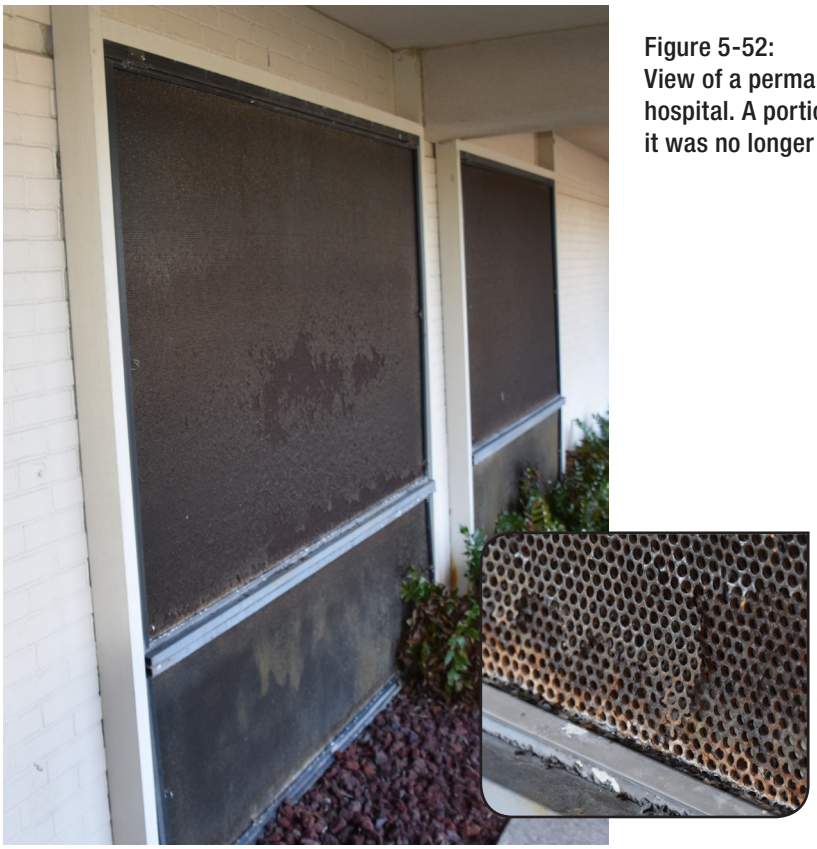


Figure 5-52:
View of a permanently mounted screen shutter at a hospital. A portion of the screen was severely corroded; it was no longer capable of protecting the glazing.

- Permanently mounted screen shutters typically are hinged to allow access for window cleaning. At the school shown in **Figure 5-53**, several shutters unlatched during a hurricane, and at least one window was broken where a shutter unlatched. As part of the assessment, open a few shutters to evaluate the potential for unlatching during a storm.

Figure 5-53:
View of a shutter in the unlatched position. The red circles indicate the latching mechanism. Hurricane Michael (Florida, 2018)

- **Ensure that the glazing assemblies protected by the impact-resistant systems have been tested** for protection against wind-driven rain, as shutters do not significantly reduce wind pressures nor wind-driven rain demand on the glazing assembly (**Figure 5-54**).

Figure 5-54:
View of a school window that failed under positive wind pressure. The left photo is a view of windows protected by permanently mounted screen shutters. The solid red arrow indicates the primary wind direction during the hurricane. The right photo is a view of a window that failed due to positive pressure exceeding the resistance of the window frame. Hurricane Michael (Florida, 2018)

5.3 Non-Load-Bearing Walls, Wall Coverings, and Soffits

This section addresses non-load-bearing walls, wall coverings, and soffits. Wall coverings can be applied to both load-bearing and non-load-bearing walls and can consist of masonry veneer, concrete masonry units (CMUs), exterior insulation and finish systems (EIFS), stucco, metal panels, precast concrete, and siding. Siding can consist of cement fiber, vinyl, and wood.

Figure 5-55 is a schematic of the wall wind zones (Zone 4 and Zone 5) used in ASCE 7. Because wind suction pressures are higher in the corner areas of walls (Zone 5), it is important to pay additional attention to these areas when performing a vulnerability assessment. See the current edition of ASCE 7 for the width of the corner zone (Zone 5).

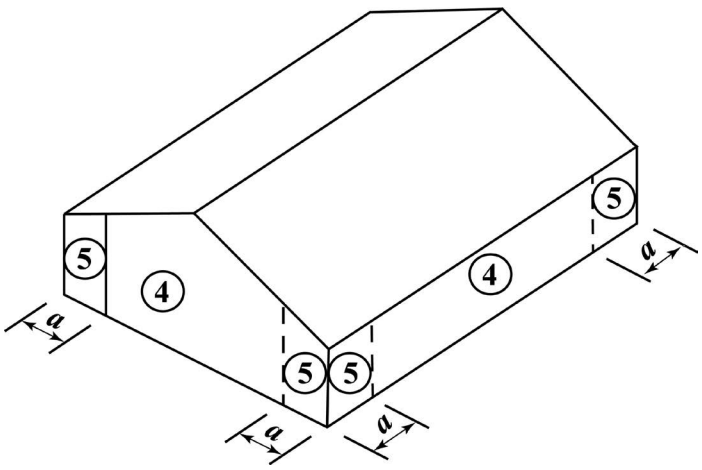


Figure 5-55:
Wind zones on walls (Zone 4 and Zone 5); a = width of the corner zone. Reproduced, based on ASCE 7-16 Figure C30.3-1, with permission from ASCE.

For guidance on evaluating wind-borne debris resistance in the types of walls that are susceptible to complete penetration of wind-borne debris into the building, see Sections 5.3.3 (EIFS and stucco), 5.3.4 (metal wall panels), and 5.3.6 (siding).

5.3.1 Masonry Veneer

The Masonry Society (TMS) 402/602-16, *Building Code Requirements and Specifications for Masonry Structures* (TMS 2016) defines masonry veneer as "[a] masonry wythe that provides the exterior finish of a wall system and transfers out-of-plane load directly to a backing, but is not considered to add strength or stiffness to the wall system." Thus, veneers are nonstructural in that they do not support in-plane (shear) loads.

Veneer may be anchored or adhered. Anchored veneer is defined as "[m]asonry veneer secured to and supported laterally by the backing through anchors and supported vertically by the foundation or other structural elements" (TMS 2016). Adhered veneer is defined as "[m]asonry veneer secured to and supported by the backing through adhesion" (TMS 2016). Adhered veneers have grown in popularity in the United States in the past decade, but anchored veneers have been widely used since the 1940s. Therefore, this document addresses only anchored veneers.

The most popular material for veneer is clay bricks, but anchored veneers also can be constructed using other types of masonry, including concrete masonry, natural stone, and cast stone. Clay brick, concrete masonry, and natural stone veneers are readily identifiable. Cast stone is a concrete product that replicates the appearance and shape of natural stone and may be confused for natural stone. In this document, anchored veneers address clay brick and CMU veneers. The other materials are not addressed, but the information provided can still be considered relevant.

Anchored veneers are anchored to a backing that supports the veneer against out-of-plane loads. The backing (i.e., the wall or surface to which the veneer is attached) provides structural support and must be moisture-protected.

The characteristics of an anchored veneer system include:

- Masonry veneer with a thickness of at least 2 ⅝ inches
- Metal anchors that are embedded in the mortar joints of the veneer and that rely on mortar bond to anchor the veneer
- Metal anchors that are mechanically fastened to the backing
- A cavity between the veneer and the backing with flashing (usually)
- Anchor spacing that is dependent on the type of anchor, wind loadings, seismic design category, and size of the cavity
- Weep holes in the veneer spaced at less than 33 inches on center

5.3.1.1 Design Assumptions

Assessing a veneer system requires an understanding of the basis for its design. The following assumptions are included in the design standard for masonry veneer (TMS 402).

- The veneer may crack in flexure under service load.
- Deflection of the backing should be limited to control the crack width in the veneer and to provide veneer stability.
- Connections of the anchor to the veneer and to the backing should be sufficient to transfer applied loads.
- Differential movement should be considered in the design, detailing, and construction.
- Water can penetrate the veneer, and the wall system should be designed, detailed, and constructed to prevent water penetration into the building or ponding in the cavity.
- Requirements for corrosion protection and fire resistance must be included.

It is acceptable for the veneer to crack some under loading. However, the veneer is not intended to disengage from the backing under wind loading. Thus, masonry veneer cracks should be evaluated to determine whether they are important, though they may not represent a life-safety or performance issue.

5.3.1.2 Common Wall Types

Anchored veneer is most commonly applied to backing constructed of masonry (**Figure 5-56**), wood framing (**Figure 5-57**), cold-formed metal framing (**Figure 5-58**), or concrete (**Figure 5-59**). These figures also show typical wall sections and anchor variations. More information on veneer anchored to varying backings is available in publications such as the National Concrete Masonry Association (NCMA) TEK Notes (https://ncma.org) and The Brick Industry Association Technical Notes (www.gobrick.org).

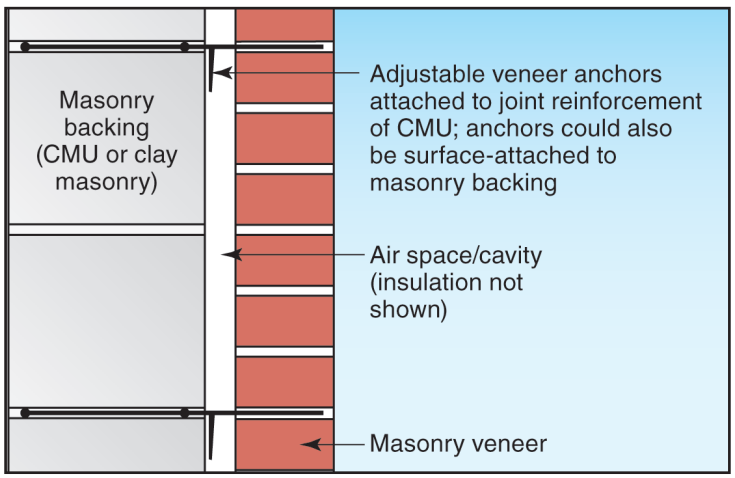


Figure 5-56:
Masonry backing (CMU or clay masonry)

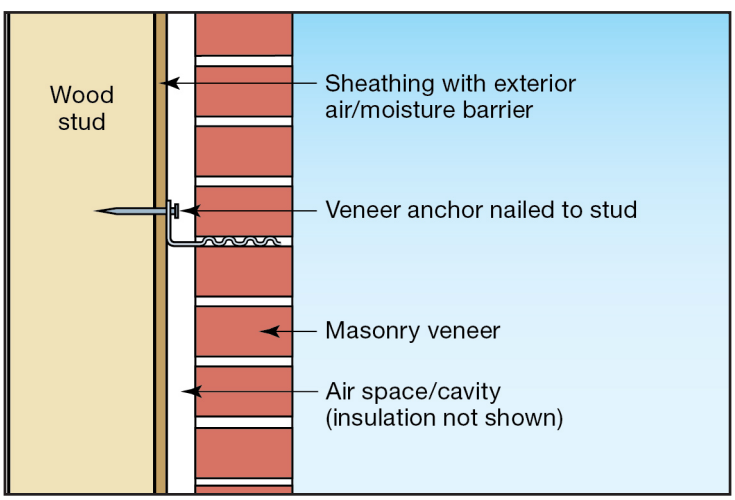


Figure 5-57:
Wood framing backing

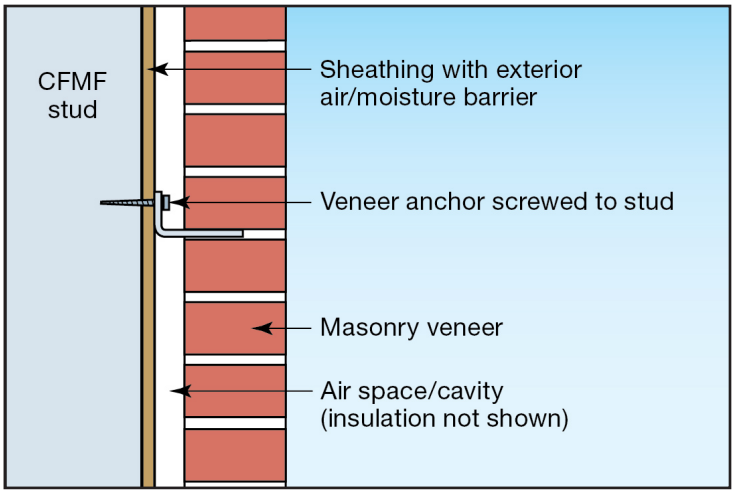


Figure 5-58:
Cold-formed metal framing backing

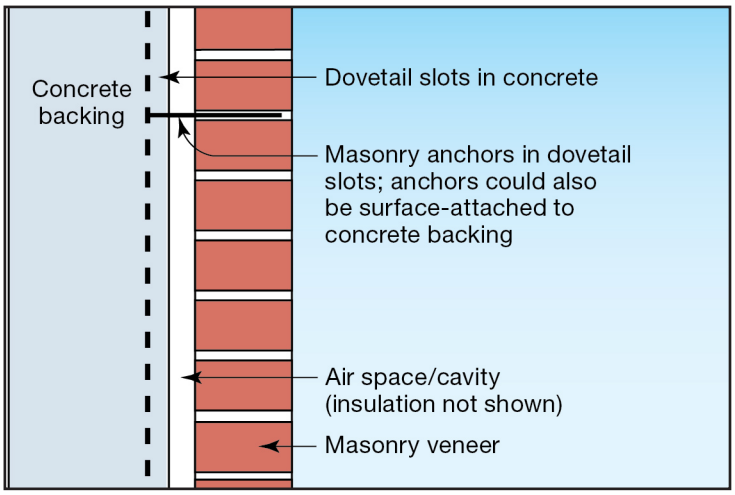


Figure 5-59:
Concrete backing

Anchors can take many forms, including sheet metal (corrugated or smooth), wire, and joint reinforcement. Anchors can be fixed or adjustable. If the veneer is attached directly to a steel element or the anchorage is wire and embedded in the masonry structure, the attachment often is called a veneer tie. In this publication, all attachments of the veneer to the backing are referred to as anchors.

By code, anchors should be less than one-half the thickness of the mortar joint so that they are fully embedded in the mortar.

5.3.1.3 Identifying Masonry Veneers

The first step in assessing a veneer system is to confirm that it is a veneer because not all masonry walls have veneers. Masonry walls have been constructed for millennia, but modern veneers were introduced to the United States in the 1940s for use with wood, concrete, and masonry construction. Masonry veneer with cold-formed metal framing was introduced in the 1960s.

The characteristics that can assist with identifying a veneer are as follows:

- **Age**. Masonry construction prior to 1950 is likely to be solid masonry and less likely to be veneer construction. For solid masonry walls, see Section 4.4.
- **Bonding pattern**. Masonry bond patterns with header bricks are unlikely to be veneer construction. These header units (units that are transverse to the wall) typically are used to bond the exterior masonry to the backing wall in solid masonry walls. However, **Figure 5-60** shows a portion of a veneer with header bricks and weep holes, indicating a brick veneer. A wall with headers and without weep holes is likely to be a solid wall and unlikely to have a veneer.
- **Weep holes and ventilation**. Weep holes (**Figure 5-61**) generally indicate that the wall has a cavity and that the masonry facade is veneer. This figure shows the veneer in a running bond pattern, which is typical of most veneers. **Figure 5-62** shows a veneer in running bond at the corner where removals have been made. A closer view would indicate that there also are weep holes.
- **Exposed flashing** over windows, doors, and shelf angles may indicate a veneer wall (**Figure 5-63**).

Figure 5-60:
Weep holes, indicating a masonry veneer, even though there appear to be headers

Figure 5-61:
Weep holes, indicating a veneer with a cavity

Figure 5-62:
Corner units, indicating brick size; weep holes, indicating veneer

Figure 5-63:
Metal flashing over shelf angle

5.3.1.4 Veneer Failure and Vulnerabilities

Veneer failure from high-wind events takes several forms. The most obvious form is full detachment and collapse (see **Figure 5-64**) and major cracking that renders the veneer unsafe to the point that it may collapse after the wind event. In some wind events, detached veneer can become wind-borne debris and can affect other structures. An additional failure is the significant water entry into the building through breaches in the moisture protection system provided by the cavity and flashings.

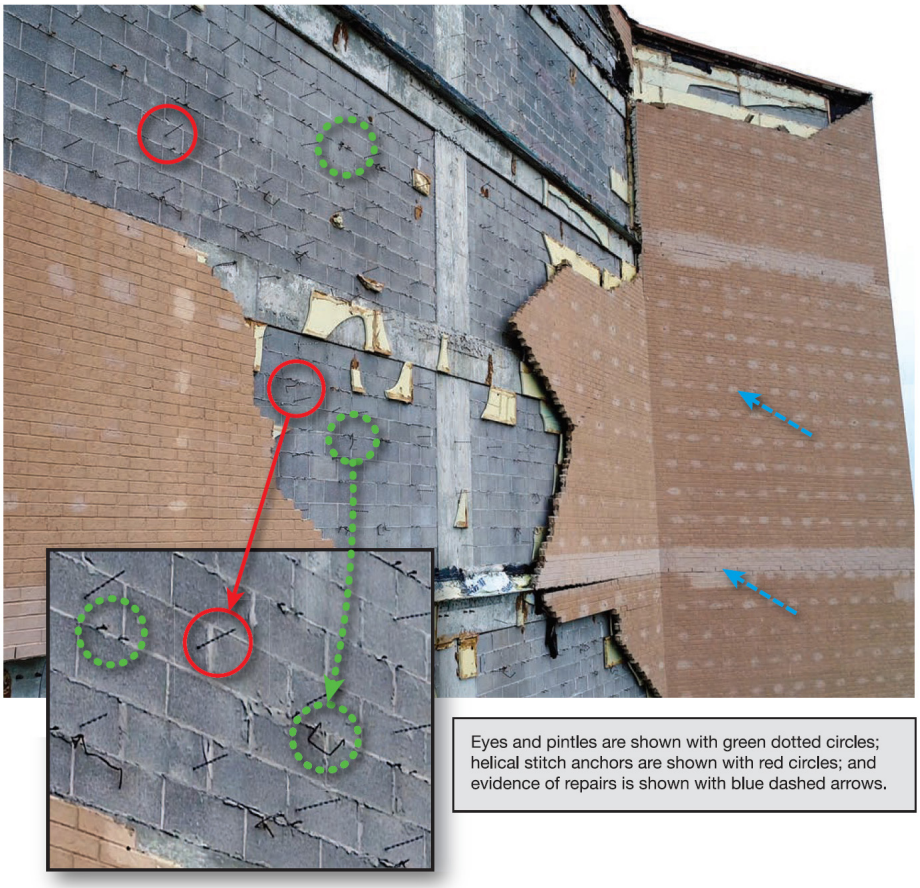


Figure 5-64: Brick veneer failure. Hurricane Harvey (Texas, 2017) (FEMA P-2022)

Masonry veneer could be vulnerable to failure primarily from high winds if:

- The number or spacing of anchors is insufficient to resist the loads.
- The anchors are not adequately attached to the backing.
- The anchors are deteriorated primarily from corrosion because of inadequate corrosion protection (lack of galvanizing or stainless steel), corrosion from chlorides in the mortar, or corrosion from exposure to salt water or rain with greater concentration of chlorides. Chlorides can occur from the sand aggregates or from additives in the mortar.
- The mortar is deteriorated and the bond to the veneer anchor is unable to support the loads.
- The mortar is cracked and the bond to the veneer anchor is compromised.
- The anchors are inadequately embedded in the mortar joints to provide sufficient bond.
- Water penetration overwhelms the moisture protection system.

These vulnerabilities should be examined to properly assess the masonry veneer. Implicit in any assessment is that the structural backing is adequate to support the loads placed on it by the veneer anchors (see Section 4.4 for the vulnerability assessment of the backing).

5.3.1.5 Level 1 Assessment of Masonry Veneer

A Level 1 assessment of brick and masonry veneer consists primarily of reviewing any design or construction documentation followed by a visual assessment. If necessary, limited nondestructive testing can be performed, as described later in this section.

If the documentation is available, the assessor should identify:

- **Type of veneer—**CMU or clay; hollow or solid
- **Specified mortar—**Type and any additives
- **Veneer anchorage system** and backup structure
- **Veneer reinforcement**, if any

In the visual assessment, it is important to identify specific problems. The problems listed below are in order of priority. The first two problems are typically the most critical because they indicate that movement of the veneer and/or support has taken place and possibly weakened the veneer and its anchorage. Mortar deterioration (#4) is a major concern in that most anchors are bonded to the veneer by the mortar. Deterioration weakens the bond and makes the veneer vulnerable to high winds.

1. **Bowing of the veneer and/or structural backing.** Construction tolerances generally allow +/- ¼ inch variation over 10 feet, in either the plumbness of a wall or from a straight line. Any bowing beyond this tolerance may indicate a problem with the anchorage system.
2. **Openings.** Gaps around windows and doors are a good indicator of bowing (**Figure 5-65**).

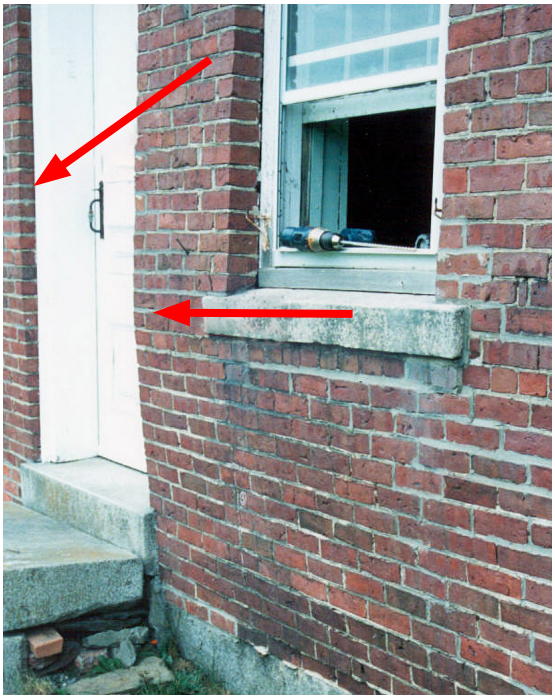


Figure 5-65:
Bowed veneer, usually noticeable at openings

3. **Deterioration or displacement of veneer support.** Any support deterioration must be evaluated to determine whether structural capacity has been compromised. Any displacement can be significant because it may indicate loss of support or an overstress of the anchoring system (**Figure 5-66**).

Figure 5-66:
Deteriorated steel support and cracked veneer at bearing

4. **Mortar deterioration or cracks in the mortars.** Assessing mortar deterioration and cracks is very difficult and usually subjective (Biggs 2000). Cracking usually leads an investigator to search for further symptoms of weaknesses that could render the veneer vulnerable to high wind failures.

   Cracks as small as 0.1 millimeter in the mortar joints or masonry units can allow water to enter. Larger cracks may indicate structural movement. Both the size

and location of the cracks are important. Cracks emanating from the corners of openings, continuous horizontal cracks (**Figure 5-67**), and diagonal cracks between openings are all examples of significant cracks that should be checked in a Level 2 assessment.

Figure 5-67:
Deteriorated mortar joints

5. **Deterioration of or cracks in masonry units.** Deterioration and cracks must be examined to determine whether: (1) the deterioration extends deeply enough into the units to affect the bond to the anchors, (2) the deteriorated unit material could become wind-borne debris in a wind event, and (3) portions of the cracked units have become dislodged from the anchors. **Figure 5-68** shows cracking in a mortar head joint of a CMU veneer that extends into the unit above. There is no cracking evident in the mortar bed joint that could affect the anchors, and there is no loose mortar or loose pieces of CMU.

Figure 5-68:
Cracks through CMU veneer and mortar

6. **Air and water leaks through the veneer and backup.** Although air and water leaks may or may not have immediate structural significance, they affect the long-term performance of the wall system. Air leakage indicates that water entry is possible in a major wind and rain event. Water entry not only causes interior damage, it also deteriorates the wall system and anchors over time.

   Masonry veneers are not intended to be watertight. Consequently, they are built with a drainage system that allows water that penetrates the veneer to be collected and diverted out of the cavity through a system of weep holes. Water is diverted by masonry flashings, which are metal fabrications or membranes that channel any water that enters the cavity to the weep holes.

   Figure 5-69 shows a sample wall with brick veneer and joint reinforcement for anchors. The flashing is a membrane. It extends upward approximately 8 inches and is embedded in the CMU backing. Numerous industry design standards are available on proper flashing installation (IMI 2009).

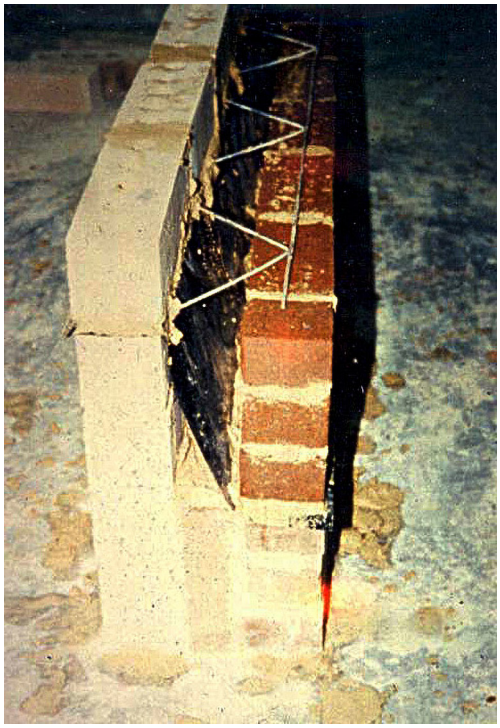


Figure 5-69:
Brick veneer with membrane flashing (NCMA)

The possible sources of water penetration into the interior of a building from masonry veneer are:

- **Improper flashing design or installation**. Improper design or installation can result in splits or tears in the flashings, inadequate flashing laps along the length of the flashing, and inadequate embedment of the flashing into the backing or sealing of the flashing to the backing. Flashing that does not extend up the backing approximately 8 inches can be prone to overflowing if the weep holes are

blocked or if the amount of water driving into the cavity exceeds the capacity of the weep holes to drain it.

- **Blocked or missing weep holes**. Excess mortar droppings into the cavity and insect debris can block the weep holes. Some older veneers may have a partial fill of stone in the cavity to aid drainage. These were eliminated in designs due to unintended failures of aiding mortar droppings to block weeps.

  More modern veneers may be constructed with a synthetic material in the cavity to prevent mortar blockage. Some weep holes have internal screens. Blocked weep holes have historically been less of a problem than problems with the flashing.

  By code (TMS 402), weep holes must be at least 3⁄16 of an inch in diameter and spaced no farther apart than 33 inches. Often, the bond break created between the flashing and the veneer allows water seepage from the cavity.

The weep hole spacing and height of the cavity flashing should be assessed to ensure that they are sufficient. The wall height should be considered when determining the amount of wind-driven water that may enter the cavity. For example, at the hospital shown in **Figure 5-70**, the weep holes/cavity flashing at the taller wall could experience higher water demand than the weep holes/cavity flashing at the shorter wall, depending on the direction of the wind-driven rain, the area of the wall, and the relative condition of the flashings at each location.

Figure 5-70:
At this hospital, water leaked inside along the base of the brick veneer walls (solid red arrow). Hurricane Katrina (Louisiana, 2005) (FEMA 577)

Although flashings and weep holes are most commonly associated with the base of walls, they also are required above door and window openings and at the junction of roofs and walls, as illustrated in **Figure 5-72**. The concerns for the base of walls discussed above also apply to openings. The roof-to-wall juncture introduces the following concerns that should be assessed:

- Sometimes during reroofing work, new base flashing is installed over the weep holes. This can result in blocked wall drainage or allow water within the cavity to migrate under the roof membrane. Weep holes should be checked to determine whether they are above the roof counterflashing.
- If construction of a building addition results in a low roof, the through-wall flashing and weep holes should be checked to determine whether they were installed as part of the addition. If the new base flashing was placed over the veneer and covered with a surface-mounted reglet, water within the cavity can leak into the building addition.
- The masonry sealant should be checked for lack of bonding to masonry or for split or missing sealant at veneer joints (**Figure 5-71**). Split sealants allow water entry. In addition, water that enters is trapped by the remaining working sealant. Sealants should be checked to determine whether they are split or debonded completely through the joints. Knowing the age and maintenance history of the building may provide data regarding the age and type of sealant used. Sealants more than 8 to 10 years old are likely to need maintenance.

Figure 5-71:
Split and deteriorated sealant

Veneer in some areas of the building is more vulnerable to wind effects than veneer in other areas. The areas shown in red in **Figure 5-72** and **Figure 5-73** are the more vulnerable locations and should be examined during the visual assessment.

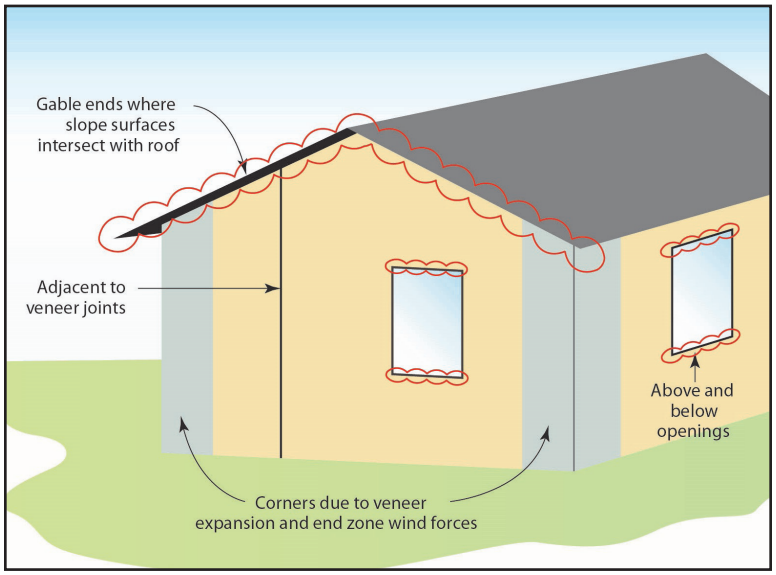


Figure 5-72:
Vulnerable wind locations for veneer on gable ends

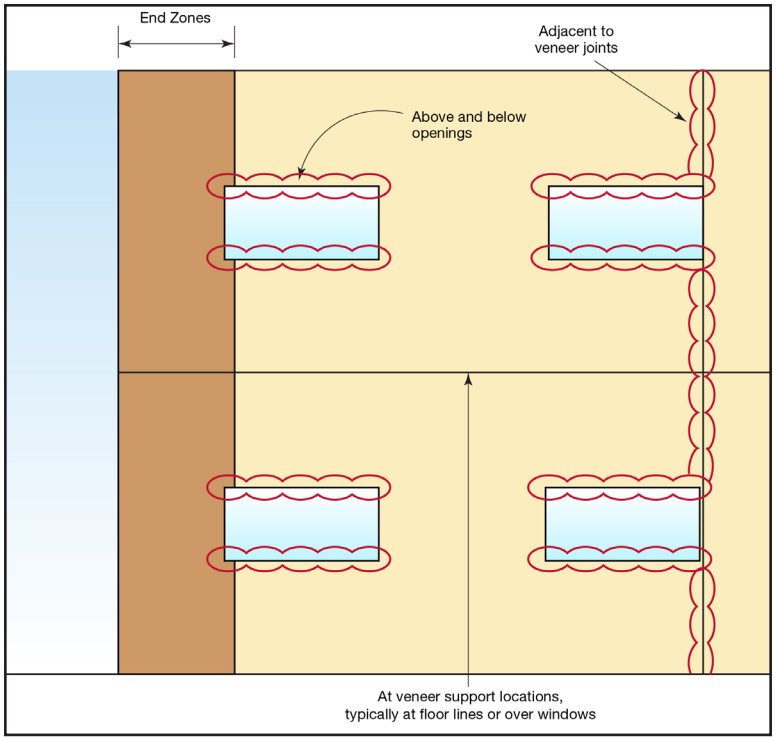


Figure 5-73:
Vulnerable wind locations for veneer on multi-story elevations

Nondestructive evaluation (NDE) is useful as part of the visual assessment to identify the location of veneer and joint reinforcement and to evaluate the mortar hardness. The following techniques can be used:

- **Magnetic reluctance testing**. Magnetic reluctance testing involves using a handheld metal locator to find veneer anchors. Since some stainless steels are non-magnetic, a locator that detects stainless steel as well as standard metal anchors is recommended. This testing can identify the location of veneer and joint reinforcement, but it does not determine whether the anchors are intact or the reinforcement was installed properly.

  This technique should be used for buildings in hurricane- and tornado-prone regions and for portions of buildings over entries when visual observations indicate there may be a problem.

- **Mortar hardness testing**. A scratch test can be used to evaluate mortar hardness based on the Mohs Scale, and this in turn can help in determining the mortar type. Even using a screwdriver to determine whether the mortar is easily scratched is valuable in assessing the type and condition of the mortar and ultimately the bond.

  According to Biggs and Forsberg (2001):

  > If you can determine an approximate value of hardness based on the Mohs Scale, that number can be associated with an approximation of the compressive strength, or type, of the mortar. Based on personal experience, Mohs numbers up to 3 correspond to Type O mortar; between 3 and 5 correspond to Type N mortar; and above 5 correspond to Type S and M mortars. This is not an exact correlation and is for general guidance only.
>
> Without the Mohs Scale, simply scratching the mortar with a screwdriver or chipping away some mortar with a chisel can reveal some approximation of mortar strength. Mortar that is easily scratched from the joint is likely a Type O, while mortar that can be scratched, but not removed, is likely Type N. Be sure to not scratch known deteriorated mortar.

  The mortar should be tested for hardness when visual assessment indicates there may be a problem, avoiding any sections where mortar has deteriorated.

