Attachment of Rooftop Equipment in High-Wind Regions

HURRICANES IRMA AND MARIA IN THE U.S. VIRGIN ISLANDS *Recovery Advisory 2, March 2018*

Purpose and Intended Audience

Observations after the 2017 hurricanes have once again shown that rooftop equipment is often damaged during high winds. Damaged equipment can impair the operation of the facility, and the equipment can detach and become damaging wind-borne debris. In addition, water can enter the facility where equipment was displaced or damaged. The most common problems typically relate to inadequate equipment anchorage, inadequate strength of the equipment itself, and corrosion of equipment and connectors.

The purpose of this Recovery Advisory is to recommend practices that will enhance the wind resistance of rooftop equipment in high-wind regions[1] such as the U.S. Virgin Islands. This guidance is intended for architects, engineers, contractors, building officials, and building owners. Additional detailed criteria can be found in FEMA's *Design Guide for Improving School Safety in Earthquakes, Floods, and High Winds* (FEMA P-424, 2010).

Design Guide for Improving School Safety in Earthquakes, Floods, and High-Winds (FEMA P-424, 2010)

FEMA P-424 provides guidance for the protection of school buildings from natural disasters. The guidance concentrates on grade schools, K-12. FEMA P-424 covers earthquakes, floods, and high winds. Additional recommendations applicable to securing rooftop equipment in the U.S. Virgin Islands can be found here: https://www.fema.gov/media-library/assets/documents/5264

Key Issues

1. **Facilities in the planning stage:** Designers should calculate wind loads on rooftop equipment and specify equipment that has sufficient strength to resist the calculated loads. Equipment attachments must be well detailed and capable of resisting the high wind loads. During construction, contractors should implement quality control and quality assurance procedures to confirm that the design intent is met. Design criteria are provided in this Recovery Advisory. In high wind areas that also have moderate or high seismic loads, designers should specify equipment attachment that has sufficient strength to resist the wind and earthquake design loads.
2. **Existing rooftop equipment:** It is recommended that the building owner hire a qualified architect or engineer to perform a wind vulnerability assessment. If significant vulnerabilities are identified, corrective action to mitigate the vulnerabilities is recommended.
3. **Preparations prior to hurricane landfall:** It is recommended that the building owner have their maintenance staff or a contractor perform the following:
   - Remove debris from roof drains, scuppers, and gutters.
   - Remove loose objects (such as buckets, lumber, and sheet metal) from the roof.
   - Install 3 inch wide (minimum) truck cargo straps around heating, ventilation, and air conditioning (HVAC) units. Install 2 or 3 straps around each unit (depending upon unit height) and straps over/under the unit

Public Assistance Program and Policy Guide (FEMA PAPPG, 2018)

According to the *PAPPG*, additional grant funding may be available on eligible repairs to provide hazard mitigation against future events. For more information, see *PAPPG* Appendix J, Section III, B. Roof-Mounted Equipment: "Secure to roof top via a continuous load path, using tie-downs, straps, or other anchoring systems that will resist expected wind forces."

[1] In this advisory, a high-wind region means an area where the basic (design) wind speed is greater than 115 miles per hour for a Risk Category II building, as defined the 2016 edition of the American Society of Civil Engineers Standard 7, *Minimum Design Loads and Associated Criteria for Buildings and Other Structures* (ASCE 7-16, 2016). Using this criterion, all the USVI is considered a high-wind region.

where it projects beyond the curb.

- If there is sufficient time, check attachment of all rooftop equipment to its curbs or other mountings, and add anchors if the existing attachment is inadequate. When performing emergency attachment of fans, relief air hoods, and small HVAC units to wood or sheet metal curbs, space the screws (#12 stainless steel, if available) at approximately 5 inches on center (o.c.) at each side of the equipment.

4. **After a high-wind event:** Post-event assessments of buildings should be done by qualified inspectors to determine any damages to rooftop equipment. If there are damages, this is an opportunity to enhance the wind-resistance described in this Recovery Advisory during the repair process.

Table 1 is the minimum attachment schedule provided in FEMA P-424 and presents an engineered solution for equipment attachment. Although the table gives a wind speed conversion from the American Society of Civil Engineers Standard 7, *Minimum Design Loads for Buildings and Other Structures* (ASCE 7-05, 2006) to ASCE 7-10, the conversion to ASCE 7-16 would be the same.