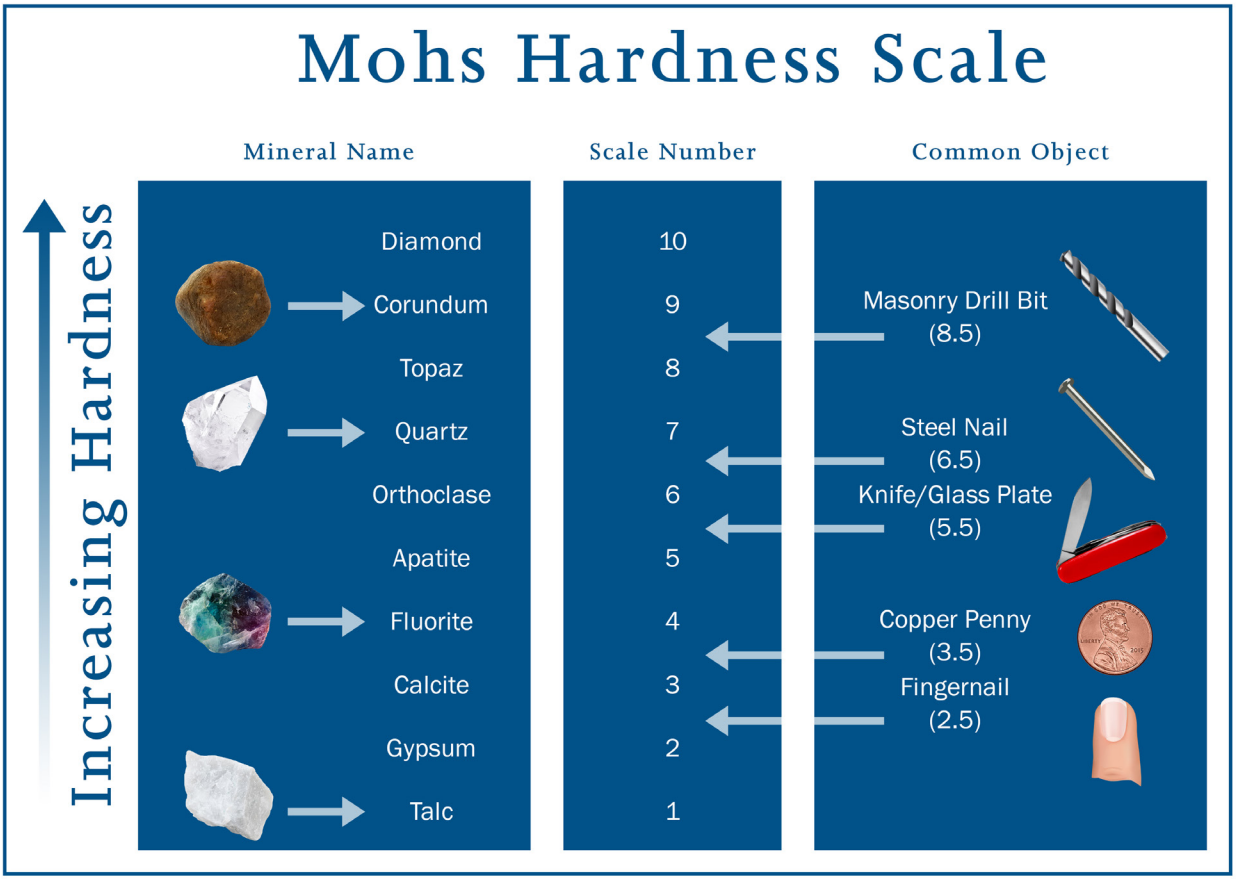


Figure 5-74: Mohs Hardness Scale (Graphic adapted from National Park Service)

5.3.1.6 Level 2 Assessment of Masonry Veneer

A Level 2 assessment should be performed if the Level 1 assessment: (1) identifies significant problems or (2) reveals that the veneer has several more years of useful service life and the building is located in an area where the basic wind speed is greater than 120 mph.[26]

Level 2 assessments should include:

- Partial removals of the veneer
- Moderate destructive evaluation (MDE)
- Additional NDE

Partial Removals

Partial removals are invasive but allow for the physical examination of the masonry units, mortar, flashings, and veneer anchorage. Samples also can be retrieved for laboratory testing and evaluation and will be discussed in Section 5.3.1.7.

26 The 120-mph basic wind speed is based on ASCE 7-16, Risk Category III and IV buildings.

One removal on each major wall should be used as a starting point. The results of the removals can be used to determine whether: (1) additional removals are needed, or (2) the NDE and MDE methods discussed later will be adequate to supplement the removals.

During partial removals, it is essential to examine the anchors. The anchors must be properly embedded in the mortar, and the mortar must be well-bonded to the anchor and veneer unit.

Figure 5-75 shows an adjustable anchor attached to a CMU backing using a double pintle anchor. The photograph of this improper construction was taken at a stoppage in the original construction work that resulted in a toothed (zipper) joint, which is not recommended practice. The stoppage created a vulnerable joint in the wall that may develop cracking over time. When the original work is resumed, the adjacent bricks will be pushed into the gap that was created, and the mortar will not be properly compressed. In this partial removal inspection example, note that: (1) the anchor is embedded at least 1½ inches, as required by code, (2) there is no visible corrosion, (3) the anchor is properly engaged in the pintle, and (4) the anchor is sitting on the veneer unit and not fully embedded in the mortar joint.

Figure 5-75:
Adjustable masonry veneer anchor

Although **Figure 5-75** shows an adjustable anchor that has been fairly common since the 1970s, earlier buildings, and many buildings today, use corrugated metal anchors that are attached to the backing by screws or nails (**Figure 5-76**).

Figure 5-76:
Corrugated tie screwed to backing (Photo courtesy of Heckmann Building Products, Inc.)

Some corrugated anchors of older buildings were constructed of mill-galvanized, 26-gauge metal. Mill-galvanized and 26-gauge anchors are highly vulnerable to deterioration and failure and are not approved for masonry veneers. Mill galvanizing does not provide long-term corrosion protection. By code, modern anchors are required to be 22 gauge or heavier and are either hot-dipped galvanized or stainless steel.

Figure 5-77 shows brick veneer failure at a fire station that is the result of anchor corrosion. In the **Figure 5-77** inset, the metal is missing for half of the width of the anchor at two locations (red arrows). The left end of the anchor was still embedded into a CMU backup wall. The right end is where the anchor failed in tension, thus leaving a portion of the anchor embedded in the collapsed brick. Partial removal is required to identify this type of vulnerability.

Figure 5-77: Brick veneer failure due to anchor corrosion. Hurricane Ike (Texas, 2008) (Top photo, FEMA P-499, Fact Sheet 5.4)

Moderate Destructive Evaluation

MDE is partially invasive but can provide significant data. MDE techniques are endoscopy using a borescope, bond wrench test, drill test, and flatjack tests.

- **Endoscopy using a borescope** requires partial removal or a bore hole in order to insert a borescope (**Figure 5-78**) and view the cavity behind the veneer. Endoscopy is useful in verifying the localized condition of the anchors.

  If the partial removals indicate the anchors are in good condition, endoscopy is not required. If anchor problems are observed during the partial removals, it would be appropriate to assess approximately 2 percent to 5 percent of all anchors using bore holes and endoscopy. Selective removals may be required to validate the endoscopic results.

  Examining the flashings themselves is recommended if any interior leaks near through-wall flashings are detected. If flashings are not exposed during the partial removals, endoscopy is the preferred method of checking the condition of flashings. Checking the height of the flashing for tears, splits, or openings also is recommended. Preferably, the flashing extends at least 8 inches above the veneer course, and the cavity is not blocked.

Figure 5-78:
Borescope used to check the cavity of CMU veneer

- **A drill test** determines mortar strength based on drill resistance (**Figure 5-79**). Effectively, the test measures hardness and correlates to strength. It is available in Europe but, as of 2019, has not been standardized in the United States. The Windsor pin system, available commercially in the United States, is used under ASTM C803, *Standard Test Method for Penetration Resistance of Hardened Concrete* (ASTM 2018a) for hardened concrete, and is adapted for use with masonry (**Figure 5-80**). The system drives a pin into the mortar, and the pin depth then is measured and correlated to the compressive strength of the mortar.

Figure 5-79:
Drill test in mortar

- **Flatjack tests** use thin, bladder-like flatjack devices to measure the average compressive stress in a masonry veneer (**Figure 5-81**). See ASTM C1196, *Standard Test Method for In Situ Compressive Stress Within Solid Unit Masonry Estimated Using Flatjack Measurements* (2014a) and ASTM C1197, *Standard Test Method for In Situ Measurement of Masonry Deformability Properties Using the Flatjack Method* (ASTM 2014b). Although masonry veneers usually are not designed for stress, measuring the vertical stresses can be a useful diagnostic tool to determine whether stress-relieving is necessary as a repair technique. The figure shows a thin metal bladder inserted into a mortar joint, with a hose attached that connects to a hand pump and pressure gauge. Metal points are inserted into the wall above and below the joint. Initial measurements taken across the joint prior to cutting the joint, inserting the bladder, and pressurizing the joint back to its initial readings provide a means to indicate the stress in the veneer.

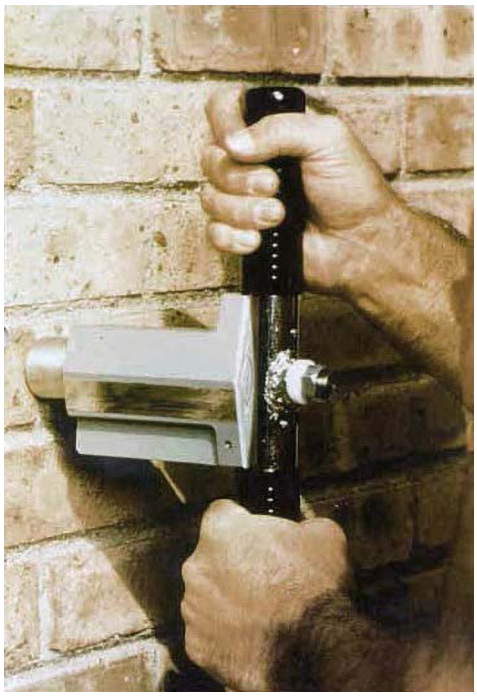


Figure 5-80:
Windsor pin system (Photo courtesy of Qualitest International, Inc.)

Figure 5-81:
Flatjack in a mortar joint

To minimize the number of removals required, NDE and MDE can be calibrated to the results derived from any removals. For example, performing a partial removal will allow the extraction of mortar samples. The samples can be laboratory tested and the results correlated to a drill or scratch test, which can then be used in lieu of performing further removals.

5.3.1.7 Laboratory Testing

Sometimes field evaluation is not sufficient for an adequate assessment. The partial removals provide an opportunity to extract samples for laboratory testing. These tests are beyond the scope of any normal assessment and require the advice of experts.

- **A bond wrench test** requires a partial removal. See ASTM C1072, *Standard Test Method for the Measurement of Masonry Flexural Bond Strength* (ASTM 2013c). Currently, researchers test bond in the laboratory from field-extracted samples (**Figure 5-82**). An in-situ test device is still under development. These tests are used to assess the relative mortar bond to the masonry units. One representative sample per building can be selected based on the results of mortar hardness testing and drill tests. Bond values of less than 80 psi can indicate an inherent weakness that may require additional testing and evaluation.

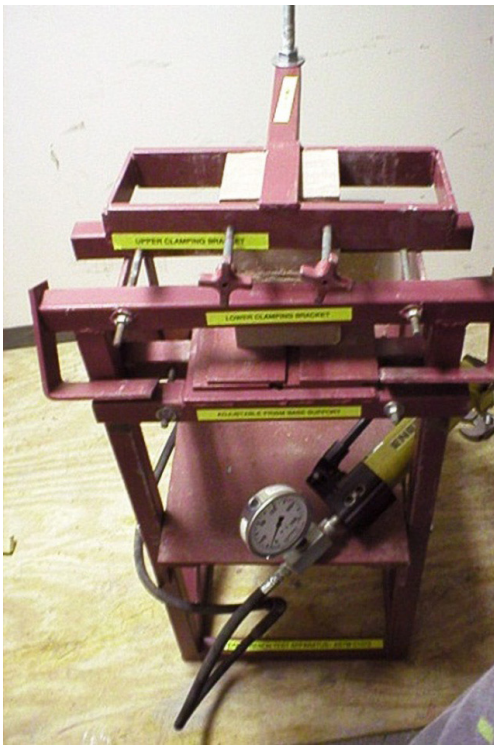


Figure 5-82:
Bond wrench test equipment

- **Mortar testing** in accordance with ASTM standards can be performed if the quality of the mortar is a concern. Chemical analyses can be performed to determine whether the mortar has mixtures that affect the bond strength or the durability of the mortar.
- **Masonry unit testing** in accordance with ASTM standards can be performed when the quality of the masonry units is in question. This usually is done only when there are signs of excessive spalling of the units from environmental effects, particularly freezing-thawing.

5.3.2 Concrete Masonry Units

CMUs are used often in exterior non-load-bearing walls (**Figure 5-83**). These walls protect the interior but are subject to both positive and negative wind pressures, in-plane stresses due to sway in the MWFRS, and wind-borne debris. These walls can be damaged severely if not reinforced sufficiently to resist wind pressures and wind-borne debris. This type of wall often is used as an infill wall between concrete floors and columns, an exterior wall in steel-frame buildings, and an exterior wall for precast roof and/or floor systems (**Figure 5-83**). CMU walls may be perceived as having high wind resistance; however, when unreinforced or inadequately reinforced, this type of wall can topple, presenting a significant risk for building damage and life-safety issues.

Figure 5-83:
Collapsed unreinforced CMU wall at a school. Hurricane Marilyn (U.S. Virgin Islands, 1995) (FEMA P-424)

CMU walls that enclose the building frame but do not support it are considered components and cladding, as defined in ASCE 7. As such, the design wind pressures reflect the exterior pressure coefficients used for the building elements, including the higher coefficients used for wall corners. Based on codes (IBC [ICC 2018a]) and standards (ACI 524R-16, *Guide to Portland Cement-Based Plaster* [ACI 2016]) in force when this manual was published (2019), the wind pressures for wall components in hurricane- and tornado-prone regions require some level of reinforcement in CMU walls. CMU walls not used for load bearing or lateral resistance and built before approximately 1990 are not commonly reinforced; therefore, they are vulnerable to damage from high winds.

Unreinforced, ungrouted, or unfilled CMU is very susceptible to damage from wind-borne debris. The debris generated during hurricane and tornado events can have enough momentum to fully penetrate the wall material and put anyone inside the building at risk of injury. Grout alone can provide resistance to wind-borne debris of limited momentum. While grouting typically is done in conjunction with reinforcement, some grouting is done for fire resistance where steel is not installed.

5.3.2.1 Level 1 Assessment

The following items can be checked to determine the likely performance of CMU walls without using destructive testing.

- **Compare the contract documents and requirements** for CMU walls with the current design information related to wind pressures and building code requirements for reinforcing steel and grout in block cells. Insufficient reinforcing steel in buildings in high-wind areas suggests vulnerability to damage from high wind pressures.
- **Use a metal detector to help locate reinforcing steel placement**, if the existence or amount of reinforcing steel is uncertain. It will still be difficult to determine the size of the steel using this technique. Selective probes should be used to validate the reinforcement. Some detectors will only identify the presence of metal, while more sophisticated scanners can determine bar size if the depth of cover is known.

- **Adapt ground-penetrating radar equipment for use in walls.** This technique (termed surface-penetrating radar) will provide the cover and approximate bar size. Again, selective probes should be used to validate bar sizes.
- **Verify that cells with reinforcing steel were grouted**. For small areas, this can be accomplished by tapping the face of the CMU to detect un-grouted cells. For large areas of walls, surface-penetrating radar is the preferred method for locating grouted cells.
- **Closely inspect the top of the CMU wall** to determine if anchor bolts are used to connect the roof or floor system at the top of the wall to the CMU wall. The size and spacing of these bolts should be visible upon inspection. The depth of embedment must be determined by using selective probes or metal detection.

5.3.2.2 Level 2 Assessment

The following items can be checked to determine the likely performance of CMU walls, but will require some destructive testing.

- If required resistance to wind pressures is large enough to require assurances that the CMU can resist the pressures, it likely will be necessary to determine the size of the reinforcing steel. At a location that contains steel, break open the CMU cell to determine the size of the steel and if the cell has been filled with concrete.
- From the same horizontal location on the wall, cut the masonry wall down to the bottom of the wall to determine if the reinforcing steel is continuous in the cell and if it is connected in some way to the foundation. This also will allow for an inspection of the extent of concrete filling in the vertical cells where steel is located.
- After the spacing of the vertical steel reinforcing has been determined, break open the cell of the masonry near the bottom of the wall in a random pattern to determine if the grout has been filled completely to the bottom of the wall. Anchorage attachments to the supporting structure and foundation should also be evaluated.

At some reinforcing steel location, expose the top of the wall where an anchor bolt is installed to determine if the anchor bolt is connected to the vertical reinforcing steel to form a continuous load path.

5.3.3 Exterior Insulation and Finish Systems and Portland Cement Plaster (Stucco)

Other types of veneer cladding systems include EIFS, sometimes referred to as synthetic stucco, and Portland Cement Plaster, commonly referred to as stucco. These systems appear similar when viewed from the exterior, but EIFS and stucco have significantly different physical properties and characteristics that should be considered in a wind vulnerability

assessment. The descriptions of EIFS in Section 5.3.3.1 and stucco in Section 5.3.3.2 can be used to differentiate between EIFS and stucco.

5.3.3.1 Exterior Insulation and Finish Systems

EIFS consists of an exterior skin or lamina composed of acrylic-modified cementitious materials, reinforced by a fiberglass mesh, and applied over an insulated substrate. The lamina varies in thickness and composition, depending on the type of EIFS material. The EIFS Industry Members Association (EIMA) (https://www.eima.com/) has identified three basic types of EIFS cladding: polymer-based (PB), polymer-modified (PM), and water management (drainage type).

Polymer-based EIFS. PB EIFS generally consists of a ⅛- to 3⁄16-inch-thick lamina composed of a mesh-reinforced base coat and a colored, textured finish coat. The base coat typically is a mixture of Portland cement and proprietary acrylic polymers, usually in a proportion of one-to-one or two-to-one. The base coat encapsulates the mesh with a thin layer of base coat material on each side and generally is considered to be the waterproofing portion of the assembly. The textured finish coat generally is considered to be the aesthetic and exposed component of the assembly. The lamina is always bonded or adhered to a rigid board foam insulation that typically is adhered to the underlying substrate using the same base coat material. **Figure 5-84** shows a typical PB EIFS.

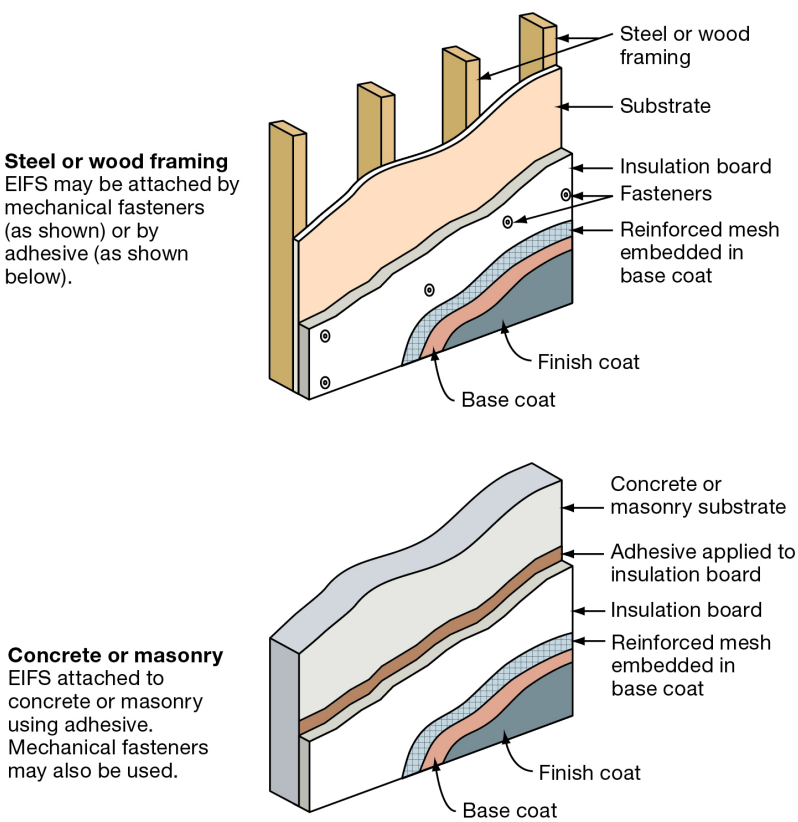


Figure 5-84: Typical polymer-based EIFS (FEMA 489)

For PB EIFS applications, molded expanded polystyrene (MEPS) foam insulation is the most common type of insulation material. Adhesion of the foam to the substrate usually is achieved by one of two methods of applying the base coat adhesive: ribbon-and-dab or notched trowel. The ribbon-and-dab method uses a continuous line of base coat adhesive around the perimeter of the insulation board, with 4- to 6-inch-diameter dabs of base coat adhesive in the middle of the board, spaced 6 to 8 inches apart. The notched trowel method, as the name suggests, uses a notched trowel to uniformly apply the base coat adhesive to the back of the foam board, typically in a vertical orientation.

The substrate, which, according to ASTM C1397, *Standard Practice for Application of Class PB Exterior Insulation and Finish Systems (EIFS) and EIFS with Drainage* (ASTM 2013d), technically is not included as part of the EIFS assembly, is nevertheless an important component of the overall wall cladding assembly. The EIFS lamina and foam may be adhered to masonry (such as brick or CMU), cast-in-place or precast concrete, and over sheathing boards supported by wood studs or cold-formed metal framing (metal studs). PB EIFS typically is applied without the use of plastering accessories, which require wall panel terminations and perimeters to be fully encapsulated within the reinforced lamina so that no foam is exposed to view or to weathering elements.

Polymer-modified EIFS. PM EIFS generally consists of a ¼- to ⅜-inch-thick lamina, composed of a fiber or metal mesh reinforced base coat and a colored, textured finish coat. The base coat typically is a mixture of Portland cement and proprietary acrylic polymers, usually in proportions of two-to-one or more. PM EIFS also encapsulates the mesh with a thin layer of base coat material on each side and generally is considered to be the waterproofing portion of the assembly. Likewise, the textured finish coat generally is considered to be the aesthetic and exposed component of the assembly. **Figure 5-85** shows a typical PM EIFS.

The lamina is always bonded or adhered to rigid board foam insulation that typically is fastened mechanically to the underlying substrate using screw fasteners with enlarged plastic disks at the head. For PM EIFS applications, extruded expanded polystyrene (XEPS) foam insulation is the most common type of insulation material. Insulation is often light blue, yellow, or pale green.

PM EIFS may be applied to the same substrates as PB EIFS, and it typically is applied using a variety of plastering accessories, which can be metal (galvanized steel and zinc) or plastic (polyvinyl chloride).

Water management EIFS. A number of proprietary water management EIFS claddings are in use that incorporate various components of both the PB EIFS and PM EIFS cladding assemblies, depending on the system and manufacturer.

The four common elements of water management EIFS claddings are: (1) a weather-resistive barrier at the substrate, (2) a drainage plane composed of proprietary drainage composite

boards or drainage channels, (3) adhered or mechanically fastened rigid foam board insulation, and (4) EIFS lamina.

- The weather-resistive barrier may be fluid-applied, trowel-applied, or a sheet membrane. The sheet membrane has common #30 building felts and proprietary synthetic building-wrap materials.
- The drainage plane may consist of expanded metal lath or proprietary drainage composite boards composed of various types of synthetic materials or that use a series of grooves and channels on the back of the foam board insulation.

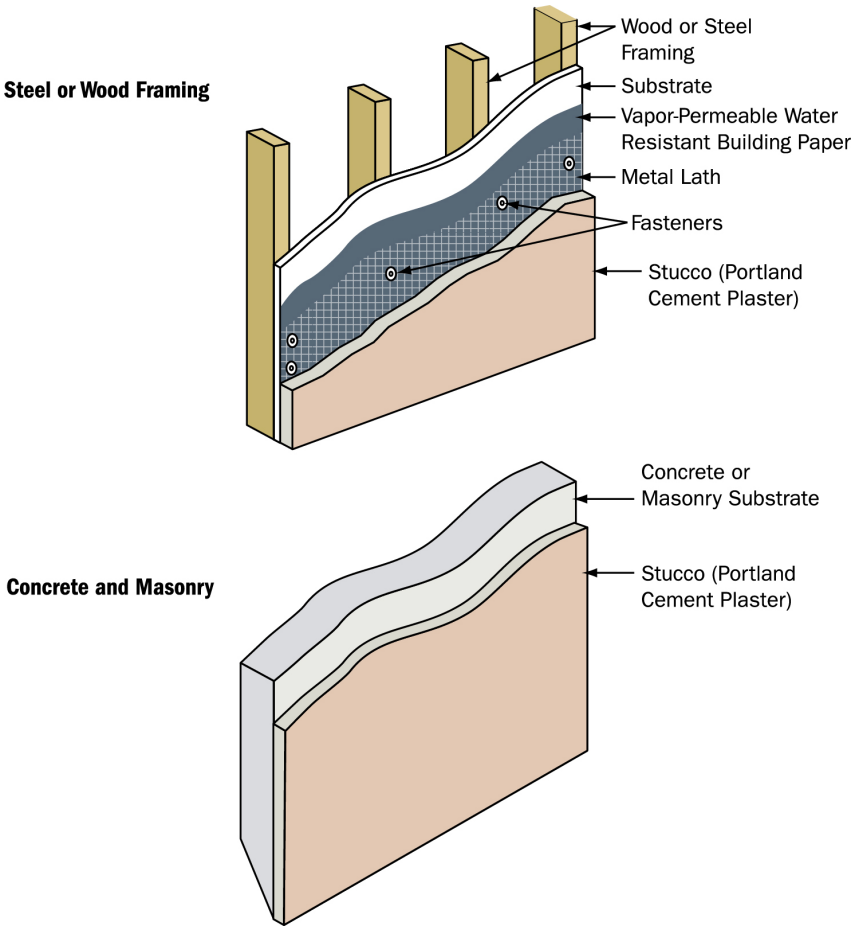


Figure 5-85: Typical PM EIFS and direct-applied traditional plaster systems (FEMA 489)

- Adhered systems generally are composed of channeled foam boards adhered with an adhesive that is compatible with the weather-resistive barrier. Mechanically fastened systems may use insulation boards with or without channels; flat stock insulation is the most common.

The critical components of a water management EIFS are:

- Appropriately designed and installed flashings
- Appropriately designed and installed weep holes at wall openings and at the base of the wall
- An effective drainage plane with proper flashings that are integrated with the weather-resistive barrier and capable of collecting any water intrusion

A plethora of hybrid systems use various materials and components from the three systems described above (PB, PM, and water management EIFS). In addition, various sheathing boards and insulation types have been used in the past, including rigid board glass fiber and mineral fiber insulations. Sheathing substrates used over the years have included ASTM C79 (ASTM 2004) gypsum sheathing, which has a cream-colored core with black or brown paper facers and—as of approximately 2001—is no longer recommended for EIFS. Other sheathing materials include exterior grade plywood and oriented strand board (OSB) sheathing. The most common exterior sheathing today is the glass mat gypsum sheathing conforming to ASTM C1177, *Standard Specification for Glass Mat Gypsum Substrate for Use as Sheathing* (ASTM 2017d). An assessment of the sheathing substrate used in a building may provide the assessor with an estimate of when the EIFS was installed.

Finally, direct-applied exterior finish systems (DEFS) incorporate an EIFS-type lamina applied directly to a sheathing or solid substrate without an insulation layer. DEFS may appear similar to EIFS but usually are readily distinguishable from the insulated systems.

Level 1 Assessment of EIFS

A Level 1 assessment of EIFS consists of data gathering, an investigation using noninvasive methods, and an investigation using invasive methods.

Preliminary Data Gathering

As with the assessment for any type of cladding, an assessment of EIFS should begin with a review of the available documents from the original construction or remediation of the facility. Architectural and structural drawings and details, the project manual, product submittals, manufacturer's specifications, and warranties should be reviewed. Industry guides (such as those from EIMA), information from design organizations (such as the Exterior Design Institute and RCI, Inc.), and manufacturer's product literature and specifications may be helpful.

Additional sources of information for EIFS cladding are the building code evaluation services, which are available online. Most manufacturers have had their most popular systems tested by the evaluation services associated with previous model building codes. The evaluation reports are available in legacy versions that include, for example, descriptions of acceptable materials, fastening and adhesion requirements, and application methods, which can be helpful in identifying the various systems.

Also helpful are a written or verbal history of interior water intrusion of any kind, including leaks, and information on any type of periodic maintenance or comprehensive remediation. Particular attention should be given to prolonged, repetitive, or chronic leakage that could lead to deterioration of substrates or corrosion of metal components and fasteners, as this could, in turn, adversely affect the wind resistance of the EIFS cladding.

Noninvasive Investigation

After the preliminary data have been gathered, the exterior of the EIFS should be examined thoroughly by walking around the perimeter of the cladding and/or by observing the EIFS from elevated walkways, balconies, or low-slope roof areas, if available. It may be necessary to use a ladder, telescoping boom lift, or swing stage if the building has multiple stories. Anyone using this equipment should be properly trained and experienced in handling and operating it.

The tools that are needed are a notepad, camera, inspection mirror, and blunt spatula for probing. Locations of photographs should be noted. A hand sketch of the building elevation (or a portion of it) with added notes and locations of the photographs can be helpful.

Examples of the conditions and aspects of the exterior construction that should be evaluated during the visual survey include:

- Surface finish consistency and aesthetics (e.g., fading, chalking, worn spots)
- Cracking or spalling of the lamina
- Unfinished areas—exposed mesh or exposed foam
- Delamination of the lamina to the foam
- Delamination of the foam to the substrate
- Bulging or other displacement of assembly
- Discoloration from lawn irrigation or normal weathering
- Surface crazing or “ghosting” of underlying elements, such as insulation joints
- Terminations of panels at the foundation, at adjoining materials, and at soffits
- Penetrations through the EIFS panels
- Presence and condition of building sealants
- EIFS cladding in relation to the fenestration, including window openings, doors, hose bibs, electrical penetrations, light fixtures, meter boxes, disconnect switches, breaker boxes, and antenna attachments

- EIFS panel edges and terminations at openings and penetrations, at the base of the wall (**Figure 5-86**), at overhanging soffits, and against adjacent dissimilar materials, such as brick, stone, and wood
- Areas of discontinuity that often are vulnerable to water and air infiltration

  EIFS manufacturers and generally recognized industry standards indicate that such interfaces and openings should be sealed using an appropriate backer rod and sealant. Most authorities recommend providing a ⅜ to ⅝-inch gap or joint between the EIFS panel edge and the adjacent dissimilar material. Cove-type sealant configurations generally should be avoided, but some manufacturers allow them in certain areas if the size of the openings is limited.

Figure 5-86:
EIFS panel termination at base

- Condition and integrity of sealants between EIFS and adjacent dissimilar materials

  Sealants should be checked regularly, but it is particularly prudent in an assessment for vulnerability to high wind. Unsealed openings can allow significant water intrusion into the system that can result in damage and deterioration of the EIFS and any sheathings, and the eventual failure of associated framing if decay or corrosion becomes advanced.

- On buildings with steep-sloped roofing, the clearance of the bottom of the EIFS cladding along rakes where the sloped roof meets an abutting wall and the flashings in these areas

  The EIFS should not be brought down to the roof surface and should normally have a clearance of 2 to 4 inches above the roof.

  At the end of the rake flashings where the roof eave occurs against a continuous rising wall, the tail end of the flashing at the roof eave should have a kick-out or diverter that deflects the water away from the wall. Since the total EIFS assembly with foam may be 1 to 3 inches thick, and the 90-degree bend of the rake flashing

(where the water runs) usually is up against the substrate, omission of a diverter flashing end can result in water repeatedly being dumped behind the cladding, with detrimental effect on the sheathing and building interior, including severe damage to the sheathing.

- Tactile evaluation (pushing on the surface) to gauge the give and resistance of the surface

  PB EIFS claddings with 1 to 2 inches of MEPS insulation readily give and temporarily depress under pressure. Take care not to permanently deform or puncture the surface. The XEPS insulation of the PM EIFS claddings typically is more dense and does not give as much as a PB EIFS, but it is still less rigid than DEFS or true stucco.

- Types of mesh and number of mesh layers at various parts of the building envelope

  Most EIFS manufacturers provide special heavy-duty mesh and recommend two layers of mesh (one standard and one heavy duty) where the cladding may be subject to physical damage (from lawn maintenance, for example), pedestrian abuse (such as at sidewalks), and other impact damage. If the facility is in a hurricane-prone region, the lower portions of the building envelope will be subject to significant wind-blown debris that could puncture the EIFS claddings.

- Areas of system detachment, if any

  Detachment can be detected by sounding across the various surfaces. Sounding should be done manually using a white rubber mallet or other implement that will not abrade, dent, or mar the surface finish. Using the knuckles to knock on an EIFS surface or an open hand to slap the surface generally produces a hollow thumping sound (similar to the sound of thumping a watermelon) because of the insulation. The hollow sound of EIFS is distinct from the more solid sound of true Portland cement plaster (stucco) and DEFS.

  When using sounding to evaluate EIFS, the idea is to listen for differences in the sound. EIFS claddings all typically sound hollow, but irregular areas of adhesion or attachment sound different and may indicate system detachment in that area.

  Although most, if not all, of the cladding surfaces should be surveyed, it may be prudent in an assessment for wind vulnerability to emphasize the corner areas since corners have the highest wind loads.

  Sounding is also helpful in identifying where the substrate material changes.

  Areas producing different sounds are presumed to have deficient attachment and should be mapped onto an elevation drawing or sketch of the building. Suspect areas also should be subjected to selective demolition in a Level 2 assessment to confirm the anomalous conditions revealed by sounding.

- Moisture

  A nonpenetrating moisture meter can be used to evaluate moisture in EIFS and other cladding systems with no metal components. Because nonpenetrating moisture meters typically use capacitance or resistivity as the evaluation mechanism, they cannot be used in assemblies containing metal lath or any kind of solid metal backing.

  After evaluating with a nonpenetrating moisture meter, all areas with suspected moisture should be tested with a penetrating moisture probe or through selective demolition in a Level 2 assessment.

  Because the meters have limitations, the investigator should be qualified and experienced in the use of nonpenetrating moisture meters. Otherwise, there is potential for misreading or misinterpreting the results, which can be affected by a change in the substrate backup. Nonpenetrating moisture meters are best suited for a quick, initial survey, and the results should be confirmed by other means.

Invasive Investigation

The next step in a Level 1 assessment is an investigation involving minor invasive actions, including testing for moisture, testing for variations in the rigidity and integrity of underlying substrates, checking the back (room) side of exterior sheathing for damage or staining, and assessing framing members and associated connections and anchorages for damage from water intrusion or poor design or installation.

- **Moisture**. Moisture probes typically have long, penetrating probes that must be pushed through the EIFS lamina or inserted through pre-drilled or pre-punched holes. In PB EIFS, the intent is normally to evaluate the presence of increased moisture at the sheathing substrate, which can cause delamination or deterioration. For other types of EIFS, the intent is to evaluate the presence and severity of hidden moisture, which can cause deterioration and corrosion.

  Moisture probes provide relative values that do not necessarily correspond to the moisture content by dry weight of the material. Relative scales for moisture probes generally are from 0 to 100 percent for concrete or masonry and from 0 to 50 percent for wood (19 percent is considered acceptable for wood substrates). Either scale may be used if consistency is maintained for all evaluated areas. The number of locations that are tested should be based on judgment, but moisture readings usually are taken at and around all openings in the EIFS, including windows, doors, and utility penetrations, because these locations can be vulnerable to water infiltration and deterioration.

  The holes created by the moisture probe, or any type of probe, should be adequately repaired when the tests have been completed.

- **Rigidity and integrity of substrates**. A manual check of the moisture probe site can be used to assess any variations in the rigidity and integrity of underlying substrates. This is important to test because sheathing can register as dry on the meter but have deteriorated from chronic wetting. This condition can occur if repairs to stop water intrusion have been made or if the interval between the last rain and the assessment is significant.
- **Damage to or staining of the back of exterior sheathing**. The back of EIFS clad assemblies should be accessed in unfinished mechanical rooms, attics, and utility areas, whenever possible, to check the back (room) side of the exterior sheathing for visible damage or staining.
- **Damage to framing members, connections, and anchors**. The framing members and associated connections and anchors should be assessed for damage from water intrusion or poor design or installation. This will require either taking test cuts through the interior or exterior of the wall to view the cavity, or using a borescope. Any conditions that could compromise the structural integrity and performance of these members should be noted, including adequacy of the attachment of the studs to the stud track or sill plate and adequacy of the attachment of the stud track (or sill plate) to the structure (**Figure 5-87**). If the structure consists of metal studs, the spacing of the fasteners that attach the sheathing to the studs should be noted.

Figure 5-87:
Stucco system that failed because the stud tracks were inadequately anchored to the concrete slabs. Hurricane Ivan (Florida, 2004) (FEMA 489)

Level 2 Assessment of EIFS

A Level 2 assessment consists of infrared thermography, selective demolition, and field pull tests. A Level 2 assessment is recommended if:

- The Level 1 assessment revealed that the EIFS has several more years of useful service life and the building is located where the basic wind speed is greater than 120 mph.[27]

27 The 120-mph basic wind speed is based on ASCE 7-16, Risk Category III and IV buildings.

- The Level 1 assessment did not produce all of the needed information.
- The assumptions drawn from the Level 1 assessment need to be confirmed.

Infrared Thermography

Infrared thermography is an NDE method and is included in a Level 2 assessment because it requires specialized, and sometimes costly, equipment and training. Because infrared thermography has limitations, it is important to follow recognized procedures, such as those in *Standard for Infrared Evaluation of Building Envelopes and Standard for Infrared Inspection of Insulated Roofs* (Infraspection Institute 2016a; Infraspection Institute 2016b); ASTM C1060, *Standard Practice for Thermographic Inspection of Insulation Installations in Envelope Cavities of Frame Buildings* (ASTM 2011a); and ASTM C1153, *Standard Practice for Location of Wet Insulation in Roofing Systems Using Infrared Imaging* (ASTM 2010).

The purpose of using infrared thermography in a wind vulnerability assessment of EIFS is to identify any abnormal thermal patterns of infrared radiation from the building envelope. Thermal anomalies may be the result of trapped or absorbed moisture, or of energy loss from the interior through leakage of cooled or heated air, lack of insulation, inconsistent insulation, thermal bridges in the wall construction, and other reasons. See **Figure 5-88.**

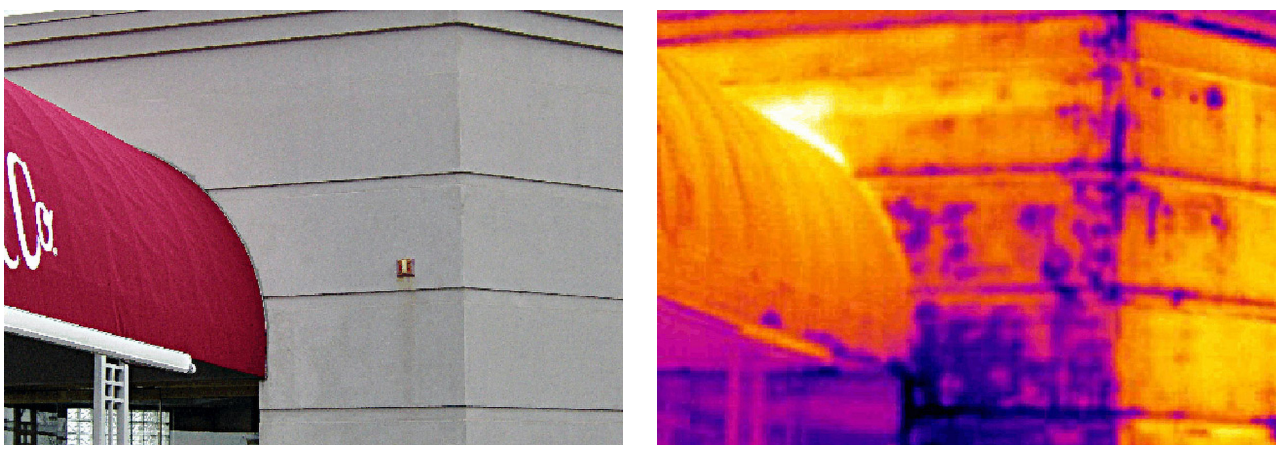


Figure 5-88: EIFS cladding (left) and infrared thermograph (right)

The results of infrared thermography are highly dependent on the time of year, weather, and other conflicting factors. It often is necessary to wait until well after sunset to obtain meaningful information from insulated EIFS wall cladding. Depending on the weather and temperature, it may be more useful to conduct the survey from the interior, but the survey will take longer.

Any moisture that is revealed by infrared thermography needs to be verified by a moisture probe, as described in the Level 1 assessment, or by selective demolition.

Infrared thermography must be used with judgment and by an assessor with the appropriate experience. It can provide valuable information that can be used in more intense and invasive investigations.

Selective Demolition

Selective demolition of EIFS, particularly PB EIFS, is relatively easy to accomplish because the lamina is thin and the insulation is soft foam. Common cutting tools and reciprocating saws typically are the only tools that are needed.

Selective demolition can provide the following information:

- Overall condition of the wall system
- Installation details, such as type of mesh, number of layers of mesh, type of foam insulation, and whether the system is adhered or mechanically attached
- In PB EIFS, the adhesion method (ribbon-and-dab or notched trowel); see **Figure 5-89**
- Qualitative evaluation of the integrity of the adhesion (assessed as the materials are manually pulled from the substrate)
- Type and thickness of the exterior sheathing substrate
- Fastener type and spacing in the exterior sheathing (this factor can affect resistance to negative wind loads)
- Any effects of past or present moisture infiltration on the substrate (e.g., water stains, corrosion, deterioration); see **Figure 5-89** and **Figure 5-90**

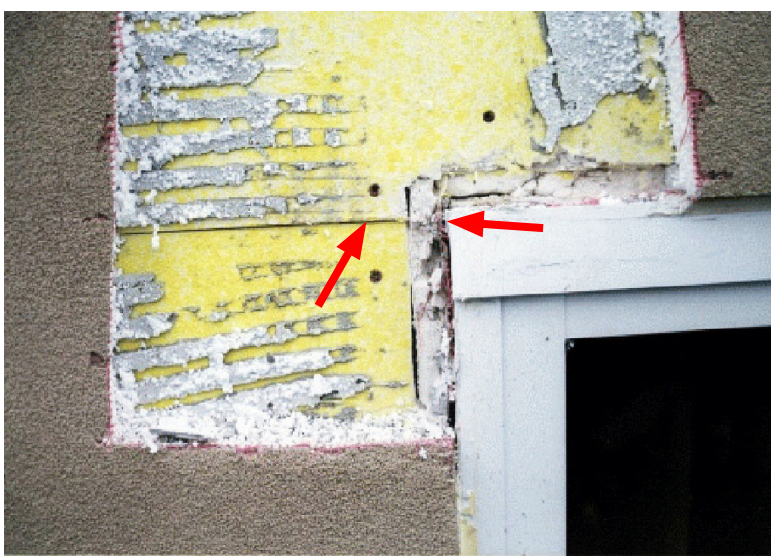


Figure 5-89:
EIFS selective demolition showing alignment of sheathing with the window opening and horizontal notched trowel application of adhesive.

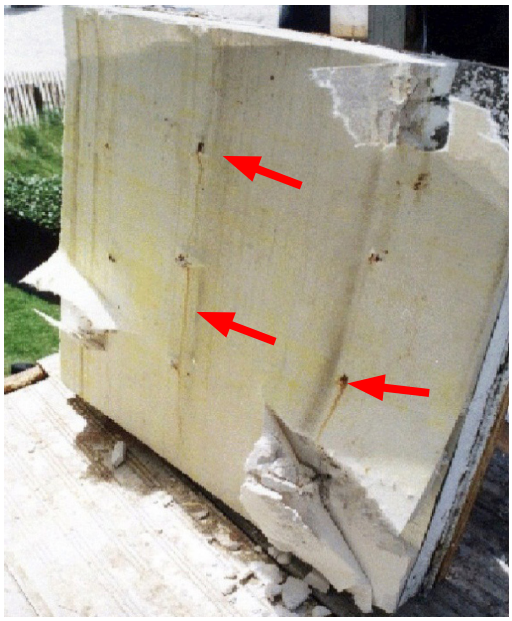


Figure 5-90:
Water stains on the back of glass-faced gypsum sheathing

Selective demolition should be performed in corner areas and other locations, including various building elevations, different heights or floors, locations of common construction, and areas that may be special or unique. If the facility has multiple floors, it will be necessary to use a ladder, telescoping boom lift, or swing stage.

If desired, samples of the materials can be obtained for compliance testing and further investigation of the material properties and characteristics. However, this information does not readily translate into performance criteria. It is more important that generally acceptable materials of good quality are properly adhered or fastened, finished, and detailed using proper workmanship and good design.

Field Pull Test

Because observing the exterior of EIFS cladding does not provide enough information for an assessment of the internal condition of the assembly and underlying substrate, a better assessment method (what became the field pull test) was developed in the 1980s for EIFS cladding that had been in place for some time and exposed to weather. The assessor may choose to use this method if they desire additional information on the wind load capacity of the EIFS system.

The method was formalized in an international standard through ASTM, which established a field pull test that was adapted from existing test protocols. The publication in 2005 of ASTM E2359, *Standard Test Method for Field Pull Testing of an In Place Exterior Insulation and Finish System Clad Wall Assembly* (ASTM 2013b) was a hallmark for field evaluation of EIFS. All of the test methods used prior to this publication involved laboratory tests performed on samples that had not been exposed to weather.

The purpose of the field pull test is to assess the installation adequacy and effects of service-related deterioration on the EIFS wall assembly. The test provides valuable information

about the condition, design, and workmanship of the EIFS and its anticipated performance in design wind pressures. A field pull test is the only way to evaluate wind performance and the only way to obtain quantifiable data on the resistance of the wall system to negative wind loads after the wall has been subjected to weathering (**Figure 5-91**).

Figure 5-91:
View of EIFS blow-off at a hospital addition that opened in 2010. The EIFS's gypsum board substrate blew off the metal studs. A Level 2 assessment or storm damage typically is needed to identify this type of weakness. Hurricane Michael (Florida, 2018)

Test areas should be selected without conscious bias and should be representative of the entire cladding system. The number of samples and distribution of the sampling should be based on experience and judgment. ASTM E2128 provides precedent for the Level 2 assessment to be used as a guide to evaluating buildings subject to water intrusion.

The equipment used in a field pull test consists of a lightweight aluminum test frame (**Figure 5-92**). The frame must be placed against a vertical exterior wall surface and supported by a scaffold or personnel positioned on either side of the test frame. The test frame is fitted with oversized contact plates, which are designed to straddle the test location and bear against the side of the building. The contact plates distribute frame reaction forces onto the wall to minimize compression of the adjacent and/or surrounding EIFS assembly or other materials.

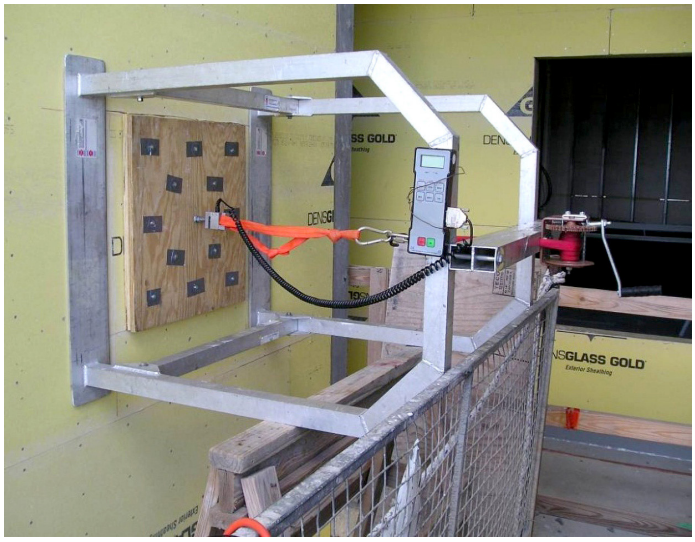


Figure 5-92:
Frame used in field pull test

The pull device consists of a manually operated worm-drive winch with 1-inch nylon webbing. A digital load cell with a range of 0 to 1,000 pounds is used in line between the cable and test module to measure applied force. The simulated negative pressure on the wall surface is transferred to the exterior cladding assembly via a 24-inch square, wooden panel that is adhered to the exterior cladding using a urethane adhesive. The wooden test panel is ¾-inch-thick plywood. A second panel is mechanically fastened to the adhered panel using twelve ¼-inch x 1½-inch wood lag screws in a prescribed pattern in order to distribute the pressure. A ½-inch-diameter hex head bolt through the center of the second panel is used as the attachment point for the digital load cell.

The process for the pull testing involves: (1) marking the locations on the wall for the test board, (2) cutting into the wall along the perimeter of the marked test board location, (3) adhering a test board to the finish coat of the EIFS wall system, and (4) pull testing the EIFS system. The results of the pull test are numerical data and data related to stud spacing, sheathing fastener type and spacing, foam or sheathing failure mode, and general condition of the substrates and framing members. The openings created by removing samples can be used as locations for the selective demolition discussed above.

Figure 5-93:
Corrosion on one face of metal stud, indicating chronic moisture

Wind-borne Debris

For buildings in hurricane-prone regions, where the current basic wind speed is greater than 135 mph[28] —except for schools[29]—determine whether the wall assembly is likely to be capable of resisting complete penetration by wind-borne debris, if tested according to ASTM E1886 or FBC TAS 201/203.[30]

TESTING FOR WIND-BORNE DEBRIS RESISTANCE.

Neither IBC nor ASCE 7 require walls to be tested for wind-borne debris resistance. However, FEMA 543 and 577 recommend test missile "E" (as defined in ASTM E1996-17) for critical facilities other than schools

5.3.3.2 Portland Cement Plaster (Stucco)

Stucco, in various forms, has been used for thousands of years. It still is used extensively throughout North America, and most people are familiar with the appearance of this type of cladding. The familiar sand, dashed, and lace surface-finishes and textures are readily discernible by even the most casual observer.

Modern stucco also is referred to as Portland cement plaster. It is composed of Portland cement (grey or white), lime (usually), masonry sand, and water in prescribed ratios. It sometimes also has integral colors and admixtures such as air-entraining agents, accelerators, anti-freeze compounds, and water repellants. Some design mixes have bonding agents and alkali-resistant fibers of polypropylene, nylon, or fiberglass. Because the materials are mixed by contractors and applicators at the job site, there are a wide variety of finished products that are influenced by local practices and preferences.

The primary reference on mixing and applying plaster is ASTM C926, Specification for Application of Portland Cement-Based Plaster (ASTM 2018c), but additional information is available from the American Concrete Institute (ACI), Portland Cement Association (PCA), and Association of Wall and Ceiling Industries, all of which publish technical guides and manuals related to plaster. Information on local traditions and preferences is available online from regional lathing and plastering bureaus.

Stucco can be applied to a variety of substrates (bases). The bases generally fall into one of two categories: direct-applied or metal lath plaster. In the case of older applications, in historical buildings, narrow, thin strips of wood called wood lath may have been used, though only in the interior.

- **Direct-applied bases** are applied directly to cast-in-place or precast concrete, clay masonry, or CMU, and generally are applied sequentially as a scratch coat and finish coat (often referred to as two-coat work). The primary issue with a direct-applied base is to ensure that a good bond, or adhesion, has been achieved. Control

28 The 135-mph basic wind speed is based on ASCE 7-16, Risk Category III and IV buildings.

29 The reasons for the school exception are: (1) schools typically are not occupied during a hurricane (unless used as a hurricane evacuation shelter) and (2) schools typically are not needed immediately after a hurricane (unless used as a congregate shelter for survivors whose homes are uninhabitable or inaccessible). If a school is to be used as an evacuation shelter, see Chapter 1.

30 Test data on various wall assemblies are available at http://www.depts.ttu.edu/weweb/Research/DebrisImpact/TestingLab.php.

joints in the plaster application should align with structural joints in the structural framing where the material in the substrate changes and wherever necessary to accommodate curing shrinkage. Guidelines for spacing and configuring control joints are available in the ACI and PCA manuals.

- **Metal lath plaster bases** generally are applied over an expanded metal or woven wire lath. Laths can be ribbed or self-furring (with dimples) and may be applied over solid sheathings of various materials, including plywood, OSB, and paper-faced and fiberglass-faced gypsum. In some regions, metal laths are installed, in what are referred to as open systems, against spaced vertical framing consisting of wood or metal studs.

For many years, building codes have required that moisture-sensitive substrates be covered with a weather-resistive barrier (WRB) over the sheathing. WRB materials traditionally have consisted of water-resistant, wax, or asphalt-coated building paper or asphalt-saturated and asphalt-coated felt. Building papers are categorized in terms of performance (e.g., 60-minute paper), and felts are categorized in terms of weight (e.g., nominally 15 or 30 pounds per 100 square foot, referred to as #15 or #30, respectively). Metal laths also are manufactured with an integral WRB, usually consisting of a 30- or 60-minute paper.

It is important for paper-backed laths to be nested properly at the laps so the configuration is metal-lath-to-metal-lath and paper-to-paper (shingled properly), not lath/paper/lath/paper, which can result in patterned horizontal cracking.

More modern WRB materials include synthetic building wraps (which should be grooved to promote drainage), self-adhering sheet membranes, and fluid-applied weather- and air-resistive barriers.

Metal lath must be mechanically fastened to the underlying substrate through the WRB, so WRB materials with a self-healing or gasket effect at the fastener are beneficial. Although it is acceptable to fasten the lath virtually anywhere on wood-based substrates (plywood or OSB), the fastening is required to be at the vertical framing members for open systems and cladding systems provided with gypsum substrates. Screws or nails installed directly into gypsum sheathings do not provide long-term integrity against gravity loads or negative wind loads because thermal expansion and contraction and building movement and racking loosen this type of fastening over time.

Each fastener through the WRB is a potential location for water intrusion, so, during construction, attempt to achieve a relatively clear drainage path behind the plaster to prevent a hydrostatic head of water pressure.

Applying plaster over a metal lath generally is three-coat work (scratch coat, brown coat, and finish coat). The respective thicknesses of the sequential applications are ⅜ inch, ⅜ inch, and ⅛ inch, with a combined thickness of ⅞ inch. Proprietary one-coat systems usually are only ⅜- to ½-inch thick and typically are applied in two sequential applications (brown coat and finish coat). The finish coat may consist of a high-performance, acrylic-based, textured

coating, similar to EIFS finish coats, that can provide enhanced waterproofing capabilities. Because of their decreased thickness (compared with traditional three-coat stucco), proprietary one-coat systems are prone to cracking and typically also include strength admixtures and fibers to assist in improved performance.

Level 1 Assessment of Stucco

A Level 1 assessment of stucco consists of data gathering, a noninvasive investigation, and an invasive investigation.

Preliminary Data Gathering

As with the assessment of EIFS cladding, as much information as possible should be obtained in an assessment of stucco. See the subsection on preliminary data gathering in Section 5.3.3.1 for the recommended data to use for a wind vulnerability assessment of stucco. Legacy evaluation reports for stucco most likely will not be available because stucco tends to be job-mixed and comprised of common materials in a prescribed manner. Evaluation reports may be available for proprietary one-coat plasters.

There are ASTM standards and guides related to installation of lath and metal bases (ASTM C1063), as well as for mixing and applying the stucco (ASTM C926). Because "one-coat" plaster systems are a variance from "standard" ASTM guides, the manufacturers of these systems generally have been required to have these systems tested by the evaluation services to obtain code acceptance.

Noninvasive Investigation

The first step of noninvasive investigation is a visual survey of the building elevations and cladding portions. Examples of the conditions and aspects of the exterior construction that should be evaluated during the visual survey are:.

- Surface finish consistency and aesthetics (e.g., fading, chalking, worn spots)
- Cracking or spalling of the stucco (patterns and repetitive features)
- Unfinished areas—exposed metal lath
- Delamination or debonding of one or more of the stucco layers
- Delamination of the metal lath—failure of the fasteners
- Bulging or other displacement of assembly
- Discoloration from lawn irrigation or normal weathering
- Displacement, damage, or deterioration of the plastering accessories
- Location, spacing, and configuration of one-piece control joints
- Location, spacing, and configuration of true two-piece expansion joints

- Terminations of panels at the foundation, adjoining materials, and soffits
- Penetrations through the plaster panels
- Presence and condition of building sealants

All of the visual survey techniques described for EIFS cladding apply to stucco and proprietary one-coat systems as well (see Section 5.3.3.1). Differences are described below.

In hurricane-prone regions, the lower portions of the building envelope are subject to significant wind-borne debris that can puncture the stucco. True Portland cement plaster generally is harder and tougher than EIFS cladding, so although wind-borne debris can damage stucco, the damage generally will be less than in EIFS cladding.

As with EIFS, sounding the stucco cladding at various locations can be useful in detecting areas of detachment. Sounding should be done with the side of a metal hammer, loop of metal chain, or other implement that will not abrade, dent, or mar the finish. Using your knuckles to rap typically is not productive because true stucco is fairly dense and the response will not be adequate. The idea is to evaluate the *differences* in the sound. Stucco claddings that are well-bonded and well-attached typically produce one type of sound, while irregular areas of adhesion or attachment will produce another type of sound. Sounding also may help identify where the substrate changes are, from one material to another.

Nonpenetrating moisture probes cannot be used in assemblies containing metal lath or any kind of solid metal backing because the probes typically use capacitance or resistivity as the evaluation mechanism. Because stucco almost always includes a metal lath or base, it cannot normally be evaluated with a nonpenetrating moisture probe.

Invasive Investigation

The next step in the assessment is an investigation involving minor invasive actions, including testing for moisture, testing for variations in the rigidity and integrity of underlying substrates, checking the back (room) side of exterior sheathing for damage or staining, and assessing framing members and associated connections and anchorages for damage from water intrusion or poor design or installation.

- **Moisture**. As noted above, moisture surveys using capacitance or resistivity meters generally are useless because the metal lath is detected, obscuring the results. Moisture surveys using penetrating probes are more problematic in true stucco than in EIFS because the hard surface of stucco must be pre-drilled, increasing the time needed for the test and limiting the areas that can be readily assessed. Insert the probe into the stucco via pre-drilled holes, but take care not to touch the metal lath, as this will give a false reading due to the conductivity of the metal. For stucco, the intent usually is to evaluate the presence of increased moisture at the sheathing substrate that may cause deterioration. As discussed in Section 5.3.3.1, moisture probes provide relative values that do not correspond to moisture content by dry weight of the material.

The holes created by the moisture probe, or any type of probe, should be adequately repaired when the tests have been completed.

- **Damage to or staining of the back of exterior sheathing**. The back of stucco cladding should be accessed in unfinished mechanical rooms, attics, and utility areas, whenever possible, to check the back (room) side of the exterior sheathing for visible damage or staining.
- **Damage to framing members, connections, and anchors**. Assess the framing members and associated connections and anchors for damage from water intrusion or from poor design or installation workmanship. Any conditions that could compromise the structural integrity and performance of these members should be noted. Emphasize the corner areas since they are subjected to the greatest negative wind pressure.

Level 2 Assessment of Stucco

A Level 2 assessment consists of infrared thermography, selective demolition, and laboratory testing. A Level 2 assessment is recommended if:

- The Level 1 assessment revealed that the stucco has several more years of useful service life and the building is located where the basic wind speed is greater than 120 mph.[31]
- The Level 1 assessment did not produce all of the needed information.
- The assumptions drawn from the Level 1 assessment need to be confirmed.

Infrared Thermography

As stated previously, infrared thermography is a nondestructive method that can be used for a variety of purposes, including detection of moisture in roofing and the building envelope. Because infrared thermography has limitations, it is important to follow recognized procedures, such as those promulgated by the Infraspection Institute (2016), ASTM C1060, and ASTM C1153.

The purpose of using infrared thermography in a wind vulnerability assessment of stucco is to identify any abnormal thermal patterns of infrared radiation from the building envelope; however, the metal lath in true stucco may make this more difficult. Thermal anomalies may be due to entrapped or absorbed moisture, or else to energy loss from the interior through leakage of cooled or heated air, lack of batt insulation between the studs, inconsistent insulation, thermal bridges in the wall construction, or other reasons.

The results of infrared thermography are highly dependent on the time of year, weather, and other conflicting factors. It often is necessary to wait until well after sunset to obtain meaningful information from a stucco wall cladding, which has significant thermal mass.

31 The 120-mph basic wind speed is based on ASCE 7-16, Risk Category III and IV buildings.

Any moisture that is potentially revealed by infrared thermography needs to be verified by a moisture probe, as described in the Level 1 assessment, or by selective demolition.

As stressed previously, infrared thermography must be used with judgment and by an assessor with the appropriate experience. Nevertheless, thermography can provide valuable information that can be used for more intense and invasive investigations.

Selective Demolition

Selective demolition of stucco cladding systems can be performed using common circular saws fitted with a masonry blade and grinders. Cutting plaster specimens from a wall usually is more difficult and dusty.

Selective demolition can provide the following information:

- Overall condition of the wall system
- Installation details, such as type of attachment of the sheathing and metal lath, condition of the sheathing and WRB, number of plaster layers, thickness of plaster layers, and integrity of bond
- Type and thickness of the exterior sheathing substrate
- Fastener type and spacing in the exterior sheathing
- Any effects of past or present moisture infiltration on the substrate (e.g., water stains, corrosion, deterioration)

Selective demolition should be performed at a number of locations in the exterior cladding, including building elevations, different heights or floors, locations of common construction, and areas that may be special or unique. If the facility has multiple floors, it will be necessary to use a ladder, telescoping boom lift, or swing stage.

If desired, samples of the materials can be obtained for further testing (e.g., petrographic analysis) of the material properties and characteristics.

Although several tests for plaster materials prior to construction are available, physical and material testing for cured plaster materials are limited. Probably the most useful testing is petrographic analysis, which is conducted in accordance with ASTM C823-12, *Practice for Examination and Sampling of Hardened Concrete in Constructions* (ASTM 2012a); ASTM C856, *Standard Practice for Petrographic Examination of Hardened Concrete* (ASTM 2018b); or ASTM C1324, *Test Method for Examination and Analysis of Hardened Masonry Mortar* (ASTM 2015b). This testing should be conducted by a trained and experienced petrographer familiar with Portland cement plaster and masonry mortars (not just concrete in general). Although the testing is expensive, it can provide the following information:

- Estimates of cement-sand ratios and water-cement ratios
- Presence of unhydrated cement "clinker particles"

- Percentage of air entrainment (if any) and voids
- Presence of other anomalies that could adversely affect the plaster performance or integrity

Although originally developed for evaluating EIFS cladding, ASTM E2359 can be used as a modified test standard for evaluating traditional plaster systems applied to metal lath bases. The principal difference is to obtain samples by cutting through the plaster, metal lath, and sheathing rather than through the EIFS lamina, foam, and sheathing. The ASTM E2359 method can be used to assess:

- Bond of the plaster to the metal lath
- Securement of the metal lath
- Integrity of the sheathing and its fastening to the vertical framing members

Wind-borne Debris

For buildings in hurricane-prone regions, where the current basic wind speed is greater than 135 mph[32]—except for schools[33]—determine whether the wall assembly is likely to be capable of resisting complete penetration by wind-borne debris, if tested according to ASTM E1886 or FBC TAS 201/203.[34]

TESTING FOR WIND-BORNE DEBRIS RESISTANCE

Neither IBC nor ASCE 7 require walls to be tested for wind-borne debris resistance. However, FEMA 543 and 577 recommend test missile "E" (as defined in ASTM E1996-17) for critical facilities other than schools.

5.3.4 Metal Wall Panels

This section addresses metal panel wall coverings, including panels attached with concealed or exposed fasteners.

5.3.4.1 Level 1 Assessment of Metal Panels

The following steps are recommended in a Level 1 assessment of metal panels:

- See Section 2.5.1 for information on conducting a Level 1 assessment. This should include a review of original design loads and system resistance in the historical file as well as a comparison of the historical information with design loads based on the current edition of ASCE 7. When information on the original design loads and system resistance is not available and the panels are attached with exposed fasteners (**Figure 5-94**), spot check the fastener spacing in corner areas and in

32 The 135-mph basic wind speed is based on ASCE 7-16, Risk Category III and IV buildings.

33 The reasons for the school exception are: (1) schools typically are not occupied during a hurricane (unless used as a hurricane evacuation shelter) and (2) schools typically are not needed immediately after a hurricane (unless used as a congregate shelter for survivors whose homes are uninhabitable or inaccessible). If a school is to be used as an evacuation shelter, see Chapter 1.

34 Test data on various wall assemblies are available at http://www.depts.ttu.edu/weweb/Research/DebrisImpact/TestingLab.php.

the field of the wall (see **Figure 5-55**, Zone 4 and Zone 5). The spot check should include removing a few fasteners in order to determine their type and size and to compare the resistance provided by the fasteners with the design loads based on the current edition of ASCE 7.

Figure 5-94:
Metal panels attached with exposed fasteners on the parapet of a school. Fastener spacing was inadequate to resist the wind load. Typhoon Paka (Guam, 1997) (FEMA P-424, 2004 edition)

- If the panels have snap-on battens (seam caps), spot-checking the batten attachment in the corner areas is recommended. **Figure 5-95** shows metal roof panels with snap-on battens; such a system also can be used on walls. Grab the bottom of the batten, and try to rotate it to see if it unlatches. Perform this test in a few areas on each side of the batten. Experienced investigators can detect weak battens easily, but battens that do not unlatch may be incorrectly interpreted as having adequate wind resistance. Unfortunately, a field test method (other than hand manipulation) that can be used for a more definitive evaluation of resistance does not exist currently.

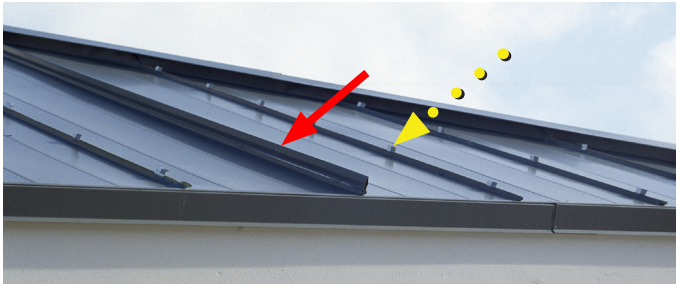


Figure 5-95:
At three of the four ribs shown in this figure, battens were blown off (the solid red arrow shows the remaining batten). The yellow dotted arrow shows one of the concealed chips that attached the panels and battens. Hurricane Andrew (Florida, 1992)

- Wind-borne debris: For buildings in hurricane-prone regions, where the current basic wind speed is greater than 135 mph[35]—except for schools[36]—determine whether the wall assembly is likely to be capable of resisting complete penetration by wind-borne debris, if tested according to ASTM E1886 or FBC TAS 201/203.[37]

TESTING FOR WIND-BORNE DEBRIS RESISTANCE

Neither IBC nor ASCE 7 require walls to be tested for wind-borne debris resistance. However, FEMA 543 and 577 recommend test missile "E" (as defined in ASTM E1996) for critical facilities other than schools.