This Recovery Advisory Addresses

- Existing facilities and those in the planning or post-event repair stage, including residential, commercial/industrial buildings, and critical facilities.
- Attachment of HVAC units, AC condensers, rooftop ductwork, exhaust fans, relief air hoods, condensers, boiler stacks, gas and condensate drain lines, electrical conduits, lightning protection systems, satellite dishes, and communications antennae.
- Use of equipment screens and mechanical penthouses, with links to further information.

Attachment of rooftop solar panels is discussed separately in U.S. Virgin Islands Recovery Advisory 5.

Design and Construction Mitigation Guidance

This section provides examples of various types of rooftop equipment problems that were observed after the 2017 hurricanes. Unless otherwise noted, all photographs are from Hurricanes Irma and Maria in the U.S. Virgin Islands. This section also provides design and construction mitigation guidance based on Section 6.3.4 (Nonstructural Systems and Equipment) and 6.4.3 (Remedial Work on Existing Facilities, Exterior Mounted Equipment) in FEMA P-424, along with recommendations based on professional judgement.

As an initial step in the design process or post-event repairs, it is recommended that designers calculate wind loads on rooftop equipment in accordance with ASCE 7-16 or the local building code, whichever procedure results in the highest loads. However, ASCE 7 does not result in load criteria for all types of rooftop equipment (such as lightning protection systems); guidance is presented below to address this shortcoming.

HVAC Units

At the school shown in Figure 1, a large number of HVAC units[2] blew off their curbs, and equipment debris punctured the roof membrane in numerous areas. Water intrusion at curb openings and roof punctures caused extensive interior damage.

To anchor small HVAC units, exhaust fans, and relief air hoods, the minimum attachment schedule provided in Table 1 is recommended. For HVAC units that are larger than the units listed in Table 1, unit-specific wind loads should be calculated, and appropriate connections specified. The attachment of the curb to the roof deck also needs to be designed and constructed to resist the wind loads.

Figure 1. HVAC units blown off their curbs (red arrows). Curb openings were temporarily covered with plywood. Patches had been installed at membrane punctures (blue arrow). Hurricane Harvey, Texas.

[2] HVAC units are also known as rooftop units (RTU).

Table 1. Number of #12 screws for base case attachment of rooftop equipment, from FEMA P-424 Table 6.1.

Case No.	Curb Size and Equipment Type	Equipment Attachment	Fastener Factor for Each Side of Curb or Flange
1	12 in. x 12 in. Curb with Gooseneck Relief Air Hood	Hood Screwed to Curb	1.6
2	12 in. x 12 in. Gooseneck Relief Air Hood with Flange	Flange Screwed to 22 Gauge Steel Roof Deck	2.8
3	12 in. x 12 in. Gooseneck Relief Air Hood with Flange	Flange Screwed to $^{15}/_{32}$ in. Gauge Steel Roof Deck	2.9
4	24 in. x 24 in. Curb with Gooseneck Relief Air Hood	Hood Screwed to Curb	4.6
5	24 in. x 24 in. Gooseneck Relief Air Hood with Flange	Flange Screwed to 22 Gauge Steel Roof Deck	8.1
6	24 in. x 24 in. Gooseneck Relief Air Hood with Flange	Flange Screwed to $^{15}/_{32}$ in. OSB Roof Deck	8.2
7	24 in. x 24 in. Curb with Exhaust Fan	Fan Screwed to Curb	2.5
8	36 in. x 36 in. Curb with Exhaust Fan	Fan Screwed to Curb	3.3
9	5 ft. 9 in. x 3 ft. 8 in. Curb with 2 ft. 8 in. High HVAC Unit	HVAC Unit Screwed to Curb	4.5*
10	5 ft. 9 in. x 3 ft. 8 in. Curb with 2 ft. 8 in. High Relief Air Hood	Hood Screwed to Curb	35.6*

Notes to Table 1:

1. The loads are based on ASCE 7-05. The resistance includes equipment weight. When using ASCE 7-10, convert the 7-10 Category III / IV basic wind speed to a 7-05 basic wind speed as follows: 7-10 speed divided by the square root of (1.15 x 1.6) = 7-05 speed.
2. The Base Case for the tabulated numbers of #12 screws (or ¼ pan-head screws for flange-attachment) is a 90 mph basic wind speed, 1.15 importance factor, 30 ft. building height, Exposure C, using a safety factor of 3. The 7-05 Base Case is equivalent to 120 mph for 7-10 Risk Category III and IV buildings.
3. For other basic wind speeds, multiply the tabulated number of #12 screws by $(V_D^2/90^2)$ to determine the required number of #12 screws (or ¼ pan-head screws) for the desired basic wind speed, V_D (mph).
4. For other roof heights up to 200 ft., multiply the tabulated number of #12 screws by (1.00 + 0.003 [h - 30]) to determine the required number of #12 screws or ¼ pan-head screws for buildings between 30 ft. and 200 ft.
   - Example A: 24 in. x 24 in. exhaust fan screwed to curb (table row 7), Base Case conditions (see Note 1): 2.5 screws per side; therefore, round up and specify 3 screws per side.
   - Example B: 24 in. x 24 in. exhaust fan screwed to curb (table row 7), Base Case conditions, except 120 mph: 120^2 x 1 ÷ 90^2 = 1.78 x 2.5 screws per side = 4.44 screws per side; therefore, round down and specify 4 screws per side.
   - Example C: 24 in. x 24 in. exhaust fan screwed to curb (table row 7), Base Case conditions, except 150 ft. roof height: 1.00 + 0.003 (150 ft. – 30 ft.) = 1.00 + 0.36 = 1.36 x 2.5 screws per side = 3.4 screws per side; therefore, round down and specify 3 screws per side.

* This factor only applies to the long sides. At the short sides, use the fastener spacing used at the long sides.

Figure 2. HVAC units at this nursing home were blown completely off the roof. Hurricane Harvey, Texas.

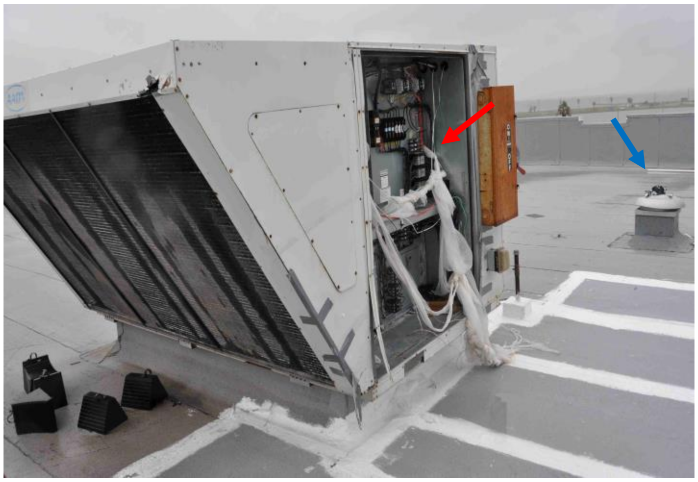

Figure 3. Blown-off access panel at a hotel (red arrow) and blown-off fan cowling (blue arrow). Hurricane Harvey, Texas.

At the nursing home in Figure 2, several HVAC units blew off the roof. Blown-off equipment can injure people or damage lower roofs, adjacent buildings, or vehicles. Although people are normally not outdoors during a hurricane, it is not uncommon for people to go to a hurricane-evacuation shelter or a hospital during a hurricane.

Another common HVAC unit problem is blow-off of access panels (Figure 3). Blown-off panels can puncture and tear roof membranes and allow rain to enter the building. Unless the equipment manufacturer specifically engineers the panel attachment to resist the design wind load, the following from FEMA P-424, Chapter 6 is recommended:

> *Job-site modifications, including attaching hasps and locking devices like carabiners, are recommended. The modification details need to be customized. Detailed design may be needed after the equipment has been delivered to the job site. Modification details should be approved by the equipment manufacturer (FEMA P-424, 2010, page 6.101).*

In addition to blown-off of access panels, the sheet metal unit enclosure (cabinet) may be blown away as shown in Figure 4. New HVAC units should be designed and fabricated by the equipment manufacturer to resist the design wind and seismic loads at the location where the units are installed. Documentation should be provided by the equipment manufacturer to the designer, contractor, and local officials showing that the unit has sufficient strength to meet the design loads. For existing units where the strength of the unit enclosure is unknown, installation of truck cargo straps around and over units prior to hurricane landfall is recommended to avoid enclosure blow-off.

Figures 5 and 6 illustrate membrane damage that was attributed to blown-off access panels and unit enclosures. Figure 6 shows a punctured roof membrane at a school. Several punctures had been temporarily repaired at the time of observation. However, three unrepaired punctures or tears were found. Small tears and punctures can be difficult to see.