If the Level 1 assessment reveals the metal panel system has several more years of useful service life, a Level 2 assessment is recommended for the following conditions:

- Panels are attached with exposed fasteners, and the building is located in an area where the current basic wind speed is greater than 165 mph.[38] Note that the 165-mph trigger speed is higher than the 120-mph trigger speed for the concealed fastener assessment (see below) because panels with exposed fasteners are less likely to fail than panels with concealed fasteners.
- Panels are attached with concealed fasteners, and the building is located in an area where the current basic wind speed is greater than 120 mph.[39]
- Panels that are attached with concealed fasteners extend more than 30 feet above grade.

5.3.4.2 Level 2 Assessment of Metal Panels

Panels with Exposed Fasteners

Removing a panel in at least one corner area and the field of the wall is recommended to be able to determine whether there is a WRB, such as asphalt-saturated felt or housewrap, over the sheathing. As shown in **Figure 5-96**, if the metal panels blow away and there is no WRB over the sheathing, a large amount of wind-driven rain can be blown into the building.

35 The 135-mph basic wind speed is based on ASCE 7-16, Risk Category III and IV buildings.

36 The reasons for the school exception are: (1) schools typically are not occupied during a hurricane (unless used as a hurricane evacuation shelter) and (2) schools typically are not needed immediately after a hurricane (unless used as a congregate shelter for survivors whose homes are uninhabitable or inaccessible). If a school is to be used as an evacuation shelter, see Chapter 1.

37 Test data on various wall assemblies are available at http://www.depts.ttu.edu/weweb/Research/DebrisImpact/TestingLab.php.

38 The 165-mph basic wind speed is based on ASCE 7-16, Risk Category III and IV buildings

39 The 120-mph basic wind speed is based on ASCE 7-16, Risk Category III and IV buildings.

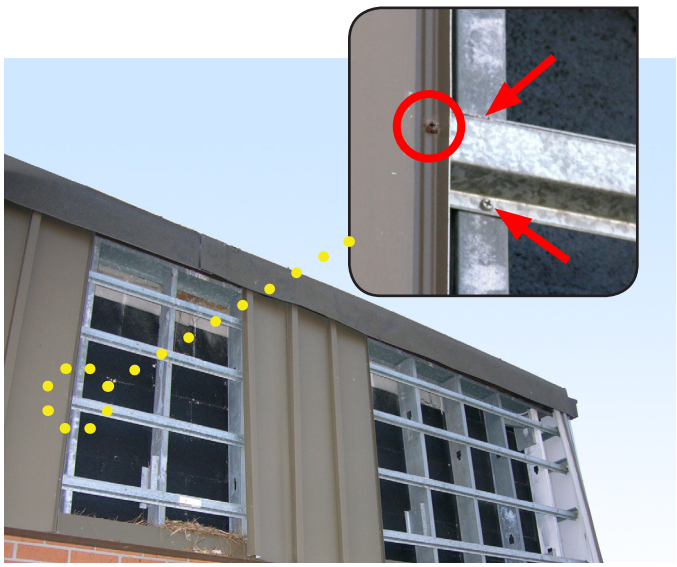


Figure 5-96:
Metal panel blow-off at a school. Without a moisture barrier over sheathing, wind-driven water blew into the school. The solid red circle indicates a concealed panel fastener. The solid red arrows indicate hat channel fasteners. Hurricane Ivan (Alabama, 2004)

If several panels blow away, unless the WRB is well-attached (which is atypical), the barrier also may be blown away.

Checking the framing that the panels are attached to is recommended, as described in the section below.

Panels with Concealed Fasteners

The following steps are recommended for panels with concealed fasteners:

- Remove a panel in at least one corner area and the field of the wall to determine whether there is a WRB over the sheathing, as described above.
- Remove a few clip fasteners to determine their type and size and to compare the resistance provided by the fasteners with the design loads based on the current edition of ASCE 7.
- If the metal panels are copper, check the clips to see whether they are copper or stainless steel.[40]

Checking the adequacy of the framing that the panels are attached to is recommended, as follows:

- If the framing is wood (**Figure 5-97**), check the adequacy of the framing connections and the adequacy of the attachment of the framing to the building.
- If metal hat channels are present, check the attachment of the channels. Determine whether fasteners occur in the top and bottom flange at each vertical

40 FEMA P-499 Fact Sheet 7.6 recommends that copper panels in areas with a basic wind speed greater than 120 mph be attached with stainless steel clips. The 120-mph basic wind speed is based on ASCE 7-16, Risk Category III and IV buildings.

framing member, as shown in the **Figure 5-96** inset. If fasteners occur only in the top or bottom flange, as shown in **Figure 5-98**, the hat channel can twist and create prying forces on the channel fasteners.

- Check fastener edge distances (**Figure 5-99**). The wall panel damage shown in **Figure 5-98** and **Figure 5-99** occurred at a power plant outside of a hurricane-prone region. The winds were well below the ASCE 7 basic wind speed.
- When the panels are removed, check for the presence of sealant or sealant tape. When actual wind speeds approach 120 mph, the potential for wind-driven rain to force in between unsealed panel laps increases.

Figure 5-97:
At a portion of the school shown in Figure 5-96, the metal panels were attached to wood framing that was inadequately attached to CMU. Hurricane Ivan (Alabama, 2004) (FEMA P-424)

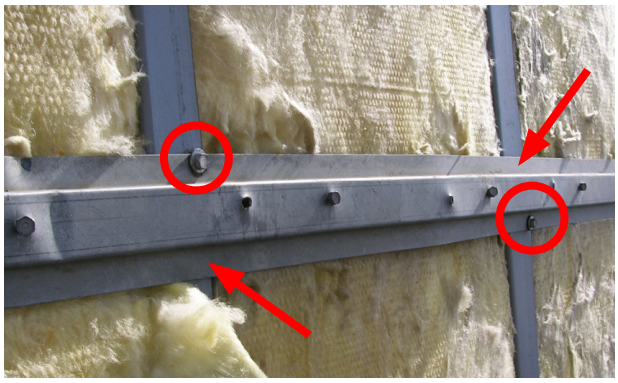


Figure 5-98:
This hat channel had only one fastener at each vertical member (red circles). A fastener also should have been installed on the opposite flange (solid red arrows). At this location, the exposed fastener panels blew off, but at most blow-off areas, the hat channels blew away.

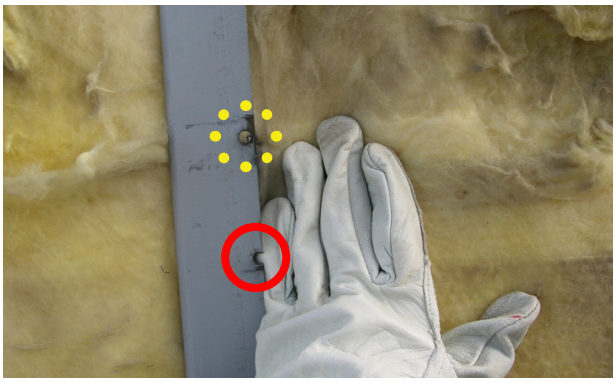


Figure 5-99:
At this location, the hat channel had fasteners at the top and bottom flanges, but the fasteners were too close to the edge (solid red circle and yellow dotted circle). Nearly half of the shank of one fastener (solid red circle) did not engage the framing.

5.3.5 Precast Non-Load-Bearing Wall Panels

Precast concrete is used frequently in exterior cladding and the exterior walls of large buildings. See Chapter 4 for a discussion of exterior walls of large buildings.

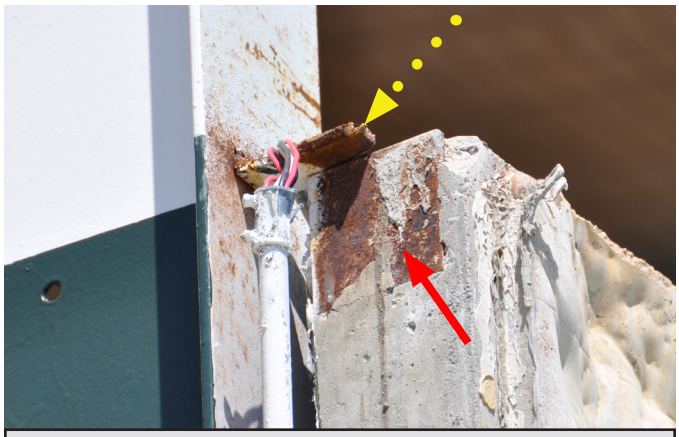
5.3.5.1 Exterior Cladding

Exterior cladding constructed of precast concrete is normally only a few inches thick and can be similar to the cladding shown in **Figure 5-100**. The figure shows a panel that blew off during a tornado. The vulnerability of the panels to high winds is generally in the attachment of the panels to the building frame. In the figure, the steel braces (yellow arrows), where the precast panel used to be, suggest that the panel was attached by bolts or welds.

Figure 5-100:
Missing precast concrete wall panel. Joplin Tornado (Missouri, 2011) (FEMA P-908)

Installing precast concrete cladding usually involves lifting the panels with a crane or other high-weight lifting technique and then mechanically fastening the panels to the building frame. Panels are most commonly fastened with bolts or welds. Assessing the panels should focus on the adequacy of the attachment. The assessment method should follow the technique described in Section 4.5, Assessment of Structural Elements. These connections may need to be exposed in order to properly assess the condition. If a visual inspection is not possible, a borescope or other non-invasive technique may be required.

Problems with attachments involving bolts or welding include: corrosion, inadequate spacing of bolts or welds, inadequate welding (**Figure 5-101**), inadequate attachment of weld plates to the panel, and improper location of the weld plates in the panels. In coastal areas, both bolts and welds can corrode, reducing the strength of the connection. The number of bolts that were installed in the original installation may have been inadequate, or the welds may have been incomplete or inadequate. Adequate attachment of the panels to the building frame, using either bolts or welds, depends in part on the proper location of the steel plates embedded in the panels. Any shortcomings in the attachment can jeopardize the resistance of the attachment to the pressures caused by high winds.



The red arrow indicates a weld plate cast into the panel. The dotted yellow arrow indicates a plate that was welded to the frame and the panel weld plate.

Figure 5-101:
Precast panel failure at a school due to insufficient welding. Hurricane Harvey (Texas, 2017) (FEMA P-2022)

5.3.6 Siding (Fiber Cement, Vinyl, Plywood, Wood Boards)

5.3.6.1 Fiber Cement Siding

Fiber cement siding is available in boards, flat sheets, and shingle-look-alike shapes. This product has a cementitious base and is, therefore, resistant to rot and deterioration, but the typical issues of weathering, caulking, nailing, and maintenance are similar to issues in wood siding.

The typical nailing method with this siding product is called blind nailing (see **Figure 5-102**), in which the nails are driven through the product in a location that hides the nail when the next piece of siding is "lapped" on top. FEMA P-499, Fact Sheet 5.3, suggests that blind nails be kept between ¾ inch and 1 inch away from the top edge of the siding panel and a minimum of ⅜ inch from the butt ends of the panel.

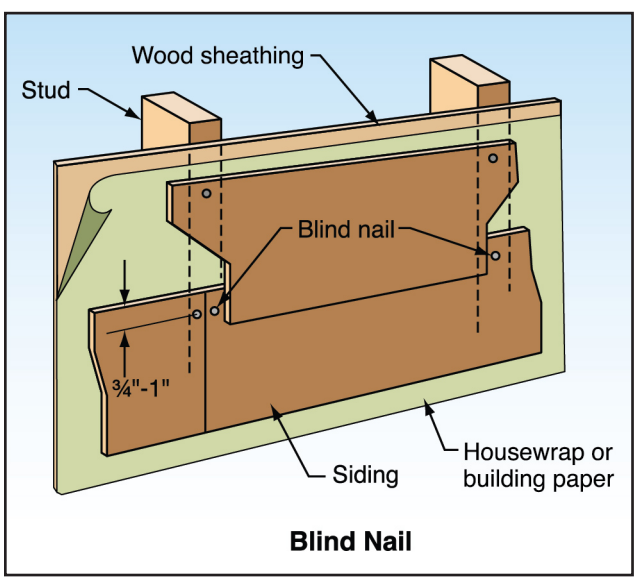


Figure 5-102:
Blind nailing (FEMA P-499, Fact Sheet 5.3)

The primary vulnerability to wind is poor attachment to the building frame. Siding also is vulnerable to bending failure when blind nailed. The product should be nailed into the wall studs to secure it properly, and in high-wind areas, nails should be placed through the face of the product, which makes the nail spacing visible (see **Figure 5-103**). In FEMA P-499, Fact Sheet 5.3, face nailing is recommended in areas where the design wind speed is 100 mph or greater unless the local building official has more restrictive requirements.[41] **Figure 5-104** illustrates damage to this siding when it is not face-nailed.

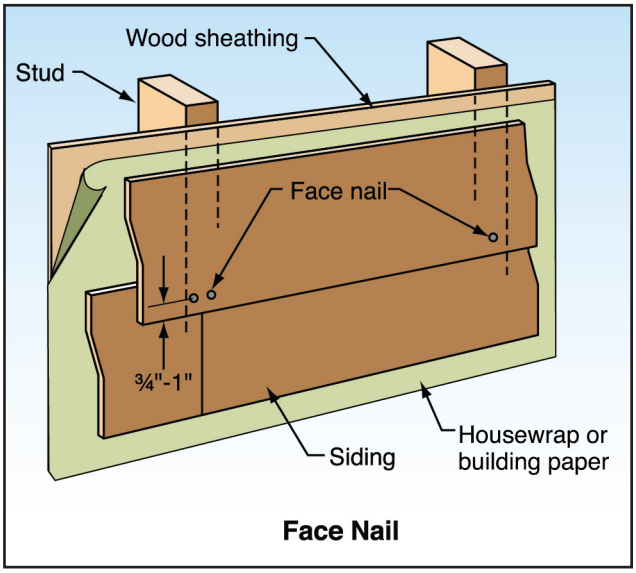


Figure 5-103:
Face nailing (FEMA P-499, Fact Sheet 5.3)

Figure 5-104: Fiber cement siding attached with blind nails (solid red circle). Because of the high design wind speed, face nails should have been used (blue dashed circle). Hurricane Francis (Florida, 2004) (FEMA P-424)

41 The 100 mph is based on ASCE 7-05. This is equivalent to 126 mph, using ASCE 7-16, Risk Category II.

In coastal environments, the nails should be corrosion-resistant. Stainless steel or hot-dipped galvanized nails are considered corrosion resistant for these applications. Corrosion-resistant nails may be installed on furring strips that provide a cavity in order to facilitate drainage of water from the space between the WRB and the backside of the siding. The water drainage cavity also facilitates drying of the siding and the moisture barrier (see **Figure 5-105**). The siding manufacturer's instructions for rain screen applications in high-wind areas must be followed. The furring strips should be attached to the building framing or otherwise incorporated into the structural load path. Where this is done, siding can be attached to the furring strips, with or without penetration to the building framing, in accordance with manufacturer's instructions.

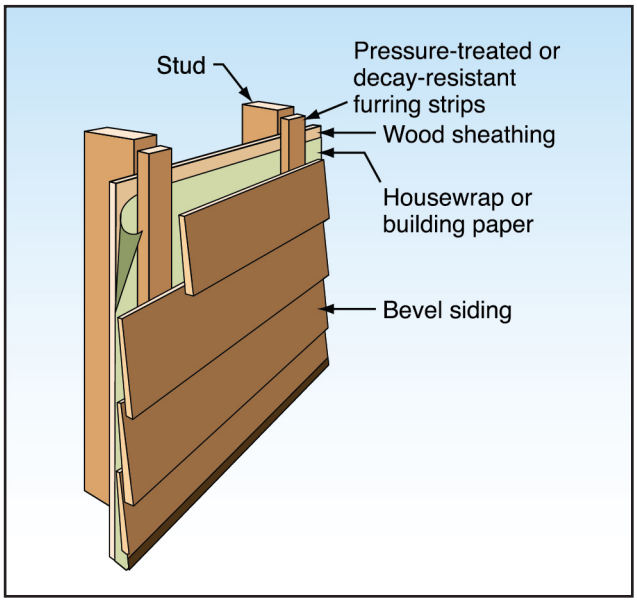


Figure 5-105:
Water drainage cavity (FEMA P-499, Fact Sheet 5.3)

Fiber cement siding is unlikely to resist damage from wind-borne debris in hurricanes and tornadoes, and the damage from debris can be significant (see **Figure 5-106**).

Figure 5-106:
Hurricane wind-borne debris damage to fiber cement siding. The debris penetrated the plywood substrate. This siding was face-nailed. The siding blow-off likely would not have occurred, were it not for the debris impact. Hurricane Harvey (Texas, 2017)

Level 1 Assessment of Fiber Cement Siding

The following steps are recommended as part of the Level 1 assessment:

- **Wind suction pressures and system resistance.** See Section 2.5.1 for information on conducting a Level 1 assessment. This should include a review of original design loads and system resistance in the historical file as well as a comparison of the historical information with design loads based on the current edition of ASCE 7.
- If information on the original design loads and system resistance is not available, conduct the following:
  - If the siding is attached with exposed fasteners, spot check fastener spacing in corner areas and the field of the wall to verify that the nailing is attached to the wall studs and to determine the spacing for load resistance calculations. Remove a few fasteners to determine type and size. Compare the resistance provided by the fasteners with the design loads based on the current edition of ASCE 7.
  - Check the bottom of the lowest piece of siding (see **Figure 5-107)** to determine whether it is attached to the starter section of wall sheathing. The lowest course of siding should be face-nailed to a starting spacer that is flush with the bottom of the lowest course of siding. This was not done in **Figure 5-107**.
- Attempt to identify the product, and consult the manufacturer's instructions on product installation. These instructions are the most authoritative source of information on installation requirements. Building construction records or retained files from architects or builders are other sources for this information.

Figure 5-107:
Exposed gap (solid red circle) (FEMA P-499, Fact Sheet 5.3)

Building code evaluation reports and/or manufacturer's websites could provide wind rating information.

Level 2 Assessment of Fiber Cement Siding

The following steps are recommended as part of the Level 2 assessment:

- **Panels with exposed fasteners**. If the current design wind speed is 135 mph[42] or greater, remove some siding in at least one corner area and the field of the wall to determine whether a WRB (such as asphalt-saturated felt or housewrap) occurs over the sheathing. If some siding blows away and there is no water-resistant barrier and sheathing, a large amount of wind-driven rain can be blown into the building.
- **Panels with concealed fasteners**. If the current design wind speed is 135 mph[43] or greater, proceed as above for exposed fasteners.
  - If the framing is wood, check the adequacy of the siding connections to the sheathing and the adequacy of the attachment of the sheathing to the building frame (check for continuity of load paths).
  - If the siding is installed over furring strips that provide a water drainage cavity behind the siding, check the attachment of the furring strips to the wall framing, including nailing size and spacing, to determine wind resistance of the wall assembly, including the furring strips.
  - Check nail spacing with a magnetic stud/nail finder. However, note that this works only with nails manufactured with a sufficient quantity of iron; this method does not provide clear results for stainless steel nails. Stud finders that do not rely on the magnetic detection of nails can be used to find the studs. Nail spacing also can be determined by gently prying up a few pieces of siding along the bottom edge, along approximately a 4-foot-long section, and observing where the resistance to being pried away is located and what the spacing is.
  - If this method does not provide sufficient clarity on nail spacing, remove the top piece of siding near a soffit. The concealed fasteners should be evident near the top of the siding, revealed by removing the top piece.

42 The 135-mph basic wind speed is based on ASCE 7-16, Risk Category III and IV buildings.

43 The 135-mph basic wind speed is based on ASCE 7-16, Risk Category III and IV buildings

- **Wind-borne debris**. For buildings in hurricane-prone regions, where the current basic wind speed is greater than 135 mph[44]—except for schools[45]—determine whether the wall assembly is likely to be capable of resisting complete penetration by wind-borne debris, if tested according to ASTM E1886 or FBC TAS 201/203.[46]

TESTING FOR WIND-BORNE DEBRIS RESISTANCE

Neither IBC nor ASCE 7 require walls to be tested for wind-borne debris resistance. However, FEMA 543 and 577 recommend test missile "E" (as defined in ASTM E1996-17) for critical facilities other than schools.

5.3.6.2 Vinyl

Vinyl siding is attached with nails, similar to the fiber cement siding described above. Nails are usually roofing nails and must be corrosion-resistant. Stainless steel roofing nails provide protection against corrosion. Vinyl is attached to the wall with a nailing flange or hem at the top of each vinyl panel.

All vinyl siding is tested and rated for different wind design pressure applications; the rating of the siding used for the building should be at least as high as the local design pressure for components and cladding. Vinyl siding that is rated for higher wind pressures may have greater overall thickness, a more robust locking mechanism, and thicker or doubled-over nail hem (see **Figure 5-108**). Even if the exact design pressure rating cannot be determined, it is often possible to determine if the siding has a higher wind rating by looking for these features.

High-wind vinyl siding has been available for many years but has often not been found in many high-wind areas during damage investigations, making it unlikely that many older buildings have this product, except in re-siding or retrofit situations.

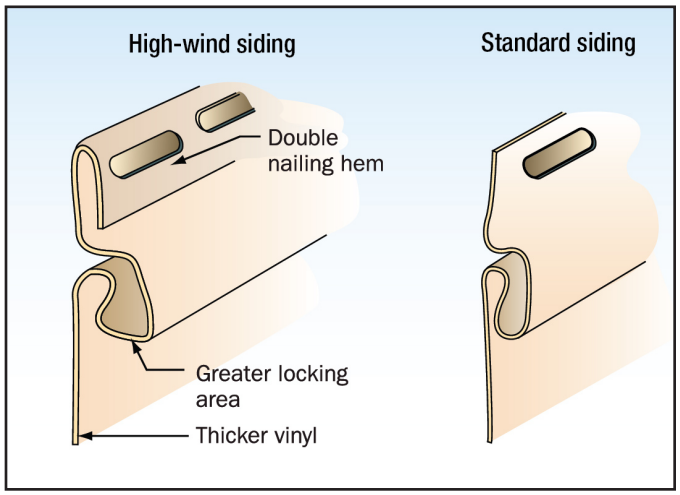


Figure 5-108:
High-wind vinyl siding profile

44 The 135-mph basic wind speed is based on ASCE 7-16, Risk Category III and IV buildings.

45 The reasons for the school exception are: (1) schools typically are not occupied during a hurricane (unless used as a hurricane evacuation shelter) and (2) schools typically are not needed immediately after a hurricane. If a school is to be used as an evacuation shelter, see Chapter 1.

46 Test data on various wall assemblies are available at http://www.depts.ttu.edu/weweb/Research/DebrisImpact/TestingLab.php.

Vinyl siding is required by the IBC and the *International Residential Code®* (IRC®) to comply with ASTM D3679, *Standard Specification for Rigid Poly(Vinyl Chloride) (PVC) Siding* (ASTM 2017b), which requires the siding to withstand wind pressures equivalent to 110 mph on a Risk Category II building up to 30 feet tall in Exposure B.[47] If the siding manufacturer and model can be identified, the manufacturer's instructions will provide information on proper installation, including any additional provisions for installation in high-wind areas. If the siding manufacturer cannot be identified, the Vinyl Siding Institute (VSI) has an installation manual that provides basic considerations for installing vinyl in high-wind areas (VSI 2018). In addition, building code evaluation service reports for the manufacturer have information on wind design pressure rating and installation specifications. This information could provide the assessment team with guidance on whether an inspected product is rated for the design conditions at the building location and is installed properly to achieve that level of performance.

Wind-borne debris can cause significant damage to vinyl siding in both hurricanes and tornadoes. This siding product is not likely to be thick enough to resist the damage.

As with fiber cement siding, vinyl siding must normally be attached to wall studs. The most common exception is vertical siding that is attached only to wood structural sheathing and is not commonly rated for use in high-wind areas. Vertical siding should be inspected closely to determine its wind design pressure rating and to verify that the type and spacing of fasteners are correct.

Level 1 Assessment of Vinyl Siding

The following steps are recommended as part of the Level 1 assessment:

- **Wind suction pressures and system resistance**. See Section 2.5.1 for information on conducting a Level 1 assessment. This should include a review of original design loads and system resistance in the historical file as well as a comparison of the historical information with design loads based on the current edition of ASCE 7.
- If information on original design loads and system resistance is not available, conduct the following:
  - Spot check fastener spacing in corner areas and the field of the wall to verify that the nailing engages the wall studs and to determine the spacing for load resistance calculations. As noted above, vinyl siding is attached with concealed fasteners since the nails are installed through the top flange of the siding panels. Depending on the flexibility of the siding material, the siding panels can be pulled away from the wall to determine the approximate locations of nails. Remove a short section of siding at a corner and then remove a few fasteners to determine type and size. Compare the resistance provided by the fasteners with the design loads based on the current edition of ASCE 7.

47 The 110 mph is based on ASCE 7-05. This is equivalent to 139 mph, using ASCE 7-16, Risk Category II.

- Check the bottom of the lowest piece of siding to determine whether it is attached to a proper starter strip used for vinyl siding.
- Spot check to ensure that the bottom of the vinyl siding is locked onto the flange on the top of the previous course. This can be determined by pulling on the bottom of the siding panels. A lack of interlocking is shown in **Figure 5-109**.

Figure 5-109:
Incomplete interlocking of flanges (FEMA P-757)

Level 2 Assessment of Vinyl Siding

The following steps are recommended as part of the Level 2 assessment:

- If the current design wind speed is 135 mph or greater, remove some siding in at least one corner area and the field of the wall to determine whether a WRB (such as asphalt-saturated felt or housewrap) occurs over the sheathing. If some siding blows away and there is no WRB over the sheathing, a large amount of wind-driven rain can be blown into the building.
  - If the framing is wood, check the adequacy of the siding connections and the adequacy of the attachment of the siding to the building frame (check for continuity of load paths).
  - If the siding is installed over furring strips that provide a water drainage cavity behind the siding, check the attachment of the furring strips to the wall framing, including nailing size and spacing, to determine wind resistance of the wall assembly, including the furring strips.

- **Wind-borne debris**. For buildings in hurricane-prone regions, where the current basic wind speed is greater than 135 mph[48]—except for schools[49]—determine whether the wall assembly is likely to be capable of resisting complete penetration by wind-borne debris, if tested according to ASTM E1886 or FBC TAS 201/203.[50]

TESTING FOR WIND-BORNE DEBRIS RESISTANCE

Neither IBC nor ASCE 7 require walls to be tested for wind-borne debris resistance. However, FEMA 543 and 577 recommend test missile "E" (as defined in ASTM E1996-17) for critical facilities other than schools.

5.3.6.3 Plywood

Plywood siding usually comes as a product called T1-11. This siding is installed with nails directly onto wood or metal studs used for the wall framing or over other exterior sheathing. The nails used to secure the siding to the wall should be visible in most of the wall area. Plywood panels must be nailed around the edges and in the field of the panel such that the panel will resist being pulled off the building. The panels normally are not intended to provide lateral wind resistance; they are meant to provide cover only of the building interior from environmental effects such as cold, rain, snow, and other normal weather or seasonally related effects.

Vulnerability of this material to damage from wind is most likely caused by a nailing pattern that does not adequately resist nail withdrawal or by the thin plywood material being pulled out over the head of the nail. Plywood is more resistant to low-momentum wind-borne debris than fiber cement and vinyl. However, thin 15⁄32" plywood can be penetrated by debris.

Level 1 Assessment of Plywood Siding

The following steps are recommended as part of the Level 1 assessment:

- **Wind suction pressures and system resistance.** See Section 2.5.1 for information on conducting a Level 1 assessment. This should include a review of original design loads and system resistance in the historical file as well as a comparison of the historical information with design loads based on the current edition of ASCE 7.
- If information on original design loads and system resistance is not available, conduct the following:
  - If the siding is attached with exposed fasteners, spot check fastener spacing in corner areas and the field of the wall to verify that the nailing is attached to the wall studs and to determine the spacing for load resistance calculations. Remove a few fasteners to determine type and size. Compare

48 The 135-mph basic wind speed is based on ASCE 7-16, Risk Category III and IV buildings.

49 The reasons for the school exception are: (1) schools typically are not occupied during a hurricane (unless used as a hurricane evacuation shelter) and (2) schools typically are not needed immediately after a hurricane. If a school is to be used as an evacuation shelter, see Chapter 1.

50 Test data on various wall assemblies are available at http://www.depts.ttu.edu/weweb/Research/DebrisImpact/TestingLab.php.

the resistance provided by the fasteners with the design loads based on the current edition of ASCE 7.

Level 2 Assessment of Plywood Siding

The following steps are recommended as part of the Level 2 assessment:

- **Panels with exposed fasteners.** If the current design wind speed is 100 mph or greater, remove some siding in at least one corner area and the field of the wall to determine whether a WRB (such as asphalt-saturated felt or housewrap) occurs over the sheathing. A full 4-foot x 8-foot piece of siding may need to be removed for this inspection. If some siding blows away and there is no WRB over the sheathing, a large amount of wind-driven rain can be blown into the building.
- **Panels with concealed fasteners.** If the current design wind speed is 100 mph or greater, proceed as noted for exposed fasteners.
  - If the framing is wood, check the adequacy of the siding connections and the adequacy of the attachment of the siding to the building frame (check for continuity of load paths).
  - If the siding is installed over furring strips that provide a water drainage cavity behind the siding, check the attachment of the furring strips to the wall framing, including nailing size and spacing, to determine wind resistance of the wall assembly, including the furring strips.
- **Wind-borne debris.** For buildings in hurricane-prone regions, where the current basic wind speed is greater than 135 mph[51]—except for schools[52]—determine whether the wall assembly is likely to be capable of resisting complete penetration by wind-borne debris, if tested according to ASTM E1886 or FBC TAS 201/203.[53]

TESTING FOR WIND-BORNE DEBRIS RESISTANCE

Neither IBC nor ASCE 7 require walls to be tested for wind-borne debris resistance. However, FEMA 543 and 577 recommend test missile "E" (as defined in ASTM E1996) for critical facilities other than schools.

5.3.6.4 Wood Board

Wood board siding is usually in the form of long narrow planks. Wood board siding may be referred to as lap siding because installation involves lapping one board on top of another, which exposes the same amount of wood board throughout the installation.

51 The 135-mph basic wind speed is based on ASCE 7-16, Risk Category III and IV buildings.

52 The reasons for the school exception are: (1) schools typically are not occupied during a hurricane (unless used as a hurricane evacuation shelter) and (2) schools typically are not needed immediately after a hurricane. If a school is to be used as an evacuation shelter, see Chapter 1.

53 Test data on various wall assemblies are available at http://www.depts.ttu.edu/weweb/Research/DebrisImpact/TestingLab.php.

This product is nailed through the face of the material into the studs that frame the exterior walls. The product must be face-nailed to resist high winds. Nails should be visible on the siding, making the nail spacing visible.

In coastal environments, nails should be stainless steel. Other nail materials most likely will corrode in a short period, which will reduce the attachment resistance.

This product may be installed on furring strips that provide a water drainage cavity behind the siding that helps keep the exterior wall surface dry. See Section 5.3.6.1 for information on water drainage cavities.

Level 1 Assessment of Wood Board Siding

The following steps are recommended as part of the Level 1 assessment:

- **Wind suction pressures and system resistance.** See Section 2.5.1 for information on conducting a Level 1 assessment. This should include a review of original design loads and system resistance in the historical file as well as a comparison of the historical information with design loads based on the current edition of ASCE 7.
- If information on original design loads and system resistance is not available, conduct the following:
  - If the siding is attached with exposed fasteners, spot check fastener spacing in corner areas and the field of the wall to verify that the nailing is attached to the wall studs and to determine the spacing for load resistance calculations. Remove a few fasteners to determine type and size. Compare the resistance provided by the fasteners with the design loads based on the current edition of ASCE 7.
  - Check the bottom of the lowest piece of siding to determine whether it is attached to the starter section of the wall sheathing.
  - Compare the actual nail spacing and nail type and size with the attachment recommendations in *Natural Wood Siding: Selection, Installation, and Finishing* from the Western Wood Products Association (WWPA) (WWPA 2007).

Level 2 Assessment of Wood Board Siding

The following steps are recommended as part of the Level 2 assessment:

- **Boards with exposed fasteners**. If the current design wind speed is 135 mph or greater, remove some siding in at least one corner area and the field of the wall to determine whether a moisture-resistant barrier (such as asphalt-saturated felt or housewrap) occurs over the sheathing. If some siding blows away and there is no WRB over the sheathing, a large amount of wind-driven rain can be blown into the building.

- **Boards with concealed fasteners**. If the current design wind speed is 135 mph or greater, proceed as noted for exposed fasteners.
  - If the framing is wood, check the adequacy of the siding connections and the adequacy of the attachment of the siding to the building frame (check for continuity of load paths).
  - If the siding is installed over furring strips that provide a water drainage cavity behind the siding, check the attachment of the furring strips to the wall framing, including nailing size and spacing, to determine wind resistance of the wall assembly, including the furring strips.
- **Wind-borne debris.** For buildings in hurricane-prone regions, where the current basic wind speed is greater than 135 mph[54]—except for schools[55]—determine whether the wall assembly is likely to be capable of resisting complete penetration by wind-borne debris, if tested according to ASTM E1886 or FBC TAS 201/203.[56]

TESTING FOR WIND-BORNE DEBRIS RESISTANCE

Neither IBC nor ASCE 7 require walls to be tested for wind-borne debris resistance. However, FEMA 543 and 577 recommend test missile "E" (as defined in ASTM E1996) for critical facilities other than schools.

5.3.7 Soffits

This section addresses the resistance of soffit systems to wind pressures and the resistance of soffit vents to wind-driven rain.

5.3.7.1 Level 1 Assessment of Soffits

The following steps are recommended in a Level 1 assessment:

- Determine the original design wind loads and system resistance to both positive and negative pressures.

  See Section 2.5.1 for information on conducting a Level 1 assessment. This should include a review of original design loads and system resistance in the historical file as well as a comparison of the historical information with design loads based on the current edition of ASCE 7. Soffit loading criteria were not included in ASCE 7 until the 2010 edition.

SOFFIT DESIGN AND APPLICATION

For soffit design and application recommendations, see FEMA P-499, Fact Sheet 7.5, *Minimizing Water Intrusion Through Roof Vents in High-Wind Regions* (FEMA 2010c).

54 The 135-mph basic wind speed is based on ASCE 7-16, Risk Category III and IV buildings.

55 The reasons for the school exception are: (1) schools typically are not occupied during a hurricane (unless used as a hurricane evacuation shelter) and (2) schools typically are not needed immediately after a hurricane. If a school is to be used as an evacuation shelter, see Chapter 1.

56 Test data on various wall assemblies are available at http://www.depts.ttu.edu/weweb/Research/DebrisImpact/TestingLab.php.

- If information on original design loads and system resistance is not available, or if the building is located in an area where the current basic wind speed is greater than 120 mph,[57] a Level 2 assessment is recommended.

5.3.7.2 Level 2 Assessment of Soffits

The following steps are recommended in a Level 2 assessment:

- Evaluate the soffit panels and framing system for resistance to both positive and negative (suction) pressures. **Figure 5-110** shows a soffit that had insufficient resistance.
- Evaluate soffits with vents for resistance to wind-driven rain.

Figure 5-110: At this school, the exterior wall stopped just above the soffit (solid red arrows). After the metal soffit panels blew away, wind-driven rain blew into the attic space and saturated the fiberglass batt insulation, causing the ceiling boards to collapse. Hurricane Katrina (Mississippi, 2005) (FEMA P-424)

5.4 Roof Systems

This section addresses the following types of roof systems: membrane, asphalt shingle, metal panel, tile, and vegetative. The information in this section is based primarily on Smith (2011). This section includes checking for roof covering punctures and tears in the immediate vicinity of rooftop equipment, and it includes checking rooftop equipment flashings. See Section 5.5 for information on the assessment of rooftop equipment.

57 The 120-mph basic wind speed is based on ASCE 7-16, Risk Category III and IV buildings.

5.4.1 Level 1 Assessment of Roof Systems

The following steps are recommended as part of a Level 1 assessment for membrane, asphalt shingle, metal panel, tile, and vegetative roofs. Additional Level 1 assessments that are specific to the type of roof system are discussed in Sections 5.4.1.1 through 5.4.1.5.

- **Leaking roof**. If the roof is leaking, refer to ASTM D7053-17, *Standard Guide for Determining and Evaluating Causes of Water Leakage of Low-Sloped Roofs* (ASTM 2017c) for determining and evaluating the cause of the leakage.

- **Wind uplift pressures and system resistance**. See Section 2.5.1 for information on conducting a Level 1 assessment. This should include a review of original design loads and system resistance in the historical file as well as a comparison of the historical information with design loads based on the current edition of ASCE 7.

  If the original system uplift resistance rating (e.g., FM 1-60) is not identified on the drawings, specifications, or submittals in the historical file, try to determine whether a roof membrane manufacturer's warranty was issued. If so, the warrantor may have this information. If not, find out which building code or standard would likely have been used to determine the original design uplift pressures, and then calculate the field, perimeter, and corner loads in accordance with that code or standard. Also, calculate the design loads based on the current edition of ASCE 7, and compare the original design loads with current loads.[58]

  If the original uplift resistance rating is identified, compare that rating with the rating that would be required based on current design loads. If the original rating is significantly less than what would be required currently, the existing system will need to be enhanced (if possible) or replaced, or the system will present a residual risk of failure.

  The resistance of the roof deck and deck support framing also should be determined and compared with current criteria as part of the structural vulnerability assessment (see Chapter 4).

  Also, if any edition later than the 2006 edition of *Loss Prevention Data Sheet 1-29: Roof Deck Securement and Above-Deck Roof Components* from FM Global (FM Global 2016) was used to adjust fastener or adhesive ribbon spacings at corners and the perimeter, be aware that prior to the 2006 revision of 1-29, a safety factor of 1.5 was used. In 2006, the safety factor in the corners and perimeter was increased to 2 so it would match the safety factor of 2 that had been used in the field of the roof.

  If the drawings, specifications, or submittals reference a test method, determine whether there have been any significant changes to the test method that would negatively affect the uplift test results. For example, if the existing roof system

58 For buildings in a hurricane-prone region, a 1.0 for the directionality factor for the roof system is recommended in FEMA P-424, 543, and 577.

is a mechanically attached single-ply system that was installed around 1990, and the submittals indicate that it had an FM 1-60 rating, then the system was tested on a 5-foot x 9-foot apparatus. However, in 1993, the test method was revised to require a 12-foot x 24-foot apparatus for most mechanically attached single-plies. The apparatus size was changed because it was determined that the smaller test frame typically overestimated the load capacity of the system.

In addition, determine whether the test method that was used originally is recommended currently. For example, metal roof systems can be tested in accordance with UL 580 or ASTM E1592-05(2017), *Standard Test Method for Structural Performance of Sheet Metal Roof and Siding Systems by Uniform Static Air Pressure Difference* (ASTM 2017f). ASTM E1592 generally is recommended because it gives a better representation of the system's uplift resistance.

Another example is asphalt shingles, which can be tested in accordance with ASTM D3161/D3161M-19, *Standard Test Method for Wind-Resistance of Asphalt Shingles (Fan-Induced Method)* (ASTM 2019b), or by a method referenced in ASTM D7158/D7158M-19, *Standard Test Method for Wind Resistance of Asphalt Shingles (Uplift Force/Uplift Resistance Method)* (ASTM 2019c). The method referenced in ASTM D7158 is the current state-of-the-practice and is believed to provide a better representation of shingle wind resistance.

- **Nailers.** Check the drawings and specifications to determine whether attachment criteria were given for nailers that occur below edge flashings and copings (see **Figure 5-111**). If so, determine whether the specified attachment is sufficient to resist current uplift loads, using a safety factor of 3 (as recommended in FEMA P-424, 543, and 577).[59] Field assessment of nailers is addressed in the Level 2 assessment (Section 5.4.2).

Figure 5-111:
The nailer at this medical office building had inadequate wind resistance. It lifted and caused progressive lifting and peeling of the roof membrane. The nailer was part of the original construction, but its attachment was apparently not checked when the building was reroofed. Hurricane Michael (Florida, 2018)

59 Although a safety factor of 2 typically is used for roof systems, a safety factor of 3 for critical facilities is recommended for edge flashings, copings, nailers, and curbs because of wind-loading uncertainties and the relative importance of these elements and consequences of their failure.

5.4.1.1 Membrane Roof Systems

This section addresses built-up, modified bitumen, and single-ply membrane roof systems.

General Field Assessment

The field assessment of a membrane roof system and associated flashings should address the general condition of the roof (i.e., remaining service life). For guidance on a general condition assessment, see RILEM TC 166-MRS (2003), which was prepared by a joint CIB/RILEM committee, and Smith (2001).

The recommended general field assessment includes the following:

- **Observe the roof for signs of distress and detachment**, such as tented fasteners (see **Figure 5-112**) and large blisters. Walk the entire perimeter of the roof. Make one trip if the width of the perimeter zone is less than 4 feet. If the perimeter width exceeds 4 feet, make trips at intervals not exceeding approximately 4 feet. In addition, walk the field of the roof at intervals not exceeding approximately 20 feet. Be sensitive with each footfall to changes in the softness of the substrate, which could indicate wet insulation or displaced materials. Also, be sensitive to an indication of a lack of attachment of adhered roof membrane and insulation boards. For the systems that are appropriate for testing with an electrical capacitance moisture meter, a reading is recommended approximately every 10 feet while walking the roof (see **Figure 5-113**).

SIGNS OF ROOF DISTRESS

If signs of distress are found, normally a test cut such as the one shown in the **Figure 5-112** inset is taken to evaluate the distress.

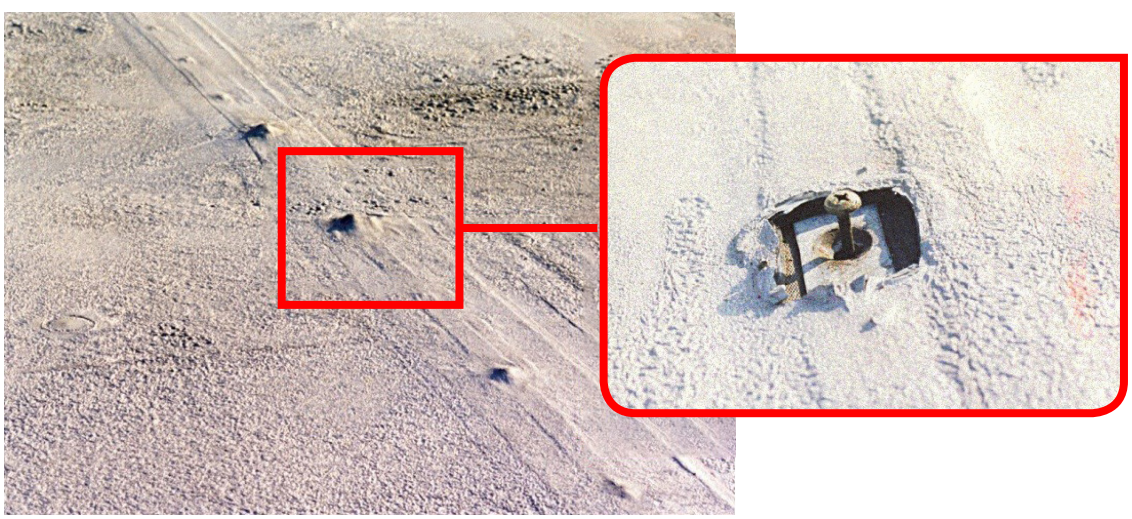


Figure 5-112: This mechanically attached single-ply membrane had several tented fasteners. A test cut revealed that the wood fiberboard below the membrane had compressed because it had gotten wet.

Figure 5-113:
Electrical capacitance moisture meter shows a high reading near a damaged cap sheet.

Field Assessment of Mechanically Attached Single-ply Membranes

The recommended field assessment of mechanically attached single-ply membrane includes the following:

- **Spot check fastener row spacing and spacing of fasteners along the rows**. This can be accomplished in a number of ways: (1) by using a magnetic or electronic stud finder, (2) by looking for dust or debris at fastener plate depressions, or (3) by feeling or lightly scrubbing the surface of the membrane over the fastener line. Spot checks are recommended at each corner,[60] at the perimeter, and in the field of the roof.
- **Spot check for fastener plate bending** by feeling the membrane at plate locations. Normally, it is sufficient to check plate bending at just the corner zones (as defined in ASCE 7). Where plate bending checks are made, also carefully observe the membrane in the vicinity of the plate and the nearby seam, looking for fatigue-induced holes, cracks, or tears.
- **If the deck is steel, check to see whether the fastener rows are perpendicular to the deck ribs**. If the rows are parallel to the ribs, the decking may be susceptible to blow-off (see FEMA P-424, 543, and 577).

Field Assessment of Edge Flashings and Copings

The recommended field assessment of edge flashings and copings includes the following:

- **For shop-fabricated units, determine whether the vertical flange is cleated**. (For copings, check both vertical flanges.) If the vertical flange is face-fastened, remove at least one fastener to determine the fastener type and size. Also, spot check

60 If the building has several roofs, it is usually not necessary to check all corners. Also, if the building is not in a hurricane-prone region, test the corner(s) of the prevailing wind direction plus the perimeter and field. If the prevailing direction is not known, test the northwest and southwest corners plus the perimeter and the field.

fastener spacing. If the flange is not adequately face-fastened or if it is not cleated, the edge flashing or coping is quite susceptible to blow-off.

- **Grab the bottom of the vertical flange with both hands and try to rotate the flange**.[61] On copings, try to rotate both the inner and outer flanges. Perform this rotation test at each side of each corner[62] and at a few locations along the perimeter. Experienced investigators can detect weak edge flashings and copings easily. However, an edge flashing or coping may be very resistant to rotation and be incorrectly interpreted as having adequate wind resistance. Unfortunately, a field test method (other than hand manipulation) that can be used for a more definitive evaluation of resistance does not exist currently.
- **For pre-engineered edge flashings and copings, check submittal data for wind resistance information**. (A safety factor of 3 is recommended for edge flashings and copings in FEMA P-424, 543, and 577).[63] To the extent possible, determine whether the units were installed in accordance with the submittal data. In addition, perform the above rotation tests.
- **For shop-fabricated and pre-engineered edge flashings, determine whether the horizontal flange was placed over the membrane and then stripped in**, rather than placed under the membrane. When the horizontal flange is under the membrane, it is unable to clamp the edge of the membrane, thereby making the membrane susceptible to lifting and peeling.

Field Assessment of Gutters

The recommended field assessment of gutters includes the following:

- **Visually check the gutter** to see whether there is a mechanical connection or interlock between the gutter and gutter bracket (see **Figure 5-114**). If the gutter is not connected or is inadequately connected to the brackets, the gutter is susceptible to blow-off.
- **Perform the rotation tests as described above.** For some tests, place a hand on either side of a bracket. For other tests, place both hands midway between two brackets. Unfortunately, a field test method (other than hand manipulation) that can be used for a more definitive evaluation of resistance does not exist currently.
- **Evaluate the gutter load path.** The uplift and rotational wind load exerted on the gutter will be transferred to the wall, nailers, or deck, depending on the bracket design and attachment. A safety factor of 3 is recommended for gutters.

61 Appropriate safety precautions should be taken when performing rotation tests.

62 If the building has several roofs, it is usually not necessary to check all corners. Also, if the building is not in a hurricane-prone region, test the corner(s) of the prevailing wind direction plus the perimeter and field. If the prevailing direction is not known, test the northwest and southwest corners plus the perimeter and the field.

63 Although a safety factor of 2 is typically used for roof systems, a safety factor of 3 for critical facilities is recommended for edge flashings, copings, nailers, and curbs because of wind-loading uncertainties and the relative importance of these elements and consequences of their failure.

Figure 5-114:
This gutter was screwed to each bracket.
Hurricane Ike (Texas, 2008) (FEMA P-757)

Field Assessment of Parapet Base Flashings

The recommended field assessment of parapet base flashing includes the following:

- **For fully adhered base flashings, visually check for detachment**.
  - **Check for detachment by spot-slapping** with the palm of the hand. Slap at intervals not exceeding approximately 3 feet along the parapet. Check each corner zone,[64] and check a few locations along the perimeter.

    If the parapet is between 2 feet high and 4 feet high, slap near the upper and lower thirds of the parapet. If the parapet is taller than 4 feet, slap at 3 or more vertical locations, depending on parapet height.
- **For mechanically attached base flashings, spot check fastener locations** using one of the techniques described above for locating mechanically attached single-ply membrane fasteners. Perform spot checks at each corner[65] and at a few locations along the perimeter.

  If the base flashing is mechanically attached, but the membrane is fully adhered at the roof, ballooning of the base flashing has high potential to cause lifting and peeling of the roof membrane (as shown in **Figure 1-4**).
- **Base flashing substrate attachment and integrity**: Base flashings are often attached to wood sheathing or gypsum board that is attached to studs. Detachment of the sheathing can result in progressive lifting and peeling of the roof membrane (**Figure 5-115**). A Level 2 assessment is typically needed to evaluate attachment.

64 If the building has several roofs, it is usually not necessary to check all corners. Also, if the building is not in a hurricane-prone region, test the corner(s) of the prevailing wind direction plus the perimeter and field. If the prevailing direction is not known, test the northwest and southwest corners plus the perimeter and the field.

65 If the building has several roofs, it is usually not necessary to check all corners. Also, if the building is not in a hurricane-prone region, it is usually sufficient to check the northwest and southwest corners plus the perimeter and field.

Spot-slapping the base flashing may detect gypsum board deterioration caused by water leakage.

Figure 5-115:
The base flashing at this medical office building remained adhered to the sheathing, but the sheathing detached from the metal studs. In this case, the roof membrane did not lift and peel. Hurricane Michael (Florida, 2018)

- **Determine whether the base flashing is applied directly to brick**. If so, the base flashing is likely inadequately attached as a result of the surface irregularity (i.e., lack of planar flatness) that often is associated with the roof-side of brick parapets.

Field Assessment of Ballasted Single-plies

The recommended field assessment of ballasted single-ply membranes includes the following:

- If the building is not in a hurricane-prone region and has a single-ply membrane ballasted with aggregate, pavers, or cementitious-coated insulation boards, determine whether the system (including parapet height) complies with ANSI/SPRI RP-4 2013, *Wind Design Standard for Ballasted Single-ply Roofing Systems* (ANSI/SPRI 2013) (see **Figure 5-116**).

Figure 5-116:
The ballasted single-ply aggregate on this hospital roof does not meet the gradation requirements in ANSI/SPRI RP-4. The under-sized aggregates are more susceptible to blow-off. Hurricane Katrina (Mississippi, 2005) (FEMA 549)

- If a building in a hurricane-prone region has aggregate surfacing, lightweight pavers (i.e., less than 22 psf), or cementitious-coated insulation boards, FEMA P-424, 543, and 577 recommend replacing the roof system. If the roof is ballasted with pavers weighing 22 psf or greater, calculate the uplift loads and resistance in accordance with the procedure given in Appendix A of Mooneghi et. al., 2017.

Wind-borne Debris Resistance

The recommended field assessment of wind-borne debris resistance includes the following:

- If the building is located in a hurricane-prone region, determine whether the roof system includes a secondary membrane that will avoid water leakage into the building if the roof membrane is punctured by wind-borne debris. If as-built drawings or submittals are not available, a test cut to determine the roof system composition is recommended. If the roof is sprayed polyurethane foam and the thickness is in accordance with the recommendations in FEMA P-424, 543, and 577, or if the roof is surfaced with concrete pavers that weigh a minimum of 22 psf, the foam itself or the pavers should provide adequate protection.

Field Assessment of Drainage

The recommended field assessment of drainage includes the following:

- If the building is located in a hurricane-prone region and the building has primary through-wall scuppers or roof drains, evaluate the potential for the scuppers or drains to become blocked by leaves, tree limbs, and other wind-borne debris. See FEMA P-424 and Sections 8.2, Roof Drainage, and 8.3, Design Rain Loads, in ASCE 7.

- Verify that secondary drainage is provided for all roof areas that have parapets or edge flashings on raised curbs.

5.4.1.2 Asphalt Shingles

See Section 5.4.1 for a discussion of wind-resistance testing of shingles. If the historical file indicates a class rating (Class D, G, or H) per the test method referenced in ASTM D7158, compare the rating with the basic wind speed in the current edition of ASCE 7.[66] However, the reliability of the wind ratings is uncertain. Field[67] and laboratory[68] investigations have documented failure of H-rated shingles at wind speeds well below the listed rating. If the building is situated in Exposure D, is more than 60 feet tall, or is sited on an abrupt change in topography (such as an isolated hill, ridge, or escarpment), consult the shingle manufacturer.[69]

66 Shingles that have been evaluated in accordance with ASTM D7158 have a Class D (115 mph), G (150 mph), or H (190 mph) ultimate wind speed rating, based on Exposure C and a 60-foot mean roof height.

67 FEMA P-757 (FEMA 2009b)

68 SERRI Report 02-90100 (Oak Ridge National Laboratory 2013)

69 For definitions of Exposure D and abrupt change in topography, refer to ASCE 7.

The recommended field assessment of asphalt shingle systems includes the following:

- **Unsealed tabs**. If shingles are unsealed or partially sealed, they are vulnerable to wind damage. Spot checks for unsealed tabs are recommended at each corner zone[70] and at a few locations in the perimeter and ridge zones (as defined in ASCE 7) (**Figure 5-117**).

  It is recommended to use the protocol developed by the University of Florida for investigating existing shingle roofs for unsealed tabs.[71] The protocol is intended for research purposes, wherein all shingles on a roof would be investigated. However, when performing a vulnerability assessment, spot-checking normally is performed.

- **Starter course**. Investigations of damaged roofs have frequently found that the starter course was incorrectly installed, which resulted in the row of tabs along the eave being unsealed (FEMA 489, 549, P-757). Spot checks are, therefore, recommended to determine if the tabs along the eave are sealed.

Figure 5-117:
View of an unsealed tab on a school roof

- **Eaves and rakes**. If the vertical flange of the metal drip edge along the eave or rake exceeds 2 inches, additional wind load is imparted on the flange, thereby making longer (higher) flanges more susceptible to failure, as shown in **Figure 5-118**. If the vertical flange exceeds 2 inches, try to rotate the flange as described in Section 5.4.1.1 for edge flashings and copings.

70 If the building has several roofs, it is usually not necessary to check all corners. Also, if the building is not in a hurricane-prone region, it is usually sufficient to check the northwest and southwest corners plus the perimeter and field.

71 See Experimental Research Plan #6 from SERRI Report 02-90100 (Oak Ridge National Laboratory 2013).

Figure 5-118:
The metal drip edge at this school was not cleated or face-fastened. The vertical flange rotated and caused a progressive failure of the shingles. Hurricane Charley (Florida, 2004) (FEMA 488)

- **Underlayment**. Investigations of damaged roofs frequently have found that when shingles are blown off, the underlayment also is blown off (**Figure 5-119**) unless special attention is given to the design and installation of the underlayment (FEMA 489, 549, P-757). With loss of the underlayment, the building typically is susceptible to significant water infiltration. It is recommended that the assessor assume that the underlayment is susceptible to blow-off unless it is determined by destructive observation that the underlayment complies with the guidance given in FEMA P-55.

Figure 5-119:
Asphalt shingle and underlayment blow-off resulted in significant water infiltration at this school. The school was being used to shelter people at the time of the blow-off. Hurricane Ivan (Florida, 2004)

- **Wind-borne debris**: If the building is located in a hurricane-prone region where the basic wind speed is greater than 135 mph,[72] recommended assumptions are that debris may penetrate the shingles and underlayment and that leakage may occur.

72 The 135-mph basic wind speed is based on ASCE 7-16, Risk Category III and IV buildings.

5.4.1.3 Metal Panels

See Section 5.4.1 for discussion of wind-resistance testing of metal panel systems. If the historical file indicates that the system was tested in accordance with UL 580 rather than ASTM E1592, the panels may be susceptible to unlatching from concealed clips or the seams may be susceptible to opening up as shown in **Figure 5-120**.

For information regarding uplift resistance of through-fastened (i.e., exposed fastener) systems and laboratory testing of architectural panel systems, see FEMA P-499, Fact Sheet 7.6.

Figure 5-120:
View of a few seams that opened up. In the opened condition, the panels were very susceptible to progressive failure, and they were no longer watertight. At other locations on this building, several panels were blown off. Hurricane Michael (Florida, 2018)

- **Panels with exposed fasteners.** Determine whether the panel fasteners are screws or nails. If the fasteners are nails, they are susceptible to pull-out caused by dynamic loading of the panels. Spot check the fastener spacing in the corner,[73] perimeter, and field zones (as defined in ASCE 7), and determine whether the attachment is sufficient to resist current uplift loads.[74] See **Figure 5-121** for an example of metal panel roof performance that varied based on number and location of fasteners.

Figure 5-121: Metal roof panels at this school performed differently in two locations shown. In left photo, two rows of fasteners near the end of the panels (blue dashed arrows) performed better than the panels in photo on right, with only one row of fasteners that were several inches from the end (solid red arrow). (Puerto Rico, 2017) (FEMA P-2020)

73 If the building has several roofs, it is usually not necessary to check all corners. Also, if the building is not in a hurricane-prone region, test the corner(s) of the prevailing wind direction plus the perimeter and field. If the prevailing direction is not known, test the northwest and southwest corners plus the perimeter and the field.

74 Make a conservative estimate of fastener size and embedment, or remove a few fasteners to determine size and embedment. If fasteners are removed, replace them with new properly sized fasteners. Clean the panel prior to installing the new screws so that the gaskets properly seal.

- **Panels with snap-on battens (seam caps).** Spot check batten attachment as recommended in Section 5.3.4.1.
- **Panels with concealed fasteners.** If accessible, look on the underside of the roof to see whether the clip fasteners are visible. If they are, spot check the fastener spacing in the corner, perimeter, and field zones and determine whether the attachment is sufficient to resist current uplift loads.
- **Flashings at eaves and rakes.** Try to rotate the flange as described in Section 5.4.1.1 for edge flashings and copings. **Figure 5-122** shows a weak rake flashing that would likely have been detected by an experienced investigator if the roof was evaluated before the storm.

Figure 5-122:
Rake flashing failure. Failures such as this often result in progressive lifting and peeling of the panels. Hurricane Ivan (Florida, 2004)

- **Flashings at hips and ridges.** For flashings attached with exposed fasteners, spot check fastener spacings. Spacing should be commensurate with the design wind load, ranging from 12 inches to 3 inches on center. **Figure 5-123** and **Figure 5-124** show well-attached and inadequately attached ridge flashings, respectively.

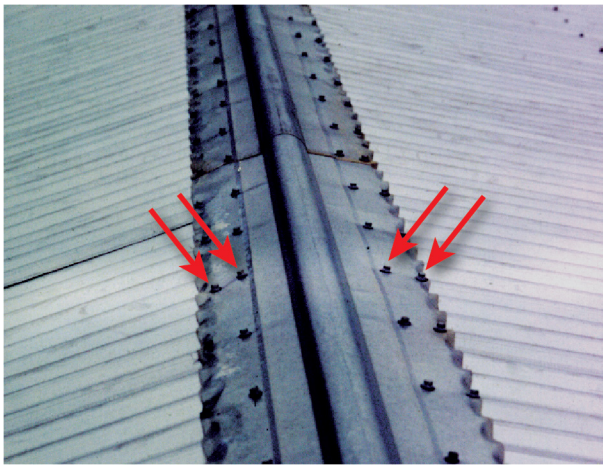


Figure 5-123:
Well-attached ridge flashing on corrugated metal panels with two rows of closely spaced fasteners on each side of the ridge line. Hurricane Marilyn (U.S. Virgin Islands, 1995) (FEMA P-499, Fact Sheet 7.6)

Figure 5-124:
Inadequately attached ridge flashing with fasteners placed too far apart and underlayment that does not wrap over the ridge. A significant amount of water leakage can occur when ridge flashings are blown away. Hurricane Charley (Florida, 2004) (FEMA P-499, Fact Sheet 7.6)

- **Wind-borne debris:** If the building is located in a hurricane-prone region where the basic wind speed is greater than 135 mph,[75] determine whether the roof system includes a secondary membrane that will avoid water leakage into the building if the metal roof panels are punctured by wind-borne debris (see FEMA P-424, 543, and 577 secondary membrane recommendations).

5.4.1.4 Tile

If the historical file contains tile attachment criteria, compare the criteria with the attachment recommendations given in the following publications:

- For buildings located where the current ASCE 7 basic wind speed is 120 mph or greater: *Florida High Wind Concrete and Clay Roof Tile Installation Manual, Fifth Edition* (Florida Roofing, Sheet Metal and Air Conditioning Contractors Association, Inc. and the Tile Roofing Institute, 2012).
- For buildings located where the current ASCE 7 basic wind speed is less than 120 mph: *Concrete and Clay Roof Tile Installation Manual* (Tile Roofing Institute and Western States Roofing Contractors Association, 2015).

The recommended field assessment of tile systems includes the following:

- **Mortar-set or foam-adhesive (adhesive-set) tiles.** It is recommended that spot checks for unbonded tiles be made in the field of the roof and at each corner zone[76] and at a few locations in the perimeter and ridge zones (as defined in ASCE 7). Also, spot check attachment of hip and ridge tiles, and cut field tiles adjacent to hips and valleys. Check by gently lifting on the tile. For cut tiles, also wiggle the cut tile while pulling it downslope.

75 The 135-mph basic wind speed is based on ASCE 7-16, Risk Category III and IV buildings.

76 If the building has several roofs, it is usually not necessary to check all corners. Also, if the building is not in a hurricane-prone region, test the corner(s) of the prevailing wind direction plus the perimeter and field. If the prevailing direction is not known, test the northwest and southwest corners plus the perimeter and the field.

Note: Damage investigations have revealed that mortar-set systems often provide limited wind resistance (FEMA P-55). If the building is in a hurricane-prone region, a recommended assumption is that the mortar-set tiles are susceptible to blow-off.

- **Tile to batten and direct deck systems.** It is recommended that spot checks for tile fasteners be made at each corner zone[77] and at a few locations in the perimeter and ridge zones (as defined in ASCE 7). Also, spot check attachment of hip and ridge tiles, and cut field tiles adjacent to hips and valleys. Check by gently lifting on the tile. For cut tiles, also wiggle the cut tile while pulling it downslope. For direct deck systems, also spot check for tile fasteners in the field of the roof.
- **Broken or slipped tile.** Check for broken or slipped tiles (**Figure 5-125** and **Figure 5-126**).

Figure 5-125:
View of a broken tile. Broken fragments can become wind-borne debris that breaks other tiles. Hurricane Ivan (Florida, 2004)

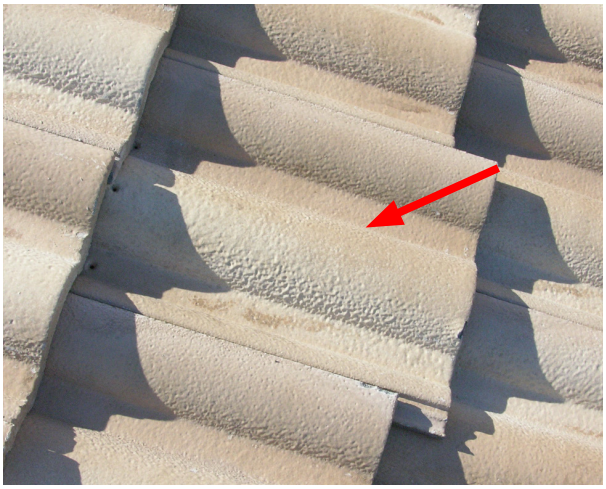


Figure 5-126:
Roof with mechanically attached tiles, but because the tile shown by the solid red arrow had not been fastened, it slipped. Loose tiles such as this one are susceptible to blow-off. Hurricane Charley (Florida, 2004)

77 If the building has several roofs, it is usually not necessary to check all corners. Also, if the building is not in a hurricane-prone region, test the corner(s) of the prevailing wind direction plus the perimeter and field. If the prevailing direction is not known, test the northwest and southwest corners plus the perimeter and the field.

- **Wind-borne debris.** Because tile is brittle, it is often damaged by wind-borne debris. If the building is in a hurricane-prone region where the basic wind speed is greater than 135 mph,[78] the recommended assumptions are that the tiles may be broken by debris (**Figure 5-127**), debris may penetrate underlayment, and leakage may occur.

Figure 5-127:
Tiles on this school were broken by wind-borne debris. Hurricane Francis (Florida, 2004)

5.4.1.5 Vegetative Roofs

If the vegetative roof has aggregate or paver ballasted areas, see the ballasted single-ply recommendations in Section 5.4.1.1.

If the building is located in a hurricane-prone region where the basic wind speed is greater than 135 mph,[79] check to see if trees or shrubs occur more than 30 feet above grade. If so, limbs may become damaging wind-borne debris.

LIMITED DOCUMENTATION ON VEGETATIVE ROOFS

Because vegetative roofs are not widespread in the United States (particularly in hurricane-prone regions), there is limited documentation of the wind performance of this type of roof system.

5.4.2 Level 2 Assessment of Roof Systems

If the Level 1 assessment reveals that the roof system has several more years of useful service life, a Level 2 assessment is recommended for buildings in areas where the current basic wind speed is greater than 120 mph.[80] The following steps are recommended as part of the Level 2 assessment:

78 The 135-mph basic wind speed is based on ASCE 7-16, Risk Category III and IV buildings.
79 The 135-mph basic wind speed is based on ASCE 7-16, Risk Category III and IV buildings.
80 The 120-mph basic wind speed is based on ASCE 7-16, Risk Category III and IV buildings.

- For systems that have insulation below the roof covering, perform an NDE to check for moisture. In some instances, it is prudent to perform the NDE as part of the Level 1 assessment. For more information about NDE, see Smith (2001). In addition to the NDE methods discussed in Smith (2001), electronic vector mapping also is available.

- Conduct field uplift resistance testing in accordance with ASTM E907-96, *Standard Test Method for Field Testing Uplift Resistance of Adhered Membrane Roof Systems* (ASTM 2004b) for built-up, modified bitumen,[81] and fully adhered single-ply membrane roof systems (see **Figure 5-128**). Recommended assessment consists of testing at each corner[82] zone and perimeter location as well as conducting at least one test in the field of the roof. This test method cannot be used to evaluate the uplift resistance of the roof deck.

Figure 5-128:
Field uplift test apparatus

- Perform test cuts at leakage areas if the building has a history of roof leakage. Take 2-foot x 2-foot minimum test cuts down to the deck in the leakage area(s) to assess deck integrity and attachment (see **Figure 5-129**). The number of cuts depends on several factors, including deck type, leakage history, and extent of wet insulation.

81 ASTM E907 is not suitable for a modified bitumen system mechanically attached just at the seams.

82 If the building has several roofs, it is usually not necessary to check all corners. Also, if the building is not in a hurricane-prone region, test the corner(s) of the prevailing wind direction plus the perimeter and field. If the prevailing direction is not known, test the northwest and southwest corners plus the perimeter and the field.

Figure 5-129:
A 2-foot x 2-foot test cut on a school roof; superficial steel deck corrosion (solid red arrows) and deck welds (yellow dotted arrows)

- Where possible, evaluate the underside of the deck in the leakage area(s).
- If the roof system is warranted, notify the warrantor before taking the cuts, and have the repair performed by a roofing contractor that the warrantor has authorized.
- **Table 4-3** references this section for guidance on taking roof cuts to evaluate deck integrity and connections. Except for concrete decks, take a test cut that is approximately 8 inches wide by 6 feet long, down to the deck. Recommended testing consists of testing at each corner[83] zone and perimeter location as well as conducting at least one test in the field of the roof. If the deck is attached with screws or nails, remove at least one fastener at each test cut location to determine fastener type and size. See the note above regarding warrantor notification and repair. Compare the installed fasteners with the type and size of fasteners used in an assembly capable of meeting the design load based on the current edition of ASCE 7.