Figure 4. Blown-off unit enclosures at a medical clinic.

Figure 5. Torn roof membrane near the HVAC unit show in in Figure 4.

Figure 6. Punctured roof membrane at a school (pen for scale).

Exhaust fans

Exhaust fans are frequently blown off their curbs because too few fasteners were used for attachment. Table 1 specifies the number of screws for attachment. Fan cowlings are also frequently blown off (Figure 3). Blown-off cowlings can tear roof membranes. Unless the fan manufacturer specifically engineered the cowling attachment to resist the design wind load, FEMA P-424 recommends job-site installation of cable tie-downs (metal straps may also be used). The fan cowling shown in Figure 7 had two tie-down straps (P-424 recommends tie-downs at each side of the curb). This fan was impacted by wind-borne debris. Although it is often impractical to place all equipment (such as fans) in penthouses, FEMA P-424 recommends doing so, to the extent possible, to avoid debris damage.

Condensers

In lieu of placing rooftop-mounted condensers on wood sleepers resting on the roof, condensers should be anchored to metal equipment stands or curbs made of concrete, sheet metal, or wood to avoid blow-off (Figure 8). Additionally, it is recommended that mechanical fasteners be used to attach the condensers rather than adhesive. At one school, several condensers were attached with adhesive to plastic pedestals (Figure 9). All the condensers were blown over, and some were blown off the roof. Additionally, some of the pedestals were broken.

Figure 7. Damaged fan cowling with damaged strap (red arrow). Note the lightning protection system conductor (blue arrow).

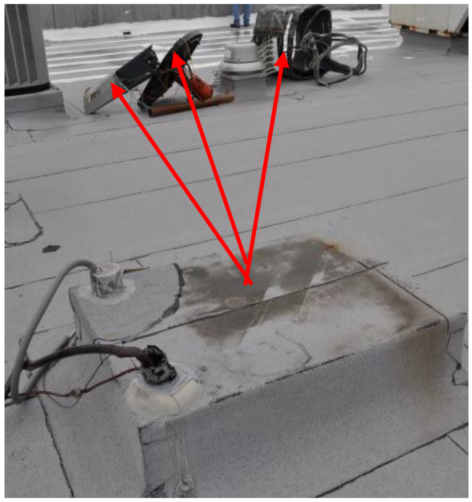

Figure 8. The condenser at this hotel was placed on the curb and was not anchored. Hurricane Harvey, Texas.

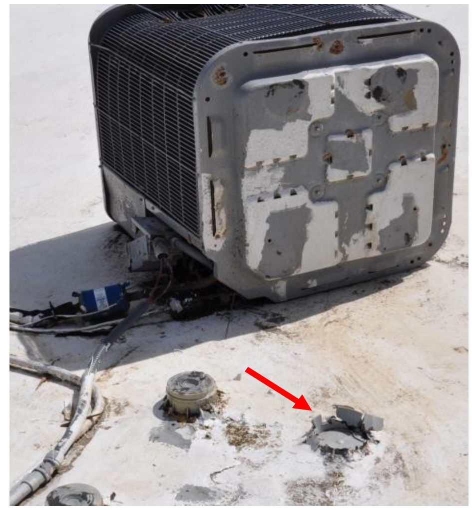

Figure 9. This condenser was blown off the plastic pedestals to which it was attached. One of the pedestals was broken (red arrow).

In addition to anchoring the base of the condenser to the stand or curb, FEMA P-424 recommends installation of 2 metal tie-down straps (cables may also be used) with 2 side-by-side #12 screws or bolts with proper end and edge distances at each strap end. Figure 10 shows a condenser with enhanced attachment, similar to the guidance in FEMA P-424.

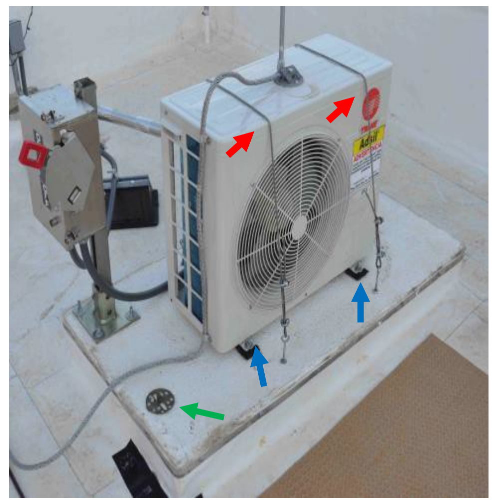

Figure 10. This condenser was bolted to the curb (blue arrows), and had tie-down cables (red arrows). The lightning protection system conductor is no longer secured by its connector (green arrow).