  Test cuts can be easily taken at membrane roof systems, as well as asphalt shingles and tiles. However, removing metal panels is relatively expensive, particularly for concealed fastener systems. Such an investigation would normally require the services of a professional roofing contractor to assist in panel removal and replacement. An alternative to removing panels is to observe the underside of the deck if access is available. However, underside observation is insufficient to assess weld quality.

  Figure 5-130 shows steel deck blow-off. Metal panels with concealed fasteners were installed over the deck. Based on observations, it appeared the lack of several contiguous deck fasteners in one or more localized areas caused the deck

83 If the building has several roofs, it is usually not necessary to check all corners. Also, if the building is not in a hurricane-prone region, test the corner(s) of the prevailing wind direction plus the perimeter and field. If the prevailing direction is not known, test the northwest and southwest corners plus the perimeter and the field.

blow-off. Discovering the deck vulnerability at this building would have been very expensive. Because of the expense, such an investigation would normally be limited to particularly important critical facilities.

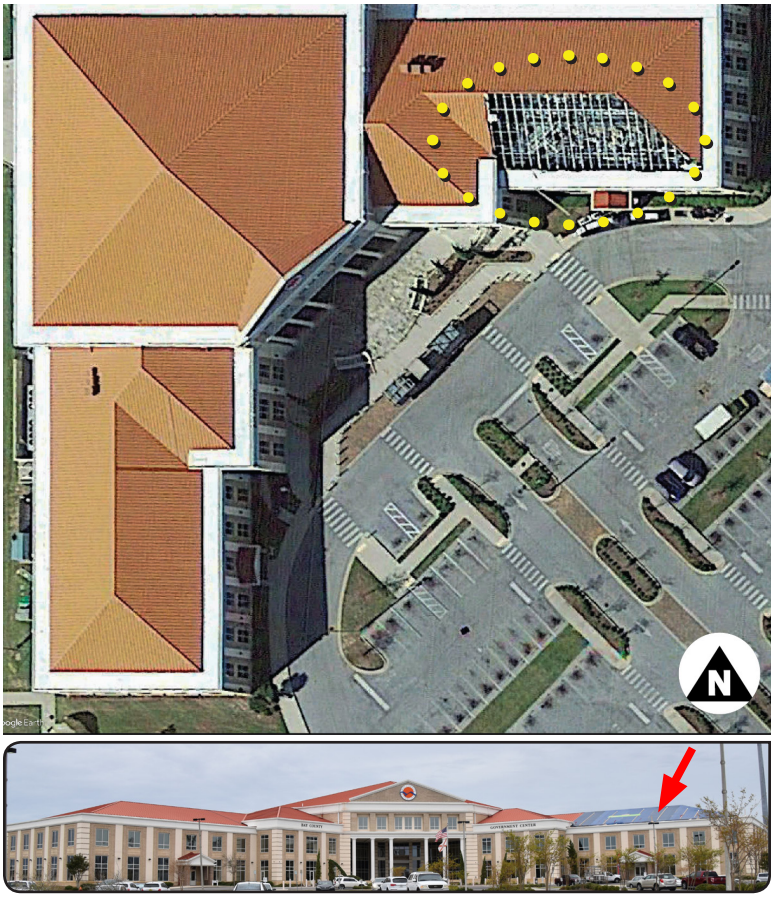


Figure 5-130:
The metal roof panels and steel roof deck blew off at the area indicated by the yellow dotted oval. An emergency roof covering (solid red arrow) had been installed prior to shooting the inset photograph. Hurricane Michael (Florida, 2018)

- Perform destructive observations of the base flashing to evaluate sheathing substrate attachment and integrity. Take test cuts through the base flashing at sheathing joints. It is recommended that a test cut be taken at each corner[84] zone and at a few locations along the perimeter. Remove at least one fastener at each test cut location to determine fastener type and size. See the note above regarding warrantor notification and repair. Compare the installed fasteners with the type and size of fasteners used in an assembly capable of meeting the design load based on the current edition of ASCE 7.

- Perform destructive observations of nailers to verify or determine the attachment of nailers that occur below edge flashings or copings. Remove lengths of edge flashing or coping (which typically are 8 feet or 10 feet long) and membrane material so the nailer fasteners can be observed. Remove at least two fasteners

84 If the building has several roofs, it is usually not necessary to check all corners. Also, if the building is not in a hurricane-prone region, test the corner(s) of the prevailing wind direction plus the perimeter and field. If the prevailing direction is not known, test the northwest and southwest corners plus the perimeter and the field.

per length of edge flashing or coping to determine fastener type and length (embedment). It is recommended that one length of edge flashing or coping be removed at each corner[85] zone and at a few locations along the perimeter. See the note above regarding warrantor notification and repair.

- Asphalt shingles. To evaluate the wind uplift resistance of existing asphalt shingle roofs, the University of Florida designed and constructed a custom portable mechanical uplift apparatus capable of performing sealant bond strength testing in accordance with the laboratory test method that is referenced in ASTM D7158 (**Figure 5-131**).[86] Because of the critical importance of sealant bond strength, field testing could be used to determine the bond strength of existing shingles. However, because this is a destructive test and because of the cost of conducting field uplift testing of shingles, use of this type of apparatus generally is more applicable to research projects rather than to vulnerability assessments.

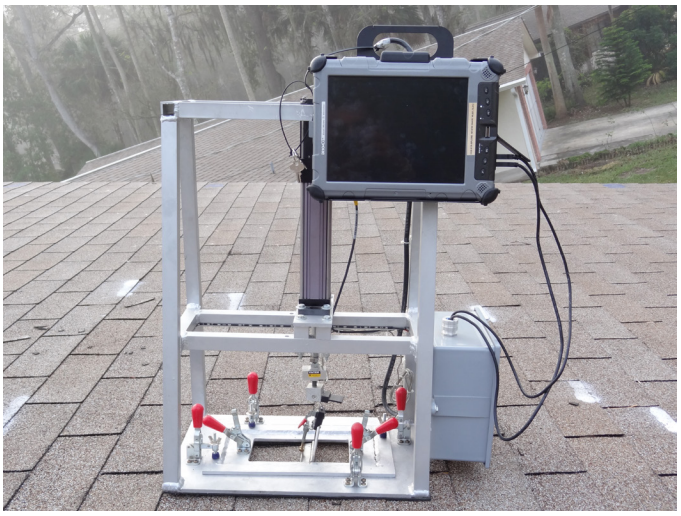


Figure 5-131:
Portable mechanical uplift apparatus (Photo courtesy of Engineering School of Sustainable Infrastructure & Environment, University of Florida)

- Metal panels. A field uplift test method does not exist currently for metal roof panel systems. If reliable information regarding the wind resistance of the system is not found in the historical file, the recommended assumption is that the system is vulnerable to wind damage or that destructive observations should be conducted, as recommended in Section 5.3.4.2. Such an investigation normally would require the services of a professional roofing contractor to assist in panel removal and replacement. Because of the expense, this investigation normally would be limited to particularly important critical facilities. As part of this type of investigation, check for fastener type and size, and for fastener and clip corrosion (**Figure 5-132**).

85 If the building has several roofs, it is usually not necessary to check all corners. Also, if the building is not in a hurricane-prone region, test the corner(s) of the prevailing wind direction plus the perimeter and field. If the prevailing direction is not known, test the northwest and southwest corners plus the perimeter and the field.

86 For further information on the field test apparatus, see SERRI Report 02-90100 (Oak Ridge National Laboratory 2013).

Figure 5-132:
Panel and clip corrosion. Note that the clip was attached with a nail, which is susceptible to pull-out. Also, this clip was designed for two fasteners, but only one fastener was installed. Hurricane Marilyn (USVI, 1995)

- Tile. It is recommended that field uplift testing be conducted in accordance with the procedure in the FBC TAS No. 106, *Standard Procedure for Field Verification of the Bonding of Mortar or Adhesive Set Tile Systems and Mechanically Attached, Rigid, Discontinuous Roof Systems* (FBC 2017b), to determine whether the tiles comply with the attachment recommendations given in the applicable publications listed in Section 5.4.1.4. It is recommended that uplift tests be made at each corner zone[87] and at a few locations in the perimeter and ridge zones (as defined in ASCE 7).

  FBC TAS No. 106 states that 75 percent of the uplift tests are required to pass the testing. However, any tile that fails the test represents a vulnerability.

  In addition to field uplift testing, destructive observation (**Figure 5-133**) could be made. Such an investigation normally would require the services of a professional roofing contractor to assist in tile removal and replacement. Because of the expense, this investigation normally would be limited to particularly important critical facilities. As part of this type of investigation, check for fastener and clip corrosion.

Figure 5-133:
View along the eave after removal of several tiles. The solid red arrow shows a clip that was attached with a nail (which is susceptible to pull-out caused by dynamic loading of the tile).

87 If the building has several roofs, it usually is not necessary to check all corners. Also, if the building is not in a hurricane-prone region, test the corner(s) of the prevailing wind direction plus the perimeter and field. If the prevailing direction is not known, test the northwest and southwest corners plus the perimeter and the field.

5.5 Exterior-Mounted Equipment

This section addresses exterior-mounted equipment, including roof- and ground-mounted mechanical equipment and equipment screens, communications towers and light fixture poles, satellite dishes, lightning protection systems, and solar arrays. See Section 5.4 for details about checking for roof covering punctures, tears, and abrasions in the immediate vicinity of rooftop equipment, and for checking rooftop equipment flashings.

5.5.1 Level 1 Assessment of Exterior-Mounted Equipment

The recommended Level 1 assessments for exterior-mounted equipment are described in the following subsections.

See Section 2.5.1 for information on conducting a Level 1 assessment. This should include a review of original design loads and system resistance in the historical file as well as a comparison of the historical information with design loads based on the current edition of ASCE 7.

Wind-borne debris: If the building is in a hurricane-prone region, where the basic wind speed is greater than 135 mph,[88] the recommended assumption is that exposed equipment may be damaged by debris.

Corrosion: For all exterior-mounted equipment, check for corrosion of the equipment, attachment of equipment to the curb or stand, and the stand itself.

5.5.1.1 Mechanical Equipment, Equipment Screens, and Louvers

The components of mechanical equipment that are recommended for assessment are equipment curbs and stands; fans, HVAC units,[89] relief air hoods, and condensers; fan cowlings; exposed ductwork and flexible connectors between ducts and fans; vibration isolators; boiler and exhaust stacks; equipment access panels and doors; sheet metal hoods and enclosures (cabinets) on HVAC units; natural gas, electrical conduits, and condensate drain lines; equipment screens; louvers; and cooling towers.

- **Equipment curbs and stands.** Check the drawings and specifications to determine whether criteria for attachment of rooftop equipment curbs and stands to the roof deck/structure were provided. If so, determine whether the specified attachment is sufficient to resist current uplift and over-turning loads for curbs and stands, using a safety factor of 3 (as recommended in FEMA P-424, 543, and 577).[90] See Section 5.5.2 for field assessment of curb and stand attachment to the roof deck/structure.

88 The 135-mph basic wind speed is based on ASCE 7-16, Risk Category III and IV buildings.

89 HVAC units are also known as rooftop units (RTU).

90 Although a safety factor of 2 is typically used for roof systems, for critical facilities a safety factor of 3 is recommended for edge flashings, copings, nailers and curbs because of wind loading uncertainties and the relative importance of these elements and consequences of their failure.

- **Fans, HVAC units, relief air hoods, and condensers.** FEMA P-424, 543, and 577 provide attachment guidance. Check the attachment of the equipment to the curb or stand (see **Figure 5-134** to **Figure 5-139**).

  Do not assume that the dead load of the equipment is sufficient to resist the wind load (**Figure 5-134**). Calculate wind uplift and over-turning load and resistance to determine whether the dead load plus resistance provided by attachment of the equipment to the curb or stand is sufficient to resist the current wind load.

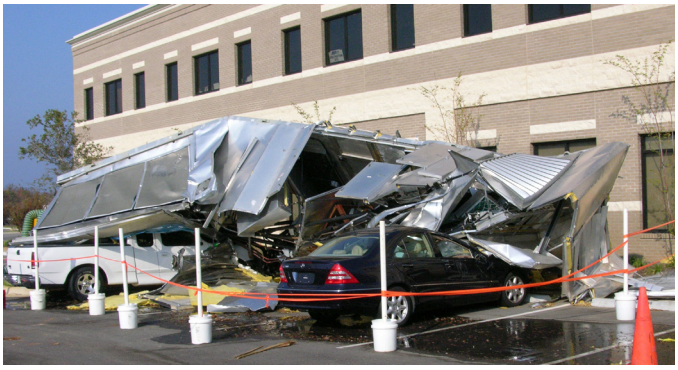


Figure 5-134:
Although this 18,000-pound HVAC unit was attached to its curb with 16 straps, it blew off the building during Hurricane Ivan. (Florida, 2004) (FEMA P-424).

Figure 5-135:
Condensers displaced from their stands on the roof of a health center. Hurricanes Irma and Maria (Puerto Rico, 2017) (FEMA P-2020)

Figure 5-136: HVAC units were anchored to the structure, but the attachment was inadequate. At left, the chain between the unit and anchor post was not taut. At right, the anchor posts were ¾-inch diameter eye bolts. Pushing at the top of the bolt moved it toward the unit. Although both units were anchored, they could lift and shift off the curb during high winds.

Figure 5-137:
Condenser at a 911 call center that was connected to 4-inch x 4-inch sleepers, but the sleepers simply rested on the roof membrane. The dead load of the condenser was inadequate to resist the design wind load. Hurricane Francis (Florida, 2004)

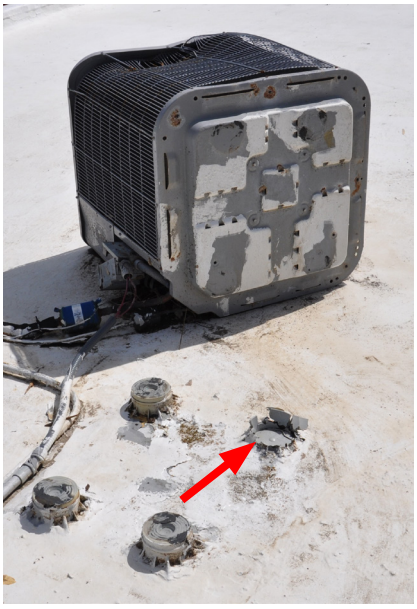


Figure 5-138:
This condenser was blown off the plastic pedestals to which it was attached with adhesive. One of the pedestals was broken (solid red arrow). U.S. Virgin Islands Recovery Advisory 2 (USVI RA2) recommends that condensers be anchored to metal stands or curb made of concrete, sheet metal, or wood, and that mechanical fasteners be used to attach the condensers rather than adhesive. Hurricane Irma (U.S. Virgin Islands, 2017)

For a qualitative evaluation, push and/or lift up on equipment. Experienced investigators may be able to detect a weak attachment or no attachment (see **Figure 5-139**). However, equipment may be very resistant to movement and incorrectly interpreted as having adequate wind resistance.

Figure 5-139:
This fan had very little over-turning resistance.

- **Fan cowlings.** In areas where the current basic wind speed is greater than 120 mph,[91] determine whether the manufacturer engineered the cowling attachment to resist the current design wind load or whether the cowling has adequate strap or cable tie-downs (see **Figure 5-140** and **Figure 5-141)**

Figure 5-140:
At this hospital, a fan cowling blew away, exposing the floors below to water infiltration and rainfall. Fan cowlings that blow off can cut roof membranes and cause other damage or injuries. Hurricanes Irma and Maria (Puerto Rico, 2017) (FEMA P-2020)

91 The 120-mph basic wind speed is based on ASCE 7-16, Risk Category III and IV buildings.

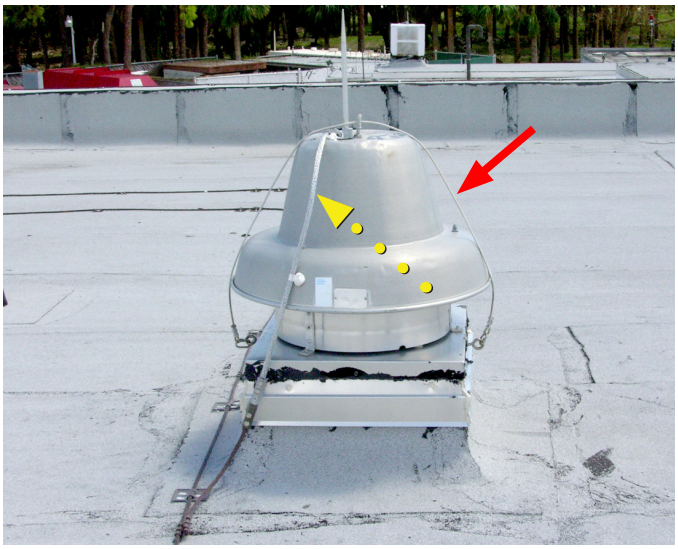


Figure 5-141:
Cable (solid red arrow) that was anchored to the curb and the cowling at this hospital. The yellow dotted arrow indicates a lightning protection system conductor. Hurricane Frances (Florida, 2004)

- **Exposed ductwork.** Evaluate the wind resistance of the ducts, and check to determine whether the ductwork is mechanically attached to supports that are anchored to the roof deck (see **Figure 5-142**).

  As a qualitative evaluation, push and/or lift up on the ductwork. Experienced investigators may be able to detect a weak attachment or no attachment. However, ductwork may be very resistant to movement and incorrectly interpreted as having adequate wind resistance.

Figure 5-142:
Duct supports that were anchored to the roof deck, but the ducts were not attached to the supports. A substantial amount of rain entered the building where the ducts penetrated the roof (solid red arrows). Hurricane Katrina (Mississippi, 2005) (FEMA 549)

- **Flexible connectors between ducts and fans.** Check the connectors for cracks or tears, which can allow water infiltration (see **Figure 5-143**). If the building is in a hurricane-prone region, the flexible connectors may be susceptible to wind-borne debris damage (see FEMA P-424 for guidance).

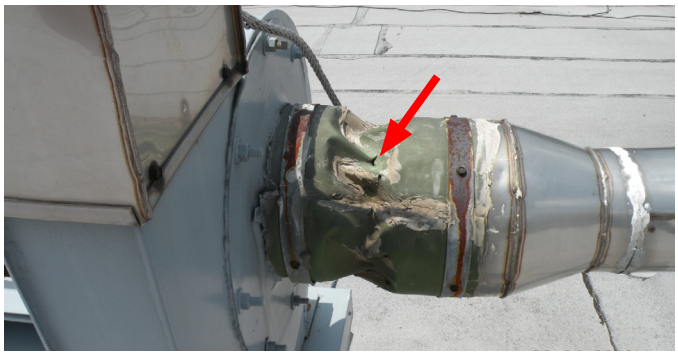


Figure 5-143:
The flexible connectors at a hospital that tore.

- **Vibration isolators.** If vibration isolators are used to support equipment, determine whether the isolators provide uplift resistance (**Figure 5-144**), or whether cables or straps are present to provide wind resistance. If the fans are small enough, it is possible to determine whether the vibration isolator provides uplift resistance by pushing and/or lifting up on the equipment.

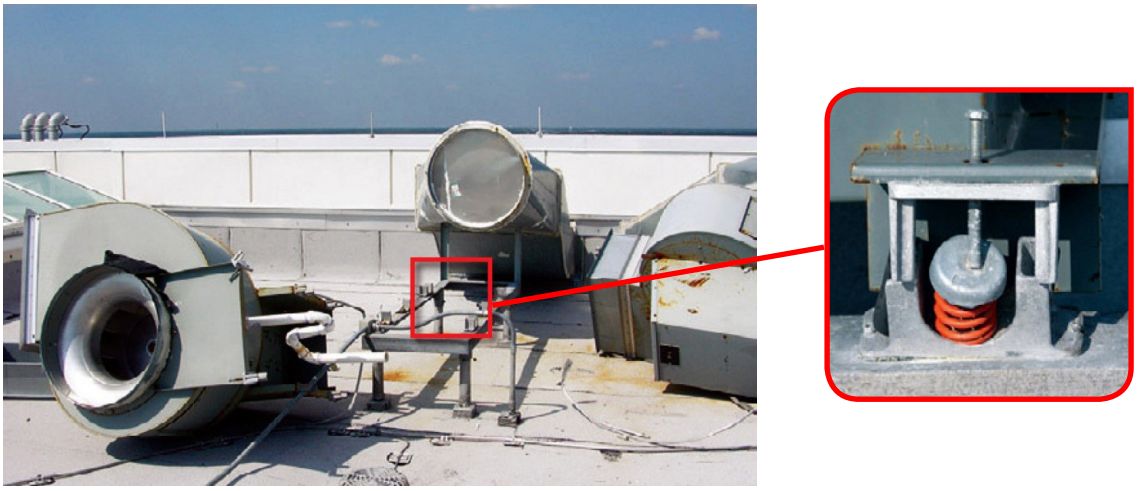


Figure 5-144: Failure of vibration isolators that provided lateral resistance, but no uplift resistance caused equipment damage. A damaged vibration isolator is shown in the inset. Hurricane Katrina (Mississippi, 2005) (FEMA P-424)

- **Boiler and exhaust stacks.** Check adequacy and tautness of guy-wires (see **Figure 5-145**). If guy-wires do not exist, check the stack's wind resistance. If the stack has a rain cap, check the adequacy of the attachment (blown-off caps can cut roof membranes and cause other damage or injury).

Figure 5-145:
Exhaust stacks secured with guy-wires at this high school were toppled by high winds when the turnbuckle failed due to corrosion, leading to water intrusion in the building. Hurricanes Irma and Maria (Puerto Rico, 2017) (FEMA P-2020)

- **Equipment access panels and doors.** FEMA P-424, 543, and 577 provide attachment guidance. Check the adequacy of the attachment (see **Figure 5-146**).

Figure 5-146:
Access panel blown away at a high school. Blown-off access panels can cut roof membranes, allow water to enter the building, and cause other damage or injury. Hurricanes Irma and Maria (Puerto Rico, 2017) (FEMA P-2020)

- **Sheet metal hoods and enclosures (cabinets) on HVAC units.** FEMA P-424 provides attachment guidance for hoods. Check the adequacy of the attachment by pushing and pulling on the hood (see **Figure 5-147**). Check the method used to attach the enclosure and evaluate its adequacy.

Figure 5-147:
Inadequately attached sheet metal hood of the unit on this school roof. Blown-off hoods and enclosures can cut roof membranes and cause injuries or other damage. Hurricane Ike (Texas, 2008) (FEMA P-424)

Figure 5-148:
Blown-off unit enclosures at a medical clinic. Hurricane Irma (U.S. Virgin Islands, 2017)

- **Natural gas, electrical conduits, and condensate drain lines.** FEMA P-424 provides attachment guidance for gas and drain lines. In areas where the current basic wind speed is greater than 120 mph,[92] check the adequacy of the attachment (see **Figure 5-149**).

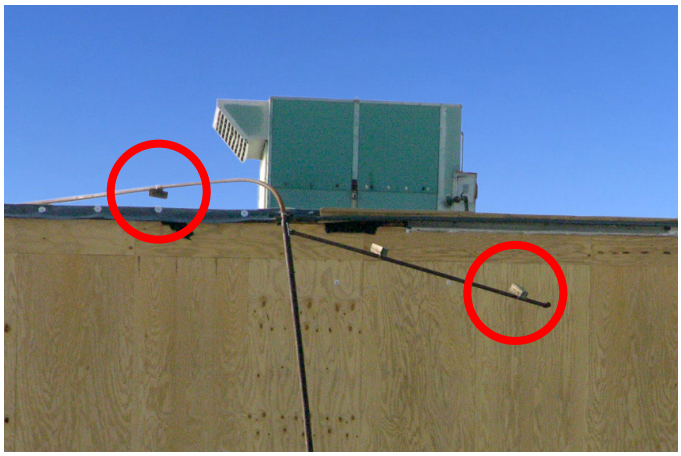


Figure 5-149:
The gas lines serving HVAC units at this school were blown off the roof. The lines were anchored to 4-inch x 4-inch sleepers, but the sleepers simply rested on the roof membrane. Hurricane Ivan (Alabama, 2004) (FEMA 489)

- **Equipment screens.** If screens exist around equipment, check the adequacy of the attachment (see **Figure 5-150**). For guidance, see Chapter 4 for screen frames and the applicable section of Chapter 5 for the screen wall covering.

92 The 120-mph basic wind speed is based on ASCE 7-16, Risk Category III and IV buildings.

Figure 5-150: Panels that were blown off the screen. Blown-off screens can cut roof membranes and cause injuries or other damage. Hurricane Ivan (Florida, 2004) (FEMA 489)

- **Louvers.** Evaluate the wind resistance of the louvers, and check to determine whether they are adequately anchored to the wall. For buildings in hurricane-prone regions where the current basic wind speed is greater than 135 mph,[93] the susceptibility of louvers to wind-borne debris depends on the type of louver and its construction as well as on debris sources. If louvers are located near significant sources of wind-borne debris (such as weak houses), determine if they are capable of resisting test missile "D" or preferably "E" (as defined in ASTM E1996-17). If the louvers are not resistant to wind-borne debris, they could be replaced with debris-resistant louvers, or screen walls could be constructed to provide protection from horizontally traveling debris. However, screen walls do not provide protection from vertically traveling debris.

  Louvers that remain open during high-wind events, such as those that provide combustion air and cooling air for fuel-fired standby or emergency generators, can increase internal pressures and can allow wind-driven rain to enter a building (see **Figure 5-151**). The size and location of louvers should be considered when determining the appropriate internal pressure coefficient GCpi used for determining wind pressures. Evaluate the wind-driven rain resistance of louvers.

Figure 5-151: Wind-driven rain entered at louvers and wetted electrical panels, which caused the circuit breakers to trip. Hurricane Michael (Florida, 2018)

93 The 135-mph basic wind speed is based on ASCE 7-16, Risk Category III and IV buildings.

FEMA P-424, 543, and 577 provide louver design guidance regarding wind-driven rain resistance.

- **Cooling towers.** Do not assume that the dead load of the cooling tower is sufficient to resist the wind load (**Figure 5-152**). Calculate wind uplift and overturning load and resistance to determine whether the dead load plus resistance provided by attachment of the cooling tower to the curb or stand is sufficient to resist the current wind load. (The cooling tower manufacturer may have wind resistance data.) The calculations should be based on the tower shipping weight (i.e., dry weight) and not on the operating weight, since it is possible for a tower to be out of service when a wind event occurs. The resistance analysis should focus on the anchors (e.g., bolts, expansion anchors, welds, or threaded rods) and the attachment points on the tower.

  Towers mounted on vibration isolators involve additional assessment to determine whether the isolators have adequate lateral and uplift load resistance. Determine whether the isolators have all-directional snubbers that are built into the isolator mounts (i.e., restrained isolators) or separate mounts. (Load ratings for spring isolator systems may be available from the isolator manufacturer.)

Figure 5-152:
Cooling tower that was inadequately attached. Hurricane Francis (Florida, 2004)

- Check that all tower accessories (e.g., extended fan stacks, sound attenuation packages, ladders, guardrails) and appurtenances (e.g., light fixtures, electrical controls, lightning protection) are securely fastened to the tower. These items can become wind-borne debris.

- Wind-borne debris. For buildings in hurricane-prone regions, where the current basic wind speed is greater than 135 mph,[94] the susceptibility of a tower to wind-borne debris depends on the type of tower and its construction as well as on debris sources.[95] If a cooling tower is located near a significant source of wind-borne debris (such as weak houses), a screen wall that is capable of resisting test

94 The 135-mph basic wind speed is based on ASCE 7-16, Risk Category III and IV buildings.

95 When cooling towers are damaged by wind-borne debris, generally they are not functionally compromised and are relatively easy to repair.

missile "D" or preferably "E" (as defined in ASTM E1996-17) could be constructed to provide tower protection from horizontally traveling debris (**Figure 5-153**). However, screen walls do not provide protection from vertically traveling debris.

Figure 5-153:
Cooling tower on the roof of a hospital with a screen wall on two sides of the tower. Although screen walls normally are intended for aesthetics, they can be designed to provide wind-borne debris protection. Hurricane Katrina (Mississippi, 2005)

5.5.1.2 Communications Towers and Light Fixture Poles

The following steps are recommended as part of a Level 1 assessment of communications towers and light fixture poles:

- **Communications masts and towers.** Check mast/tower strength and adequacy of attachment (see **Figure 5-154** and **Figure 5-155**). If satellite dishes are mounted on the mast/tower, try to determine whether the mast/tower was designed for the additional wind load that is transferred to it. See ANSI/Telecommunications Industry Association (TIA)–222 for assessment guidance.

Figure 5-154: Mast at a fire station that collapsed onto the roof. Hurricane Charley (Florida, 2004) (FEMA 488)

Figure 5-155:
The tower at this fire station buckled (solid red oval). The top of the tower is at the end of the solid red arrow. Hurricane Katrina (Mississippi, 2005) (FEMA 549)

The wind provisions of ANSI/TIA-222, *Structural Standard for Antenna Supporting Structures, Antennas and Small Wind Turbine Support Structures* (ANSI/TIA 2017) use projected wind areas for latticed structures to account for the openness of those structures. The Mitigation Assessment Team (MAT) report for the 2011 tornado outbreaks in the Southeast and Midwest (FEMA P-208) contains observations that suggest that large sections of wind-borne debris (called wind-displaced materials in that report) may have adhered to latticed structures and contributed to their collapse.

The MAT also observed failures in guyed towers where wind-displaced materials likely contributed to failure. Although ANSI/TIA222 does not require increasing projected wind areas to account for wind-displaced materials, it is recommended that wind-displaced materials be considered when assessing the risk of tower failure.

If accounting for clinging debris is desired, consider the potential debris sources in the vicinity of the tower. When clinging debris is considered, ASCE 7-16 Commentary states that, at a minimum, design for 40 square feet of projected surface area of clinging debris, located either at mid-height of the tower or at 50 feet—whichever is lower.

- **Failure of offsite communications towers (outside the critical facility campus).** The collapse of an off-campus tower or damage to the coax or waveguide may interrupt communications even if the onsite communications masts/towers are not damaged.

  In developed areas, several towers often provide service, allowing communications to be rerouted from a damaged tower to an undamaged tower. Rerouting often can be done quickly, and communications can be nearly seamless. However, a hurricane can damage many or all of the towers that serve the campus. In less developed areas, where redundant towers do not exist, the loss of a communications

tower can completely interrupt communications until temporary towers are placed in service or the collapsed tower is replaced.

The assessment should include determining whether the owner of the critical facility has contacted a representative of the communication utility about the presence or absence of redundant towers. Provisions for rerouting communications or for providing alternate forms of communication are recommended when continuity of communications is important.

5.5.1.3 Satellite Dishes

The following is recommended as part of a Level 1 assessment of satellite dishes:

- **Check the adequacy of the attachment.** If wind resistance is provided by ballast (e.g., CMU, concrete pavers), perform calculations to verify that the ballast is sufficient (see **Figure 5-156**). For facilities in hurricane-prone regions, FEMA P-424, 543, and 577 recommend that dishes be mechanically anchored rather than ballasted.

Figure 5-156:
The satellite dish at this hospital was inadequately ballasted with CMU. Hurricane Harvey (Texas, 2017) (FEMA P-2022

5.5.1.4 Lightning Protection Systems

Lightning protection systems frequently become disconnected from rooftops during hurricanes (**Figure 5-157**). Displaced lightning protection system components can puncture and tear roof membranes, thus allowing water to leak into buildings. Current lightning protection system standards do not require enhanced attachment in high-wind regions. FEMA P-424, 543, and 577 provide attachment guidance where the roof is more than 100 feet above grade or if the building is in a hurricane-prone region where the current basic wind speed is 135 mph[96] or greater. If these conditions exist and enhanced attachment guidance was not followed (e.g., FEMA P-424, 543, and 577), the recommended assumption is that the attachment is vulnerable to wind damage.

96 The 135-mph basic wind speed is based on ASCE 7-16, Risk Category III and IV buildings.

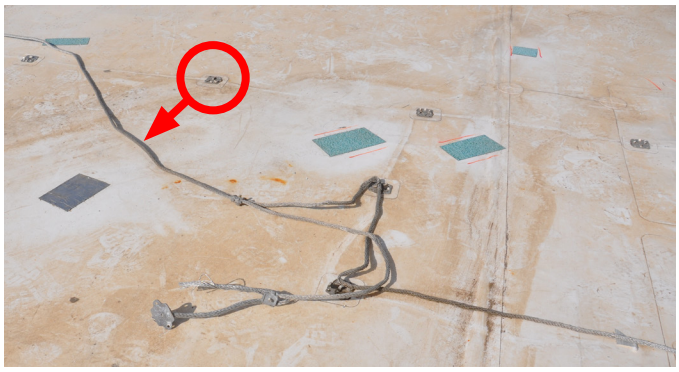


Figure 5-157:
The conductor detached from the connectors (solid red circle) at an airport terminal. Several temporary patches had been made after the hurricane. Hurricane Irma (U.S. Virgin Islands, 2017)

The following steps are recommended as part of a Level 1 assessment of lightning protection systems:

- **Spot check conductor connectors** to verify that: (1) the prongs engage the conductor (see **Figure 5-158**), (2) the conductor connectors are still anchored (**Figure 5-159**), and (3) the connectors are approximately 3 feet on center. The connector problems shown in these figures are sometimes inadvertently caused by foot traffic that kicks the conductor. If conductors are attached with a looped connector (**Figure 5-160**), remove a few fasteners to determine their adequacy.
- **Spot check the air terminals** to verify that they are anchored.

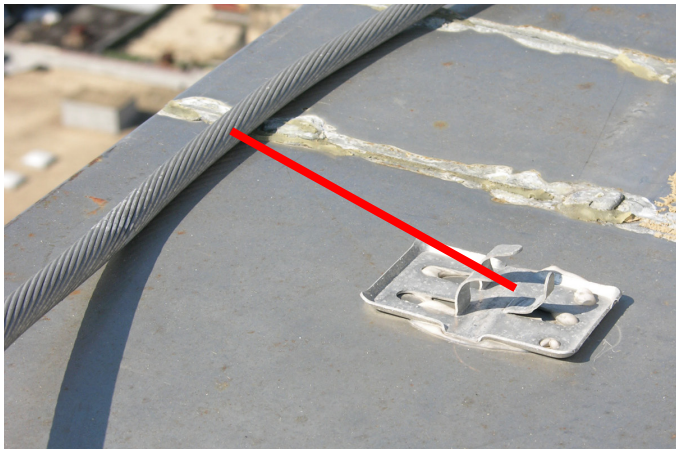


Figure 5-158:
Conductor is no longer attached to the conductor connector. Hurricane Katrina (Mississippi, 2005) (FEMA 549)

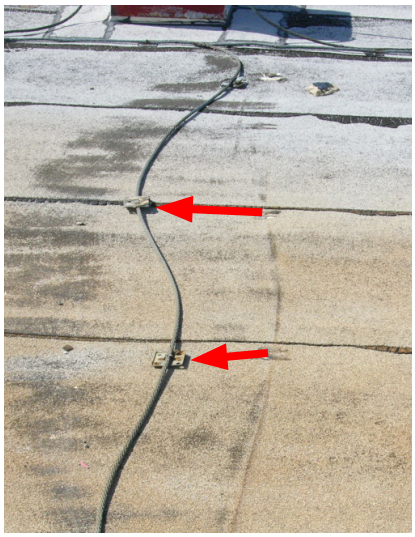


Figure 5-159:
Conductor connectors on a hospital roof that debonded from the roof membrane. Hurricane Francis (Florida, 2004)

Figure 5-160:
Conductor that was attached to the parapet coping with a looped connector. FEMA P-424 recommends the connectors be attached with #12 screws that have minimum 1¼-inch embedment into the parapet nailer. Hurricane Katrina (Mississippi, 2005) (FEMA 549)

5.5.1.5 Solar Arrays

Solar arrays, or photovoltaic (PV) systems, typically are roof- or ground-mounted (**Figure 5-161**). The term "PV modules" (also known as "solar panels") refers to manufactured units of solar cells that form the basic unit of a solar array (i.e., an assembly of PV modules). Modules are manufactured to be adhered to a substrate (e.g., roof covering) or supported by a rack.[97] The most common adhered modules are flexible thin films that are field- or factory-adhered to the roof covering; they also are referred to as "building-applied PV." Rigid modules (e.g., crystalline PV) are attached to a support system (rack) that is ballasted or mechanically anchored to a foundation or the roof deck or deck support. Other variations exist as part of proprietary PV systems.

PHOTOVOLTAIC SYSTEMS

For information on wind performance of rooftop-mounted PV, see FEMA Hurricanes Irma and Maria in the U.S. Virgin Islands Recovery Advisory 5 (RA5) (FEMA 2018c). RA 5 provides an overview of codes, standards, and guidelines that pertain to attachment of PV arrays. It also provides design and construction mitigation guidance. For information on wind performance of ground-mounted PV systems, reference FEMA P-2020, the MAT report for Hurricanes Irma and Maria in Puerto Rico (FEMA 2018a), and FEMA P-2021, the MAT report for Hurricanes Irma and Maria in the USVI (FEMA 2018b).

The following steps are recommended as part of a Level 1 assessment of solar arrays.

Ground-Mounted Solar Arrays

This section applies to ground-mounted arrays at a critical facility site, as well as solar farms that are grid-connected.

Figure 5-161: View of a ground-mounted PV array. Hurricanes Irma and Maria (USVI, 2017) (FEMA P-2021)

ASCE 7-16 does not provide criteria for determining wind loads on ground-mounted PV arrays. However, some guidance is provided in SEAOC PV2-17, *Wind Design for Solar Arrays* (SEAOC 2017). FM Global Loss Prevention Data Sheet 7-106 provides guidelines and recommendations for the design, installation, and maintenance of ground-mounted PV arrays.

If the PV array was installed after 2010, check the historical file to see if the system has an ICC Evaluation Report based on ICC-Evaluation Service's AC 428, *Acceptance Criteria*

97 Shingles fabricated from flat-plate modules also are available. However, because of their limited use on critical facilities, guidance for assessing them is not included in this edition.

for Modular Framing Systems Used to Support Photovoltaic (PV) Panels (ICC-ES 2012). If an Evaluation Report is not identified in the historical file, check the PV modules and framing system for identification of the manufacturer. If the manufacturer is identified, contact the manufacturer to determine whether the framing system has an evaluation report.

If the framing system does not have an evaluation report, and if the solar array was installed after 2011, check the historical file to see whether it was evaluated in accordance with *FM Approval Standard for Rigid Photovoltaic Modules*, Class Number 4478 (FM Approvals 2016). If it was evaluated, it is recommended that SEAOC PV2-17 and FM 7-106 be used as a guide to calculate wind loads. In calculating loads, it is recommended that the Risk Category that is applicable to the critical facility also be used for the PV array. For solar farms connected to the grid, Risk Category IV is recommended. Then, compare the system uplift resistance rating (e.g., FM 1-60) with the design loads. If the uplift resistance rating is not identified in the historical file, check the PV modules for identification of the manufacturer. If the manufacturer is identified, contact the module manufacturer to determine whether it was evaluated by FM 4478, and if it was, obtain the uplift resistance rating.

If the PV system does not have an ICC Evaluation Report or an FM uplift resistance rating, it is recommended that wind load resistance be calculated by using AC 428 as a guide.

The recommended field assessment of ground-mounted systems includes the following:

- **Nearby debris.** Determine whether there are any trees, towers, or poles that could hit the PV array if they topple.
- **Wind-borne debris.** If the array is in a hurricane-prone region, where the current basic wind speed is 135 mph[98] or greater, the recommended assumption is that the solar modules are vulnerable to wind-borne debris damage. Note: If the modules have a damage rating of "VSH" (very severe hail) per FM 4478 (FM Approvals 2016), they may not be susceptible to low-momentum debris, but they will likely be susceptible to debris with greater momentum (e.g., test missile "D" [as defined in ASTM E1996-17]).

WIND-BORNE DEBRIS

Neither ASCE 7, IBC, ICC AC 428, nor FM 4478 has wind-borne debris requirements for solar panels.

- **Spot check the interface between the PV modules and the framing system** that is used to support modules, including mechanical fasteners, snap-fit couplings, or adhesive. Perform spot checks on panel clamps with a calibrated torque wrench. Spot check the framing system fasteners and check for corrosion and fatigue cracks. Weakened or inadequately designed or installed interfaces can cause modules to blow off (see **Figure 5-162** through **Figure 5-164**).

98 The 135-mph basic wind speed is based on ASCE 7-16, Risk Category III and IV buildings.

RA 5 (FEMA 2018c) recommends double-nutting the panel clamp bolts. For the second nut, a stainless-steel lock nut with a nylon insert is recommended. If the panel clamp bolts on the array being assessed do not have double nuts, the panel attachment may be susceptible to damage caused by cyclical wind loading.

Figure 5-162:
Aerial view of PV array with most panels blown off from their ground-mount supports; many structural members were damaged. Hurricanes Irma and Maria (Puerto Rico, 2017) (FEMA P-2020)

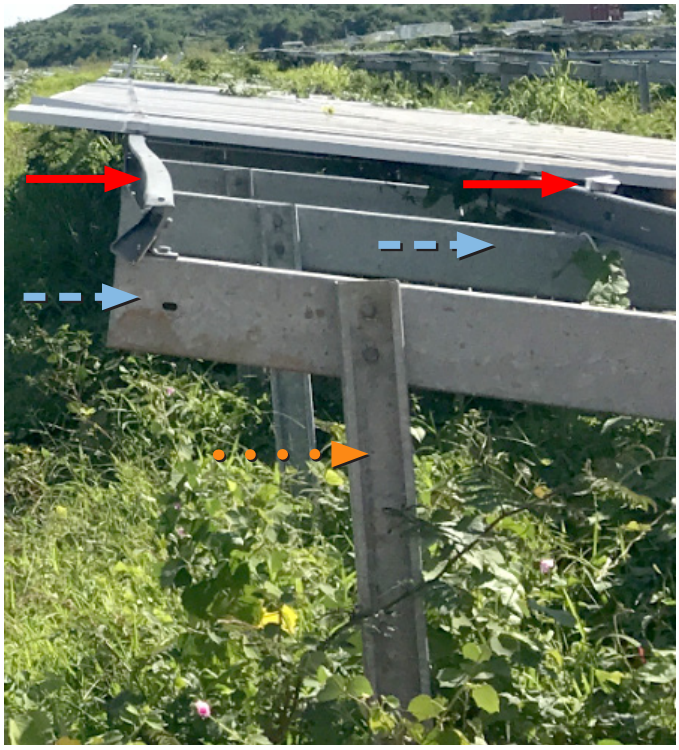


Figure 5-163:
PV array support system with ground-mounted posts (orange dotted arrow), sloped beams (blue dashed arrows), and lateral rails (solid red arrows) that directly support the PV panels. Failure occurred at the panel clamps, causing some panels to be lifted off the framing system. Hurricanes Irma and Maria (Puerto Rico, 2017) (FEMA P-2020)

Figure 5-164:
Deformed hat-shaped clamp still bolted to supporting lateral rail. The PV panel to the left was lifted out of position when the hat-shaped clamp could not resist the wind uplift pressures and was bent upward. Hurricanes Irma and Maria (Puerto Rico, 2017) (FEMA P-2020)

- **Spot check the connections** between the framing system and the foundation (i.e., concrete footings, precast concrete sitting on grade, and piles or helical piers), including spot checking bolted connections with a calibrated torque wrench.
- **Spot check piles and helical piers** for corrosion or wood decay.
- **Natural frequency and damping.** To determine whether the panel is wobbly, push down on a corner of a panel and quickly release. Use a stopwatch to record the period of motion. Repeat this evaluation a few times. If the period of motion is approximately 3 hertz or less, wobbling induced by wind can significantly increase the wind load. **Figure 5-165** is an example of a ground-mounted PV array that may be susceptible to natural frequency problems.

Figure 5-165:
View of a ground-mounted PV array

- **Microinverters or string inverters.** If the array is in a hurricane-prone region where the current basic wind speed is 135 mph[99] or greater, determine whether there are microinverters or string inverters. Unlike string inverters, microinverters have a greater chance of allowing undamaged panels of a PV array to continue to produce electrical power even if one panel is blown away or damaged by wind-borne debris. In an array using string inverters, if one panel is damaged, all the panels on the string will be offline.

PV Modules Adhered to the Roof Covering

If the PV module was installed after 2010, check the historical file to see whether the module was evaluated in accordance with *Approval Standard for Flexible Photovoltaic Modules*, Class Number 4476 (FM 4476) (FM Approvals 2011). If the module was evaluated, compare the system uplift resistance rating (e.g., FM 1-60) with the design loads based on the current edition of ASCE 7. If the uplift resistance rating is not identified in the historical file, check the PV module for identification of the manufacturer. If the manufacturer is identified, contact the module manufacturer to determine whether it was evaluated by FM 4476; if it was, obtain the uplift resistance rating.

SOLAR ARRAYS ADHERED TO ROOF COVERINGS

FM 4476 applies to PV modules adhered to membrane roofs, liquid-applied roofs, and metal roof panels.

The recommended field assessment of adhered PV modules includes the following:

- **Spot check the perimeter of the module array** to determine whether it has debonded from the roof covering. In particular, check the corner areas of the module array, as shown by the red lines in **Figure 5-166**. Perform most of the spot checks in each corner[100] and perimeter zone, and make a few checks in the field of the module array.

99 The 135-mph basic wind speed is based on ASCE 7-16, Risk Category III and IV buildings.

100 If the building has PV on several roofs, it is usually not necessary to check all corners. Also, if the building is not in a hurricane-prone region, test the corner(s) of the prevailing wind direction plus the perimeter and field areas where PV occurs. If the prevailing direction is not known, test the northwest and southwest corners plus the perimeter and the field areas where PV occurs.

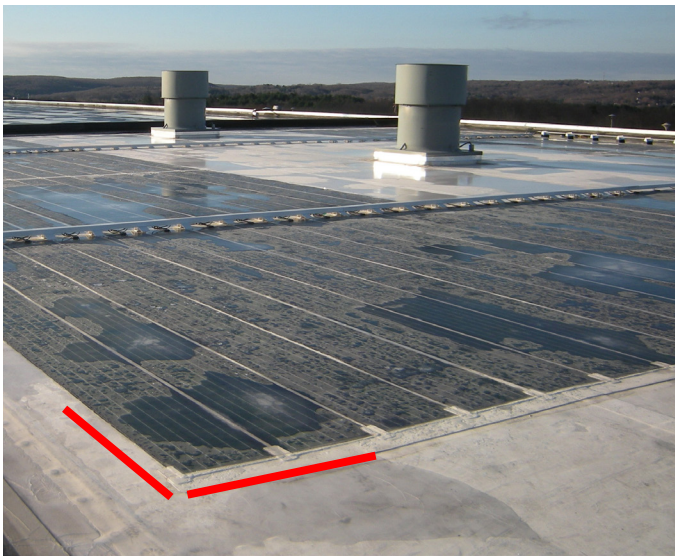


Figure 5-166:
PV module adhered to the roof membrane (Photo courtesy of Phil Dregger, Technical Roof Services, Inc.)

Rooftop Solar Arrays Mounted on Racks or Rails

The 2016 edition of ASCE 7 added wind load criteria for rooftop solar arrays mounted on racks or rails. If the solar array was installed after 2011, check the historical file to see whether it was evaluated in accordance with *Approval Standard for Rigid Photovoltaic Modules*, Class Number 4478 (FM Approvals 2016). If it was evaluated, compare the system uplift resistance rating (e.g., FM 1-60) with the design loads based on the current edition of ASCE 7-16.[101] If the uplift resistance rating is not identified in the historical file, check the PV modules for identification of the manufacturer. If the manufacturer is identified, contact the module manufacturer to determine whether it was evaluated by FM 4478; if it was, obtain the uplift resistance rating. If the PV system does not have an ICC Evaluation Report, it is recommended that wind loads in accordance with ASCE 7-16 and resistance be calculated.

The recommended field assessment of PV modules attached to ballasted racks includes the following:

- **Spot check the interface between the PV modules and the framing system** that is used to support modules, including mechanical fasteners, panel clips, snap-fit couplings, or adhesive. For a qualitative evaluation, push and lift up on the modules, and spot check bolted connections with a calibrated torque wrench.

  Perform most of the spot checks in each corner and perimeter zone, as defined in ASCE 7, and perform a few checks in the field of the array.

  Experienced investigators may be able to detect a weak connection between the modules and framing system. However, modules may be very resistant to movement

101 ASCE 7-16 provides criteria for calculating loads on PV arrays on roofs with slopes equal to or less than 7 degrees. SEAOC PV2-17 includes provisions that are not in ASCE 7-16; these are intended to clarify or provide extensions to the ASCE 7-16 requirements. Following the more detailed provisions of SEAOC PV2-17 may reduce the design wind load on portions of an array.

and incorrectly interpreted as having adequate wind resistance. In addition, check for corrosion and fatigue cracks.

- **Check to see whether bars, such as those shown by the blue arrow in Figure 5-167, connect the rows of panels.** The bars allow load sharing. If bars do not occur, determine whether the bars were inadvertently not installed or if the racks have sufficient ballast without the bars.
- **Determine whether racks have shifted from their original position.**
- If CMU or concrete pavers were used for ballast, **check for displacement/toppling and freeze/thaw deterioration of the ballast.**

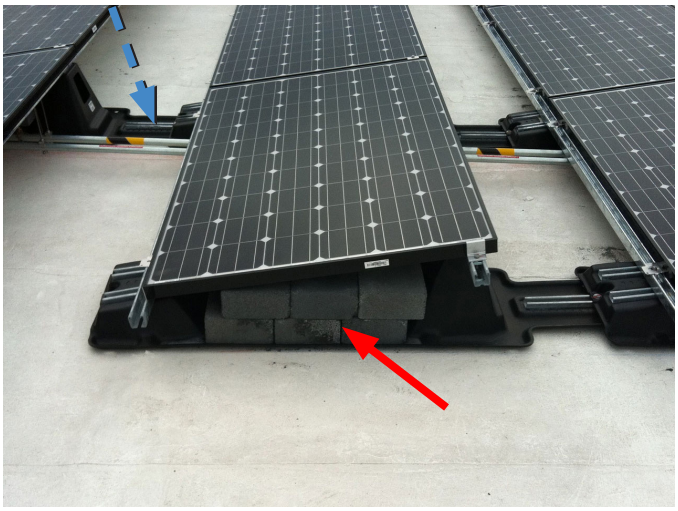


Figure 5-167:
Racks ballasted with concrete pavers (solid red arrow). The blue dashed arrow indicates a bar that connects the rows of panels.

- **Check with the module manufacturer to determine whether wind deflectors are recommended.** If deflectors are recommended, verify that they were installed.
- **Determine whether the racks occur over a mechanically attached single-ply membrane.** If they do, the racks are likely to be susceptible to shifting caused by membrane ballooning during high winds. If shifting has not occurred, lack of shifting is probably due to absence of high winds rather than stability of the racks during membrane ballooning.
- **Check for wind stability of the aggregate if the roof membrane is aggregate surfaced.** Depending on factors such as aggregate gradation, basic wind speed, building height, and parapet height, aggregate can become airborne and break the PV module's film (**Figure 5-168**).

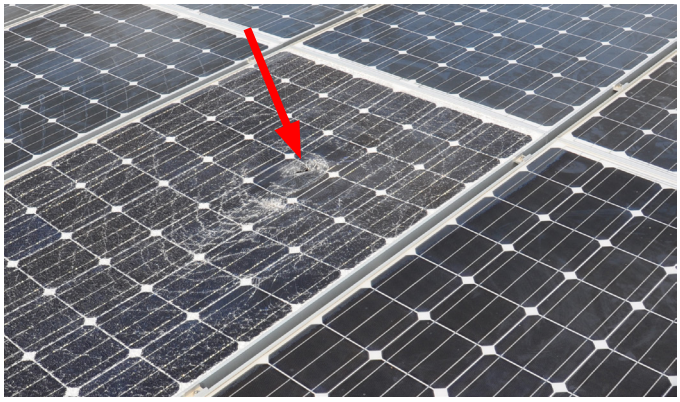


Figure 5-168:
PV module damaged by wind-borne debris (solid red arrow). Hurricane Irma (USVI, 2017)

The recommended field assessment of PV modules attached to mechanically anchored racks or rails (**Figure 5-169**) includes the following:

- **Spot check the interface between the photovoltaic modules and the framing system** that is used to support modules, including mechanical fasteners, panel clamps, snap-fit couplings, or adhesive. For a qualitative evaluation, push and lift up on the modules, and spot check bolted connections with a calibrated torque wrench. Experienced investigators may be able to detect a weak connection between the modules and framing system. However, modules may be very resistant to movement and incorrectly interpreted as having adequate wind resistance. In addition, check for corrosion and fatigue cracks.

  Perform the majority of the spot checks in each corner[102] and perimeter zone, as defined in ASCE 7, and perform a few checks in the field of the array.

Figure 5-169:
PV modules attached to rails that are mechanically anchored to the roof deck, through the liquid-applied membrane. Hurricanes Irma and Maria (USVI, 2017)

- **Check with the module manufacturer to determine whether wind deflectors are recommended.** If deflectors are recommended, verify that they were installed.

102 If the building has PV on several roofs, it is usually not necessary to check all corners. Also, if the building is not in a hurricane-prone region, test the corner(s) of the prevailing wind direction plus the perimeter and field areas where PV occurs. If the prevailing direction is not known, test the northwest and southwest corners plus the perimeter and the field areas where PV occurs.

- **Check for wind stability of the aggregate if the roof membrane is aggregate surfaced.** Depending on factors such as aggregate gradation, basic wind speed, building height, and parapet height, aggregate can become airborne and break the PV module's film.

- PV modules may be attached to standing seam metal roof ribs with external seam clamps, or modules may be attached to rails that are attached to the ribs (**Figure 5-170**). Use of rails can result in overstressing the concealed clips that attach the metal panels. At other portions of the building shown in **Figure 5-170**, several metal panels blew off (the array was still attached to the blown-off roof panels). The recommended assumption is that metal roof panels with arrays attached to rails that are attached to the ribs are vulnerable to wind damage.

Figure 5-170:
PV modules attached to rails that were attached to the metal roof ribs with external seam clamps. Several modules blew off the rails (solid red lines). In other areas, the roof panels blew off with the array. Hurricane Irma (USVI, 2017)

- **Microinverters or string inverters.** If the array is in a hurricane-prone region where the current basic wind speed is 135 mph[103] or greater, determine whether there are microinverters or string inverters. Unlike string inverters, microinverters have a greater chance of allowing undamaged panels of a PV array to continue to produce electrical power even if one panel is blown away or damaged by wind-borne debris. In an array using string inverters, if one panel is damaged, all the panels on the string will be offline.

103 The 135-mph basic wind speed is based on ASCE 7-16, Risk Category III and IV buildings.

5.5.2 Level 2 Assessment of Exterior-Mounted Equipment

If the Level 1 assessment revealed that the equipment has several more years of useful service life, a Level 2 assessment is recommended for buildings in locations where the current basic wind speed is greater than 120 mph.[104] The following steps are recommended as part of the Level 2 assessment:

- **Destructive observation of equipment curbs and stands.** To verify or determine the attachment of equipment curbs and stands (including PV support stands) to the roof deck/structure, remove the base flashing/pitch pocket.

  Destructive observation of curbs or stands is relatively expensive. Considering that curb or stand failure is rare,[105] this effort is typically reserved for facilities that are particularly important and/or where the current basic wind speed is very high.

  If the roof membrane is warranted, notify the warrantor before taking the cuts, and ensure that the repair is performed by a contractor the warrantor authorizes.

- **Cooling tower.** To determine whether corrosion has compromised the integrity of a cooling tower, request that the cooling tower be investigated by a cooling tower inspection/maintenance firm.

104 The 120-mph basic wind speed is based on ASCE 7-16, Risk Category III and IV buildings.

105 Rare failure of curbs and stands may in part be due to weak connections between the equipment and the curb or stand. As more attention is given to attachment of the equipment, curb or stand failure may become more common and hence suggest the importance of performing destructive observations to determine curb or stand resistance.

Chapter 6: Municipal Utilities

This chapter covers recommended assessments of municipal utilities that may serve a critical facility.

This chapter includes assessments of electric utilities, emergency power (generators), water service, and sewer service.

6.1 Electric Utilities

Utilities are designed and constructed to meet different codes than buildings are. Where adopted, critical facilities generally are constructed to model codes such as the International Code Council's IBC or the National Fire Protection Association's NFPA-*5000 Building Construction and Safety Code*. Overhead electrical lines typically are constructed to standards developed by the United States Department of Agriculture's Rural Utilities Service or by individual electrical utilities, many of which establish criteria that are consistent with ANSI Standard C2, also known as the *National Electrical Safety Code* (NESC) (IEEE 2017).

The NESC is a safety code intended to safeguard the public and utility workers during the installation, operation, and maintenance of electrical supply and communication lines. While the NESC contains minimum requirements for the strength of overhead lines and their ability to resist loads from wind and ice, the strength requirements are less than those for critical facility buildings, and, in many instances, significantly less.

> The NESC is a safety code, not a code that establishes minimum requirements for system reliability. According to the NESC, "The purpose of these rules is the practical safeguarding of persons during the installation, operation, or maintenance of electrical supply and communication lines and associated equipment."

The strength requirements of NESC vary. There are different requirements for lines constructed on private versus public rights of way, for lines constructed over roadways and waterways, and for urban and rural areas.

One of the greatest differences in requirements is governed by the height of the overhead lines. Taller overhead lines (those 60 feet and higher) must be stronger (in some cases, significantly stronger) than shorter lines (i.e., those under 60 feet).[108] The difference in the NESC for taller and shorter lines often is referred to as "the 60-foot exclusion." As an

108 The exact wording in the NESC is, "If no portion of a structure or its supported facilities exceeds 18 m (60 ft) above ground or water level…"

example, in areas where lines do not need to be designed to resist ice accretion, overhead lines below 60 feet must be designed to resist a 9 psf wind load, which corresponds to an Exposure C wind speed of just over 60 mph. By comparison, overhead lines higher than 60 feet must be designed to resist wind speeds of least 90 mph (85 mph for California, Washington, and Oregon) and, in some portions of the contiguous United States, wind speeds up to 150 mph.[109] Since the strength required to resist wind loads is a function of the square of the wind speed, overhead lines that are 60 feet tall and constructed to minimum NESC standards must be at least twice as strong as lines below 60 feet [(85 mph/60 mph)^2] and upwards of 6 times as strong [(150 mph/60 mph)^2] in high-wind areas of the United States. Because the wind criteria for overhead lines are based on an older version of ASCE 7, and thus lags that of the criteria for critical facilities, an exact comparison of wind loads is difficult. Generally speaking, critical facilities are designed to resist wind loads approximately 15 percent greater than those for overhead lines higher than 60 feet but 2 to 6 times greater than lines under 60 feet. Almost invariably, power must run through lines less than 60 feet tall before it reaches a critical facility; so, the overall reliability of an electrical system supplying a critical facility usually is controlled by vulnerabilities in those shorter and weaker lines that are closer to the facility. Simply stated, designers, owners, and operators of critical facilities should not question if power will be lost; rather, they should prepare for when it's lost and how the inevitable loss of power will effect the facility and its operations.

6.1.1 Duration of Electrical Power Loss

Because most power lines serving facilities are designed to resist lower wind loads than the buildings they serve, power outages should be anticipated. Power outages can last from a few seconds to several weeks. An intermittent outage that results from an untrimmed tree limb brushing against an energized line can cause a power outage that lasts only a few seconds or minutes. A fallen tree or large tree limb that causes overhead conductors to fall can result in outages that last several hours to a day or so, and more extreme events that down large sections of power lines or topple several support structures can cause outages that last several days to weeks. Storms that affect large areas, such as hurricanes, Nor'easters, winter storms, or tornadoes, can cause widespread damage that results in extensive and prolonged power outages.

For a given amount or type of power line damage, outage durations can vary greatly. Power lines often are routed through undeveloped areas that permit only limited access for utility vehicles and repair crews. Outages that result from damaged power lines in mountainous regions can be particularly long, as can outages in island nations or territories, where the logistics of shipping materials and crew can be challenging. Limited power line damage that results in relatively brief outages in some urban areas can cause extended outages elsewhere.

109 The wind criteria for lines over 60 feet are contained in Section 25 of the NESC, generally referred to as Extreme Wind (Rule 250C). For the 2017 edition of the NESC, the basic wind speed is from ASCE 74-10, Guidelines for Electrical Transmission Line Structural Loading. The ASCE 74-10 wind speed map is from the 2005 edition of ASCE 7, Minimum Design Loads for Buildings and Other Structures. Prior to the issuance of the 2012 IBC, which references the "ultimate" wind speeds specified by ASCE 7-10, the basic wind speeds used for critical facilities were consistent with those specified by ASCE 7-05.

It is also important to realize that not all outages are weather-related. Outages can also result from: human activities, such as automobile accidents that damage utility poles; animals contacting energized lines; or the accidental excavation of underground lines. Outages also can result from the normal operation of electrical equipment to isolate electrical faults.

While the duration of electrical outages cannot be accurately and precisely predicted, historical data often are available to help quantify the risk of electrical outages. Owners, operators, and designers of critical facilities should discuss outage duration with the electrical utility that supplies power. Those discussions also can help ensure that the services provided by a critical facility are considered when utilities prioritize restoration efforts.

6.1.2 Assessment of Equipment Needing Emergency Power

Assessing the emergency power needs of a critical facility requires identifying which critical services the facility needs to provide and determining which equipment must be operable in order to provide those services. For a facility to function during a prolonged power outage and provide critical services, alternate power sources will be needed in order to supply the necessary equipment.

The design and construction of critical facilities vary greatly, so it is not possible to provide specific guidance and requirements for all facilities. However, **Table 6-1** below lists equipment to consider in the assessment. The list contains equipment that may need access to emergency power, as required by locally adopted building codes. Many code requirements for emergency power are limited and only require emergency power for the time required to safely evacuate a building—typically, only 90 minutes. For critical facilities to remain functional, longer-duration standby power sources usually are needed.

For the following equipment listed in **Table 6-1**, the wind vulnerability assessment should determine:

- Is the equipment present, and does it need to operate to allow the critical facility to provide essential services?
- Are emergency/standby power sources in place that allow the equipment to operate when normal power is lost?
- Are the emergency/standby power sources sufficient to provide power for the anticipated duration of the power outage?

Table 6-1: Equipment to Consider During Electric Utility Assessment

Life Safety	Mechanical Cooling
• Emergency (egress) lighting • Fire detection systems • Fire alarm and annunciation systems • Emergency communications systems • Power-operated doors and locks	• Air-cooled chillers • Water-cooled chillers and cooling towers • Chilled water and condenser water pumps • Direct expansion (DX) air conditioning units • Air conditioning units serving computers, networks, and other communication/data equipment
Fire Suppression/Smoke Control	**Plumbing Equipment**
• Electrically powered fire and jockey pumps • Generator lighting and local power • Smoke control dampers • Stair pressurization equipment	• Domestic water heaters • Domestic hot water circulator pumps • Water system booster pumps • Sewage lift pumps • Sump pumps
Egress and Conveyances	**Food Service Equipment**
• Elevators and platform lifts • Elevator cab lighting and communication	• Food refrigeration equipment • Food preparation equipment
Lighting	**Communication/Data Equipment**
• Lighting in areas where critical functions are performed • Lighting in mechanical and electrical rooms • Corridor and staircase lighting • Task lighting outside of egress path	• Telephone equipment • Computer equipment • Network servers and routers • Intercom systems • Central clock systems • Radio communication equipment
Heating, Ventilation, and Air Distribution	
• Heating equipment (e.g., boilers) • Heated water circulating pumps • Air-handling units	• Exhaust fans • Ventilation fans • Environmental Management and Control Systems

FEMA P-1019, *Emergency Power for Critical Facilities: A Best Practice Approach to Improving Reliability* (FEMA 2014) contains guidance on identifying and providing emergency power for critical facilities. FEMA P-1019 suggests considering three levels of operation when developing approaches for providing emergency power. The levels—described as Level I, Level II, and Level III—are determined primarily by how long the facility needs to operate under emergency power and whether the emergency power system must be sized to supply air conditioning equipment. Air conditioning equipment, which is typically the largest electrical load in a facility, often has a significant effect on the design of emergency power systems.

Level I. Level I operations require power for a very short duration. Level 1 operations include code-required life safety equipment, such as fire alarm equipment, exit and egress lighting, and the minimum lighting required to allow occupants to move throughout a building. Level I operations also should allow fire pumps (when present) to operate because they are needed to adequately protect occupants in the event of a structural fire during a power outage.

Level I operations are appropriate for outages of 8 hours or less. Level I operations may be inadequate under extreme weather conditions when natural building ventilation is inadequate and the building use requires maintaining the interior temperature within ±20 degrees.

The following equipment should be supplied in order to support Level I operations:

- Life safety equipment
- Fire pumps
- Select lighting fixtures
- Pumps required to operate domestic water systems and sanitary sewer systems
- Elevators (when required for egress or for operations)

Level II. Level II operations include those for Level I, plus heating and ventilation and food preservation and preparation equipment if food is provided, as in host shelters. Level II operations are appropriate when the facility needs to operate for more than 8 hours. Level II operations may be inadequate under extreme weather conditions (particularly during periods of extreme high exterior temperatures).

The following equipment should be supplied in order to support Level II operations:

- All equipment required for Level I operations
- Heating and ventilation equipment
    - Boilers and hot water circulating pumps for hydronic systems
    - Air-handling units
    - HVAC control equipment
    - Communication equipment (when required for operations)
    - Food preservation and preparation equipment (if food is served)

Level III. Level III operations include those for Levels I and II, plus air conditioning equipment. Level III operations are appropriate for facilities that need to operate during periods of high exterior temperatures or when interior temperatures and humidity levels must be tightly controlled.

The following equipment should be supplied in order to support Level III operations:

- All equipment required for Level I and II operations
- Power for DX (direct expansion) AC units
- Power for chillers, evaporators (when used), and chilled water circulating pumps (for chilled water systems)

6.2 Providing Emergency Power

Emergency power can be provided by permanently installed onsite generators or by temporary generators that are brought to the site and connected to the electrical distribution system only when needed. Onsite generators are expensive to install and maintain and are not needed for facilities that are only rarely used as shelters. Temporary generators are less expensive, but they require provisions that allow them to be safely connected to the facility's electrical system.

6.2.1 Permanent Generators

Permanent generators are used to allow facilities to function during prolonged power outages. To achieve this purpose, permanent generators must be adequately sized in order to power the required loads, and they must be connected to the facility in a fashion that allows the required loads to be supplied. In addition, permanent generators should be installed in a manner that protects them from natural hazards, and they should be supplied from reliable fuel sources.

There are two methods of connecting a permanent generator to a facility. One method is to connect the generator in a fashion that energizes the building's main electric service; the other method is to connect the generator in a fashion that energizes only selected loads downstream of the building's main electric service.

Connecting a generator to a building's main electric service energizes the service, and, if the generator is large enough, allows the generator to power any electric load in the facility. This method offers the greatest flexibility, particularly in existing facilities, but it is rarely practical to size a generator to be large enough to power all loads in a building simultaneously. If the electrical configuration allows all loads to receive power, the generator will be overloaded if too many loads are operated simultaneously. When overloaded, generators and the engines that drive them overheat, and the generator may trip offline. When severely overloaded (for example, by attempting to start a large motor), generators can stall, trip offline, or be permanently damaged.

Unless automatic load controls are in place to prevent overloading, energizing a facility's electrical service requires loads to be manually turned on and off in order to limit the total electrical demand placed on the generator. Manual operation requires a thorough knowledge of the facility's electrical loads, their sizes, and how to control them, and the

operator needs to ensure that loading always has sufficient generator capacity in reserve to start the largest motor that may need to operate.

Alternatively, when a generator is connected in such a way that it can only power selected loads, the generator can be accurately sized to match the loads. Permanent generators are expensive, and providing the smallest generator that will supply the required and projected loads will provide the most cost-effective solution. In addition, when a generator is properly sized and energizes selected loads, manual load control is not required, and the generator may be installed to operate with little human intervention.

Connecting a generator to supply only selected loads requires that the electrical distribution within a building be designed to accommodate this approach. Because this method affects the configuration of the building's electrical distribution, it is often more involved to take this approach when powering existing facilities. But, due to the improved reliability, the cost effectiveness, and the need for less human intervention, this approach should be taken whenever possible.

To power only selected loads, the essential loads must be fed from separate portions of the electrical distribution system than the non-essential loads. Automatic transfer switches or manual transfer switches can be used to allow either normal utility power or emergency power systems to serve the critical loads. Manual transfer switches should not be allowed to supply code-required life safety loads because those loads need to be powered without human intervention.

Protecting the generator from natural hazards usually requires that generators be in the building. When properly designed, interior installations offer protection from high winds, wind-driven rain, wind-borne debris, and lay-down hazards, such as falling trees, communications towers, and light standards. Although exterior enclosures provide protection from winds and wind-driven rain, few can resist high-energy wind-borne debris and lay-down hazards.

Permanent generators also must be supplied from clean and reliable fuel sources. FEMA 543 recommends that generators be able to run 96 hours without refueling. Fuels such as diesel and liquefied propane are stored onsite, and unless site limitations prevent placing sufficiently large tanks onsite, adequate quantities of fuel can be stored. Natural gas (NG) fuel, on the other hand, is not stored onsite, but rather piped to a site from a local utility. NG supplies often are interrupted during high-wind events, flood events, or earthquakes. NG services often shut down intentionally before a storm to reduce the risk of fires and explosions that can result when buildings are damaged by the storm. Because of this, NG should not be considered a reliable fuel source unless confirmed by the local utility.

Diesel fuel is often used to supply emergency generators. However, diesel fuels can degrade if they are not used, and fuel degradation can significantly reduce system reliability. Supplying emergency generators from fuel tanks used to supply other equipment (such as fuel-fired boilers) can reduce the potential for fuel degradation. When diesel generators are

supplied from fuel tanks not used for other equipment, routine fuel testing can identify fuel degradation before it affects system reliability.

If permanent generators are relied on to provide power when utility power is lost, the vulnerability assessment should address the following:

- Is the generator large enough, and is it connected in a fashion that allows all required loads to be supplied?
- If the generator is connected in such a fashion that the main electric service is energized, are staff available who have sufficient knowledge of the facility's electrical and mechanical systems to allow loads to be manually controlled without overloading the generator?
- Are the generator and associated equipment located in a room, building, or enclosure that is designed as a Category IV building, per ASCE 7, and that can resist test missile "E" (as defined in ASTM E1996-17) when tested in accordance with ASTM E1886 or FBC TAS 201/203?
- Are the generator and associated equipment exposed to lay-down hazards?
- Is the generator supplied from reliable fuel sources that will allow it to operate a minimum of 96 hours without refueling?

6.2.2 Temporary Generators

The advantages of temporary generators, when compared with permanent generators, are:

- No large capital expenditure is required.
- Facility owners do not have to pay for regular testing and maintenance.

The disadvantages of temporary generators are:

- They may not be readily available during a power outage.
- They may have no protection from high winds, wind-driven rain, wind-borne debris, and lay-down hazards, which reduces their reliability during a high-wind event (see **Figure 6-1**).
- They must be located, transported to the facility, and set up.
- Cables from the generator to the building must be installed (see **Figure 6-2**).
- The existing electrical system must be electrically isolated from the utility to avoid back-feeding generator power into the utility lines. Back-feeding power can energize downed lines and injure or kill line workers trying to restore power.

Figure 6-1:
Trailer-mounted temporary diesel generator

Figure 6-2:
Temporary cables connecting generator to electrical service

Although locating and properly installing a temporary generator can take days, steps can be taken before the high-wind event to reduce the functional downtime. If a facility plans to use a temporary generator during a power outage, the steps that are in place or planned should be assessed.

If temporary generators are relied on to provide power when utility power is lost, the vulnerability assessment should address the following:

- Appropriateness of temporary generator
  - Is it acceptable not to operate the facility during a high-wind event, when portable generator installation may not be available?
  - Is it acceptable for the facility to be without power while the portable generator is being delivered and connected to the facility?[110]

110 Pay particular attention to code-required life safety loads, such as egress lighting, fire alarms, and exit signage. For many occupancies, code-required loads only need to function for a relatively short duration—often 90 minutes. For occupied facilities, the loss of normal power may require them to be temporarily evacuated if code-required life safety loads become inoperable before a temporary generator can provide power to the facility.

- Pre-wiring
  - Is the facility's electrical service and distribution system pre-wired to accept a portable temporary generator?
  - Is the generator large enough, and can it be connected in such a way that it can supply all required loads for the level of operation proposed?
  - Does the pre-wiring electrically isolate the generator from the utility system and prevent generator power from back-feeding onto utility lines, where it could kill or injure utility workers?
  - Does the pre-wiring allow the generator to be safely connected to the facility without exposing occupants and those operating the generator to injury?
  - Are cables and connections between the generator and the facility prefabricated to minimize connection times?
  - Is the cable run from the generator to the facility as short as is practical to limit voltage drop?
  - Is there vehicle access to allow the generator to be delivered?
  - Will the planned location of the generator support its weight?
  - Are access routes vulnerable to being blocked from lay-down or other local hazards?
- Contracts
  - Are there contracts with equipment rental agencies in place to ensure that generators will be available when needed?

6.3 Water Service

Reliable sources of potable water are needed for critical facilities to function. When equipped with sprinklers, critical facilities also need reliable water sources for fire protection. When supplied from municipal water utilities, most potable water and fire protection service piping is run underground and, thus, protected from direct wind damage. However, potable water services and services for fire protection are often interrupted during wind events, even those that produce only moderately high winds. High winds can damage power lines, preventing water pumps from filling water storage tanks or booster pumps from maintaining adequate water system pressure. High winds can also topple trees, uplifting their roots and damaging underground water piping. Extremely high winds can destroy elevated water storage tanks (**Figure 6-3**) and can cause extensive building damage, including widespread plumbing ruptures that can rapidly drain water storage tanks and depressurize water service piping. In hurricane-prone regions, high-wind events are often accompanied by storm surge, which can cause scour, and erosion that may damage buried water lines.

For critical facilities supplied by onsite water wells, high-wind events can interrupt water supplies that rely on electric pumps to deliver water to the facility, electric booster pumps to maintain water pressure within the building, or electric devices needed to maintain water quality.

Figure 6-3:
Toppled water storage tank. Hurricane Michael (Florida, 2018)

For critical facilities supplied by onsite water services, assessing water service consists of: (1) determining whether there is an alternate means of providing water to the building occupants if the normal water service is interrupted and (2) determining the vulnerability of the water service to wind. The assessment should address the following:

- Determine whether the facility has an onsite well and, if so:
  - Whether the well house, power supply, and control system are susceptible to wind or wind-borne damage.
  - Whether the well or well system has its own backup power supply or is connected to the critical facility emergency backup power supply.
  - Whether the switchover from the onsite supply to an alternate supply is automatic or requires manual control.
- Determine whether the facility has an onsite water storage tank and, if so:
  - Whether it is susceptible to wind or wind-borne debris damage.
  - Whether the tank's useful capacity is sufficient for fire protection, cooling towers, and regular service at the critical facility for the anticipated duration of the loss of water service.

  - How the tank is filled (by gravity, onsite well, public water service operating by pressure or booster pumps) and whether the onsite well or booster pumps, if any, are provided with standby power that will allow them to operate when utility power is lost.

- If the facility does not have an alternate water supply, determine whether:
  - Facility emergency preparedness includes stored water bottles at a location that is readily accessible, not subject to wind or wind-borne debris damage, and in sufficient quantities to meet the needs for the planned period of emergency.
  - The facility is equipped with adequate hygiene, disinfectants, and other supplies (if the public supply is interrupted and there is no alternate water supply) and whether the location of these supplies is known and readily accessible.
  - The facility is equipped with other options, such as end-user treatment systems, and whether these require power.
  - The facility is equipped with piping and connections that allow water to be delivered to the facility by tanker trucks (**Figure 6-4**).

Figure 6-4:
Water delivered to a hospital from tanker truck.
Hurricane Michael (Florida, 2018)

6.4 Sewer Service

High winds can disrupt sewer service, particularly in municipal systems that rely on pumps to convey wastewater but have no standby power for those pumps. High winds can also prevent a critical facility from discharging effluent if ejector pumps are needed to convey wastewater, stormwater, or groundwater to the municipal system. Ejector pumps are often needed for plumbing fixtures in below-grade portions of a building, and to discharge stormwater and groundwater that can seep into below-grade spaces.

The assessment of sewer service should address the following:

- Determine whether the facility relies on sump pumps to convey groundwater or stormwater to the sanitary or storm sewer and, if so:
  - Whether the sump pump system is redundant (two pumps).
  - Whether the control system, valves, and check valves are functional.
  - Whether the system is connected to a standby power supply that can operate the pumps when utility power is lost.
  - Whether the sump pump system and its electrical supplies are adequately protected from wind or wind-borne debris damage.
  - Whether portable sump pumps are provided onsite for emergency drainage.
  - Whether failure of the sump pump system would lead to groundwater or site drainage backing up in the facility and, if so:
    - Which critical functions at the facility would be affected.
    - What the risks would be to life, health, and property from failure of the sump system.
- Determine whether the facility has an onsite lift station to convey sanitary sewage from the facility site to the public sanitary sewer system and, if so:
  - Whether the lift station has redundancy.
  - Whether the control system, valves, and check valves are functional.
  - Whether the system is connected to a standby power supply that can operate the system when utility power is lost.
  - Whether the onsite lift station is adequately protected from wind or wind-borne debris damage.
  - Whether failure of the lift station would lead to sanitary sewage backing up in the facility and, if so:
    - Which critical functions at the facility would be affected.
    - What the risks would be to life, health, and property from failure of the lift station.

- Determine whether the facility has plumbing fixtures below the elevation of the maxium anticipated surcharge of the municipal system. That surcharge level is often considered the elevation of the manhole cover of the next upstream manhole, but may be higher in areas vulnerable to flooding and in municipal sewer systems that also convey stormwater. If so:
  - Is the connection to the municipal sewer equipped with a backwater prevention valve?
  - Do all plumbing fixtures located below the elevation of the maximum anticipated surcharge drain to a sanitary sewer sump equipped with ejector pumps?
  - Are the ejector pumps supplied by standby power that will allow them to operate in the event utility power is lost?
- Determine whether the facility has an alternate means of sanitary waste disposal, such as a holding tank that can be pumped out by a local contractor.
- Determine whether the facility is equipped with portable toilets to be used for emergencies and, if not:
  - Whether there is an adequate location for portable toilets that is readily accessible and protected from wind or wind-borne debris damage.
  - Whether the owner has agreements in place with a contractor to supply and service portable toilets on a priority basis.

Chapter 7: References and Resources

AAMA. 2010. (American Architectural Manufacturers Association). AAMA TIR-A14-10, *Fenestration Anchorage Guidelines.*

AAMA. 2012a. AAMA 502-12, *Voluntary Specification for Field Testing of Newly Installed Fenestration Products.*

AAMA. 2012b. AAMA 520-12, *Voluntary Specification for Rating the Severe Wind-Driven Rain Resistance of Windows, Doors, and Unit Skylights.*

AAMA. 2014. AAMA 503-14, *Voluntary Specification for Field Testing of Newly Installed Storefronts, Curtain Walls and Sloped Glazing Systems.*

AAMA/WDMA/CSA. 2014. (AAMA/Window and Door Manufacturers Association/ Canadian Standards Association) AAMA/WDMA/CSA 101/I.S.2/A440, *North American Fenestration Standard.*

ACI (American Concrete Institute). 2016. ACI 524R-16, *Guide to Portland Cement-Based Plaster.*

ANSI/DASMA (American National Standards Institute/Door & Access Systems Manufacturers Association International). 2012. ANSI/DASMA 108. *Standard Method for Testing Sectional Garage Doors and Rolling Doors: Determination of Structural Performance Under Missile Impact and Cyclic Wind Pressure.* Available at https://www.dasma.com/PDF/Publications/Standards/108-2012.pdf. Accessed June 30, 2019.

ANSI/DASMA. 2017. ANSI/DASMA 115. *Standard Method for Testing Sectional Garage Doors and Rolling Doors: Determination of Structural Performance Under Missile Impact and Cyclic Wind Pressure.* Available at https://www.dasma.com/PDF/Publications/Standards/DASMA-115-Web.pdf. Accessed June 30, 2019.

ANSI/SPRI (American National Standards Institute/Single Ply Roofing Industry). 2013. ANSI/SPRI RP-4 2013, *Wind Design Standard for Ballasted Single-ply Roofing Systems.* Available at https://www.spri.org/download/standards_and_technical_reports/current_ansi_spri_standards/ANSI_SPRI_RP-4-2013-Wind-Design-Standard-for-Ballasted-Single-Ply-Roofing-Systemsv2.pdf. Accessed June 30, 2019.

ANSI/TIA (American National Standards Institute/Telecommunications Industry Association). 2017. ANSI/TIA-222, *Structural Standard for Antenna Supporting Structures, Antennas and Small Wind Turbine Support Structures.*

ASCE. 2017. ASCE 7-16, *Minimum Design Loads and Associated Criteria for Buildings and Other Structures.*

ASTM International (ASTM). 2002. ASTM E783-02(2018), *Standard Test Method for Field Measurement of Air Leakage Through Installed Exterior Windows and Doors*, ASTM International, West Conshohocken, PA, www.astm.org.

ASTM. 2004b. ASTM E907-96, *Standard Test Method for Field Testing Uplift Resistance of Adhered Membrane Roof Systems*, ASTM International, West Conshohocken, PA, www.astm.org.

ASTM. 2010. ASTM C1153-10(2015), *Standard Practice for Location of Wet Insulation in Roofing Systems Using Infrared Imaging*, ASTM International, West Conshohocken, PA, www.astm.org.

ASTM. 2011. ASTM C1060-11a(2015), *Standard Practice for Thermographic Inspection of Insulation Installations in Envelope Cavities of Frame Buildings*, ASTM International, West Conshohocken, PA, www.astm.org.

ASTM. 2012. ASTM C823/C823M-12(2017), *Practice for Examination and Sampling of Hardened Concrete in Constructions*, ASTM International, West Conshohocken, PA, www.astm.org.

ASTM. 2013a. ASTM E1886-13a, *Standard Test Method for Performance of Exterior Windows, Curtain Walls, Doors, and Impact Protective Systems Impacted by Missile(s) and Exposed to Cyclic Pressure Differentials*, ASTM International, West Conshohocken, PA, www.astm.org.

ASTM. 2013b. ASTM E2359/E2359M-13(2018), *Standard Test Method for Field Pull Testing of an In Place Exterior Insulation and Finish System Clad Wall Assembly*, ASTM International, West Conshohocken, PA, www.astm.org.

ASTM. 2013c. ASTM C1072-13e1, *Standard Test Method for the Measurement of Masonry Flexural Bond Strength*, ASTM International, West Conshohocken, PA, www.astm.org.

ASTM. 2013d. ASTM C1397-13(2019), *Standard Practice for Application of Class PB Exterior Insulation and Finish Systems (EIFS) and EIFS with Drainage*, ASTM International, West Conshohocken, PA, www.astm.org.

ASTM. 2014a. ASTM C1196-14a, *Standard Test Method for In Situ Compressive Stress Within Solid Unit Masonry Estimated Using Flatjack Measurements*, ASTM International, West Conshohocken, PA, www.astm.org.

ASTM. 2014b. ASTMC1197-14a, *Standard Test Method for In Situ Measurement of Masonry Deformability Properties Using the Flatjack Method*, ASTM International, West Conshohocken, PA, www.astm.org.

ASTM. 2014c. ASTM E1233/E1233M-14, *Standard Test Method for Structural Performance of Exterior Windows, Doors, Skylights, and Curtain Walls by Cyclic Air Pressure Differential*, ASTM International, West Conshohocken, PA, www.astm.org.

ASTM. 2014d. ASTM E330/E330M-14, *Standard Test Method for Structural Performance of Exterior Windows, Doors, Skylights and Curtain Walls by Uniform Static Air Pressure Difference*, ASTM International, West Conshohocken, PA, www.astm.org.

ASTM. 2015. ASTM C1324-15, *Test Method for Examination and Analysis of Hardened Masonry Mortar*, ASTM International, West Conshohocken, PA, www.astm.org.

ASTM. 2015a. ASTM E1105-15, *Standard Test Method for Field Determination of Water Penetration of Installed Exterior Windows, Skylights, Doors, and Curtain Walls, by Uniform or Cyclic Static Air Pressure Difference*, ASTM International, West Conshohocken, PA, www.astm.org.

ASTM. 2017a. ASTM E1996-17, *Standard Specification for Performance of Exterior Windows, Curtain Walls, Doors, and Impact Protective Systems Impacted by Windborne Debris in Hurricanes*, ASTM International, West Conshohocken, PA, www.astm.org.

ASTM. 2017b. ASTM D3679-17, *Standard Specification for Rigid Poly(Vinyl Chloride) (PVC) Siding*, ASTM International, West Conshohocken, PA, www.astm.org.

ASTM. 2017c. ASTM D7053/D7053M-17, *Standard Guide for Determining and Evaluating Causes of Water Leakage of Low-Sloped Roofs*, ASTM International, West Conshohocken, PA, www.astm.org.

ASTM. 2017d. ASTM C1177/C1177M-17, *Standard Specification for Glass Mat Gypsum Substrate for Use as Sheathing*, ASTM International, West Conshohocken, PA, www.astm.org.

ASTM. 2017e. ASTM E2128-17, *Standard Guide for Evaluating Water Leakage of Building Walls*, ASTM International, West Conshohocken, PA, www.astm.org.

ASTM. 2017f. ASTM E1592-05(2017), *Standard Test Method for Structural Performance of Sheet Metal Roof and Siding Systems by Uniform Static Air Pressure Difference*, ASTM International, West Conshohocken, PA, www.astm.org.

ASTM. 2018a. C803/C803M-18, *Standard Test Method for Penetration Resistance of Hardened Concrete*, ASTM International, West Conshohocken, PA, www.astm.org.

ASTM. 2018b. ASTM C856-18a, *Standard Practice for Petrographic Examination of Hardened Concrete*, ASTM International, West Conshohocken, PA, www.astm.org.

ASTM. 2018c. ASTM C926-18b, *Specification for Application of Portland Cement-Based Plaster*, ASTM International, West Conshohocken, PA, www.astm.org.

ASTM. 2019a. ASTM C1063-19, *Standard Specification for Installation of Lathing and Furring to Receive Interior and Exterior Portland Cement-Based Plaster*, ASTM International, West Conshohocken, PA, www.astm.org.

ASTM. 2019b. ASTM D3161/D3161M-19, *Standard Test Method for Wind-Resistance of Asphalt Shingles (Fan-Induced Method)*, ASTM International, West Conshohocken, PA, www.astm.org.

ASTM. 2019c. ASTM D7158/D7158M-19, *Standard Test Method for Wind Resistance of Asphalt Shingles (Uplift Force/Uplift Resistance Method)*, ASTM International, West Conshohocken, PA, www.astm.org.

Biggs, D.T. 2000. "Repairing Masonry Cracks." *Structure*, Spring 2000, pp. 25-31.

Biggs, D.T., and Forsberg, T.E. 2001. *Field Techniques for Mortar Replication*. Proceedings of 9th Canadian Masonry Symposium.

DASMA (Door & Access Systems Manufacturers Association International). 2013a. *Vertically Reinforced Sectional Garage Doors*. DASMA TDS 153. Available at https://www.dasma.com/PDF/Publications/TechDataSheets/CommercialResidential/TDS153.pdf. Accessed June 30, 2019.

DASMA. 2013b. *Wood Horizontal and Vertical Back Jamb Detail Guidelines*. DASMA TDS 156. Available at https://www.dasma.com/PDF/Publications/TechDataSheets/CommercialResidential/TDS156.pdf. Accessed June 30, 2019.

DASMA. 2018a. *General Code Inspection Guidelines for Sectional Garage Doors*. DASMA TDS 151. Available at https://www.dasma.com/PDF/Publications/TechDataSheets/CommercialResidential/TDS151.pdf. Accessed June 30, 2019.

DASMA. 2018b. *Connecting Garage Door Jambs to Building Framing*. DASMA TDS 161. Available at https://www.dasma.com/PDF/Publications/TechDataSheets/CommercialResidential/TDS161.pdf. Accessed June 30, 2019.

DASMA. 2018c. *General Code Inspection Guidelines for Wind Load Rated Garage Doors*. DASMA TDS 181. Available at https://www.dasma.com/PDF/Publications/TechDataSheets/CommercialResidential/TDS181.pdf. Accessed June 30, 2019.

FEMA (Federal Emergency Management Agency). 2004. FEMA P-424, *Design Guide for Improving School Safety in Earthquakes, Floods, and High Winds*.

FEMA. 2005a. FEMA 488, *Mitigation Assessment Team Report: Hurricane Charley in Florida*.

FEMA. 2005b. FEMA 489, *Mitigation Assessment Team Report: Hurricane Ivan in Alabama and Florida: Observations, Recommendations, and Technical Guidance*.

FEMA. 2006. FEMA 549, *Hurricane Katrina in the Gulf Coast: Mitigation Assessment Team Report, Building Performance Observations, Recommendations, and Technical Guidance*.

FEMA. 2007a. FEMA 543, *Design Guide for Improving Critical Facility Safety from Flooding and High Winds*.

FEMA. 2007b. FEMA 577, *Design Guide for Improving Hospital Safety in Earthquakes, Floods, and High Winds*.

FEMA. 2007c. FEMA 1699 DR-KS, *Tornado Damage Investigation*.

FEMA. 2009a. FEMA P-431, *Tornado Protection: Selecting a Refuge Area in Buildings, Second Edition*.

FEMA. 2009b. FEMA P-757: *Mitigation Assessment Team Report: Hurricane Ike in Texas and Louisiana: Building Performance Observations, Recommendations, and Technical Guidance*.

FEMA. 2010a. FEMA P-424, *Design Guide for Improving School Safety in Earthquakes, Floods, and High Winds*.

FEMA. 2010c. FEMA P 499, Technical Fact Sheet 7.5, *Minimizing Water Intrusion Through Roof Vents in High-Wind Regions*. Available at https://www.fema.gov/media-library-data/20130726-1537-20490-9128/fema499_7_5.pdf. Accessed June 30, 2019.

FEMA. 2011a. Tornado Recovery Advisory 6 (RA6), *Critical Facilities Located in Tornado-Prone Regions: Recommendations for Architects and Engineers*. Available at https://www.fema.gov/media-library-data/20130726-1801-25045-8691/ra6_2011_critical_facilities.pdf. Accessed June 30, 2019.

FEMA. 2012. FEMA P-908, *Mitigation Assessment Team Report – Spring 2011 Tornadoes: April 25-28 and May 22; Building Performance Observations, Recommendations, and Technical Guidance*.

FEMA. 2014. FEMA P-1019, *Emergency Power for Critical Facilities: A Best Practice Approach to Improving Reliability*.

FEMA. 2015. FEMA P-361, *Safe Rooms for Tornadoes and Hurricanes: Guidance for Community and Residential Safe Rooms*.

FEMA. 2017. *Best Available Refuge Area Checklist*. Available at https://www.fema.gov/media-library-data/1511352781305-a1d9983e3e78bc7bc2703fead0c58905/BARA_NEW_CHECKLIST_11-20-17_508.pdf. Accessed June 30, 2019.

FEMA. 2018a. FEMA P-2020, *Hurricanes Irma and Maria in Puerto Rico: Building Performance Observations, Recommendations, and Technical Guidance*. Available at https://www.fema.gov/media-library/assets/documents/173789. Accessed June 30, 2019.

FEMA. 2018b. FEMA P-2021, *Hurricanes Irma and Maria in the U.S. Virgin Islands: Building Performance Observations, Recommendations, and Technical Guidance*. Available at https://www.fema.gov/media-library/assets/documents/170486. Accessed June 30, 2019.

FEMA. 2018c. Hurricanes Irma and Maria in the U.S. Virgin Islands Recovery Advisory 5 (RA5), *Rooftop Solar Panel Attachment: Design, Installation, and Maintenance*. Available at https://www.fema.gov/media-library/assets/documents/158123. Accessed June 30, 2019.

FEMA 2018d. "What is Mitigation?" (webpage). https://www.fema.gov/what-mitigation. Accessed June 30, 2019.

FEMA. 2019. Hurricane Michael in Florida Recovery Advisory 1 (RA1), *Successfully Retrofitting Buildings for Wind Resistance*. Available at https://www.fema.gov/media-library/assets/documents/180337. Accessed June 30, 2019.

FBC (Florida Building Code). 2017a. Testing Application Standard (TAS) No. 100(A)-95, *Test Procedure for Wind and Wind Driven Rain and/or Increased Windspeed Resistance of Soffit Ventilation Strip and Continuous or Intermittent Ventilation System Installed at the Ridge Area*. Available at https://codes.iccsafe.org/content/FTPC2017/testing-application-standard-tas-no-100-a-95-test-procedure-for-wind-and-wind-driven-rain-resistance-and-or-increased-windspeed-resistance-of-soffit-ventilation-strip-and-continuous-or-intermittent-ventilation-system-installed-at-the-ridge-area. Accessed June 30, 2019.

FBC. 2017b. TAS No. 106, *Standard Procedure for Field Verification of the Bonding of Mortar or Adhesive Set Tile Systems and Mechanically Attached, Rigid, Discontinuous Roof Systems*. Available at https://codes.iccsafe.org/content/FTPC2017/testing-application-standard-tas-no-106-standard-procedure-for-field-verification-of-the-bonding-of-mortar-or-adhesive-set-tile-systems-and-mechanically-attached-rigid-discontinuous-roof-systems?site_type=public. Accessed June 30, 2019.

FBC. 2017c. TAS No. 201-94, *Impact Test Procedure*. Available at https://codes.iccsafe.org/content/FTPC2017/testing-application-standard-tas-201-94-impact-test-procedures. Accessed June 30, 2019.

FBC. 2017d. TAS No. 203, *Criteria for Testing Products Subject to Cyclic Wind Pressure Loading*. Available at https://codes.iccsafe.org/content/FTPC2017/testing-application-standard-tas-203-94-criteria-for-testing-products-subject-to-cyclic-wind-pressure-loading. Accessed June 30, 2019.

Florida Roofing, Sheet Metal and Air Conditioning Contractors Association, Inc. and the Tile Roofing Institute. 2012. *Florida High Wind Concrete and Clay Roof Tile Installation Manual*. Available at https://tileroofing.org/wp-content/uploads/TRI-Florida-HW-Tile-Installation-Manual-Revised-5th-Ed-9-24-14.pdf. Accessed June 30, 2019.

FM Approvals LLC. 2011. *Standard for Flexible Photovoltaic Modules*, Class Number 4476. Available at https://www.fmapprovals.com/products-we-certify/understanding-the-benefits/fm-approved-photovoltaic-modules. Accessed June 30, 2019.

FM Approvals LLC. 2016. *Approval Standard for Roof-Mounted Rigid Photovoltaic Module Systems*, Class Number 4478. Available at https://www.fmapprovals.com/products-we-certify/understanding-the-benefits/fm-approved-photovoltaic-modules. Accessed February 22, 2019.

FM Global. 2012. *Loss Prevention Data Sheet 7-106: Ground-Mounted Solar Photovoltaic Power*. Available at https://www.fmglobal.com/research-and-resources/fm-global-data-sheets. Accessed June 30, 2019.

FM Global. 2016. *Loss Prevention Data Sheet 1-29: Roof Deck Securement and Above-Deck Roof Components*. Available at https://www.fmglobal.com/research-and-resources/fm-global-data-sheets. Accessed June 30, 2019.

ICC (International Code Council). 2014. ICC 500, 2014 *Standard for the Design and Construction of Storm Shelters*.

ICC. 2017. *Florida Building Code*.

ICC. 2018a. *International Building Code*. Country Club Hills, IL: ICC.

ICC. 2018b. *International Residential Code*. Country Club Hills, IL: ICC.

ICC-ES (International Code Council Evaluation Service, LLC). 2012. *Acceptance Criteria for Modular Framing Systems Used to Support Photovoltaic (PV) Panels* (AC 428). Approved November 2012. Previously approved June 2012, February 2011, and October 2010.

IEEE (Institute of Electrical and Electronics Engineers). 2017. IEEE C2-2017, *National Electrical Safety Code* (NESC).

Infraspection Institute. 2016a. *Standard for Infrared Evaluation of Building Envelopes*.

Infraspection Institute. 2016b. *Standard for Infrared Evaluation of Insulated Roofs*.

IMI (International Masonry Institute). 2009. *Base of Wall Detail – Drainage Flashing*. Masonry Detailing Series 01.030.0304. Available at http://imiweb.org/01-030-0304-drainage-flashing/. Accessed June 30, 2019.

Mooneghi, Asghari, T.L. Smith, P. Irwin, and A. Gan Chowdhury. 2017. "Concrete Roof Pavers: Wind Uplift Aerodynamic Mechanisms and Design Guidelines – A Proposed Addition to ANSI/SPRI RP-4," *Proceedings of the 32nd RCI International Convention and Trade Show*, March 2017. Available at http://rci-online.org/wp-content/uploads/2017-cts-mooneghi-smith-irwin-chowdhury.pdf. Accessed June 30, 2019.

National Park Service webpage. (Updated 2018, February 6). Mohs Hardness Scale. https://www.nps.gov/articles/mohs-hardness-scale.htm. Accessed July 23, 2019.

NOAA NWS (National Oceanic and Atmospheric Administration, National Weather Service). 2017. Storm Prediction Center Severe Weather Database Files (1950-2017), 1950-2017_actual_tornadoes.csv. Database. Available at https://www.spc.noaa.gov/wcm/#data. Accessed June 30, 2019.

Oak Ridge National Laboratory. 2013. SERRI (Southeast Region Research Initiative) Report 90100-02. *Phase II Report: Investigation of the Wind Resistance of Asphalt Shingle Roof Coverings*. Based on work supported by the U.S. Department of Homeland Security under U.S. Department of Energy Interagency Agreement 43WT10301. June 30, 2013.

Ramsdell, J.V. and Rishel, J.P. 2007. *Tornado Climatology of the Contiguous United States*, U.S. Nuclear Regulatory Commission, NUREG/CR-4461, Rev 2, Washington, DC, 2007.

Available at http://pbadupws.nrc.gov/docs/ML0708/ML070810400.pdf. Accessed June 30, 2019.

RILEM (International Union of Laboratories and Experts in Construction Materials, Systems and Structures). RILEM TC 166-MRS. 2003. *Condition Assessment of Roofs*. Final Report of the Condition Assessment Task Group, RILEM TC 166-RMS/CIB W083 Joint Committee on Roofing Materials and Systems.

SEAOC (Structural Engineering Association of California). 2017. *Wind Design for Solar Arrays*, SEAOC Wind Subcommittee and SEAOC Solar Photovoltaic Systems Sub-Committee. SEAOC Report PV2-2017.

SEAOC. 2018. *Wind Design Manual Based on 2018 IBC and ASCE/SEI 7-16*.

SEI/ASCE (Structural Engineering Institute/American Society of Civil Engineers). 1999. SEI/ASCE 11-99, *Guideline for Structural Condition Assessment*.

SEI/ASCE. 2014. SEI/ASCE 30-14, *Guideline for Condition Assessment of the Building Envelope*.

Smith, T.L. 2001. *Low-Slope Roofing II*. National Council of Architectural Registration Boards.

Smith, T.L. 2011. "Wind Vulnerability Assessment of Roof Systems and Rooftop Equipment for Critical Facilities: A Preliminary Protocol for Design Professionals," *Proceedings of the 2011 Structures Congress*, pp. 1594 – 1605, ASCE. Available at https://ascelibrary.org/doi/10.1061/41171%28401%29139. Accessed June 30, 2019.

Tile Roofing Institute and Western States Roofing Contractors Association. 2015. *Concrete and Clay Roof Tile Installation Manual*. Available at https://tileroofing.org/wp-content/uploads/TRI-Installation-Guide-2015.pdf. Accessed June 30, 2019.

TMS (The Masonry Society). 2016. TMS 402/602 *Building Code Requirements and Specification for Masonry Structures*. The Masonry Society, Longmont, CO. Available at https://masonrysociety.org/product/tms-402-602-2016/.

VSI (Vinyl Siding Institute). 2018. 2018 *Vinyl Siding Installation Manual*. Available at https://www.vinylsiding.org/wp-content/uploads/2018/08/2018-Vinyl-Siding-Installation-Manual-.pdf. Accessed June 30, 2019.

WWPA (Western Wood Products Association). 2007. *Natural Wood Siding: Selection, Installation, and Finishing*. Available at https://issuu.com/masters123/docs/natural-wood-siding-tg8. Accessed June 30, 2019.

FEMA