Grade-mounted Condensers

Grade-mounted condensers should also be mechanically attached to their support slab or platform.

Boiler and Exhaust Stacks

Toppled stacks, as shown at the building in Figure 11, can allow water to enter the building at the stack penetration, damage the roof membrane, and become wind-borne debris. FEMA P-424 recommends that wind loads on stacks be calculated and guy-wires designed and installed to resist the loads. Additionally, it recommends that the building owner have guy-wires inspected annually to confirm that they are taut.

Rooftop Ductwork

FEMA P-424 recommends that ductwork not be installed on the roof. If ductwork is installed on the roof, it recommends that the ducts' gauge and the method of attachment be able to resist the design wind loads.

For existing ductwork, recommendations are provided regarding flexible connectors between the ducts and fans. Additionally, it is recommended that a wind vulnerability assessment of rooftop ducts be performed.

Figure 11. A boiler stack at this hospital toppled (red arrow). A fan (blue arrow) and cowling (green arrow) were blown off, and the lightning protection system detached.

Natural Gas Lines, Condensate Drain Lines, and Conduits

Rooftop natural gas lines, condensate drain lines, and conduit supports often do not provide lateral or uplift resistance. Figure 12 shows a support detail that provides lateral and uplift resistance for a gas line. In this example, at periodic gas line supports, a steel angle was welded to a pipe that was anchored to the roof deck. A strap was looped over the gas line and bolted to the support angle. This detail is also applicable to anchorage of condensate drain lines and conduits. As much as possible, the conduit should be run below deck; however, in retrofits, conduit is often installed above the roof membrane.

Figure 13 illustrates conduit installed above the roof membrane that was not adequately secured.

Figure 12. Enhanced gas line support detail using a strap. From FEMA P-424 (Figure 6-100).

Electrical Service Mast

While underground service is typically preferred, it may not be feasible at all locations in the USVI. At the electrical service mast in Figure 14, the overhead power line collapsed and pulled on the service mast, which resulted in rupture of the mast flashing. FEMA P-424 recommends using underground service. Where overhead service is provided, it recommends that the service mast not penetrate the roof in order to prevent water leakage at ruptured flashing.

Figure 15 shows the use of a concrete pylon. The overhead power line ran to a service mast that was anchored to the pylon. The service was then run underground to the house. With this setup, collapse of the overhead line does not result in roof damage.

Figure 13. The displaced electrical conduit used supports (red circle) that rested on the roof. Displaced HVAC unit (red arrow) and condenser (blue arrow).

Satellite Dishes

As shown in Figure 16, the base plates of the satellite dish support legs were ballasted with solid concrete masonry units, which provided inadequate wind resistance. Displaced dishes can rupture roof membranes and cause other damage or injury. FEMA P-424 recommends that ballasts not be used to anchor satellite dishes in high-wind areas. Rather, the dish wind load should be calculated and a suitable mechanical attachment to the roof deck or structure should be designed.

Lightning Protection Systems (LPS)

LPSs frequently become disconnected from rooftops during hurricanes. Displaced LPS components can puncture and tear roof membranes, allowing water to leak into buildings (Figure 17). Prolonged and repeated slashing of the roof membrane by loose conductors (cables) and puncturing by air terminals (lightning rods) can result in lifting and peeling of the membrane. When displaced, the LPS is no longer capable of providing lightning protection to the area around the displaced conductors and air terminals.

Current LPS standards do not require enhanced attachment of LPS in high-wind regions. FEMA P-424 provides enhanced attachment guidance for several types of roof systems, including parapet attachment methods and the use of membrane flashing strips (Figure 18).

Figure 14. A collapsed overhead power line pulled over this service mast which caused flashing rupture (yellow oval).

Figure 15. Overhead power line terminated at a service mast (yellow circle) anchored to a concrete pylon (red arrow). Service ran underground from the pylon to the house.

Figure 16. The satellite dish at this hospital was ballasted with concrete masonry units. The dish was nearly blown off the roof. Hurricane Harvey, Texas.

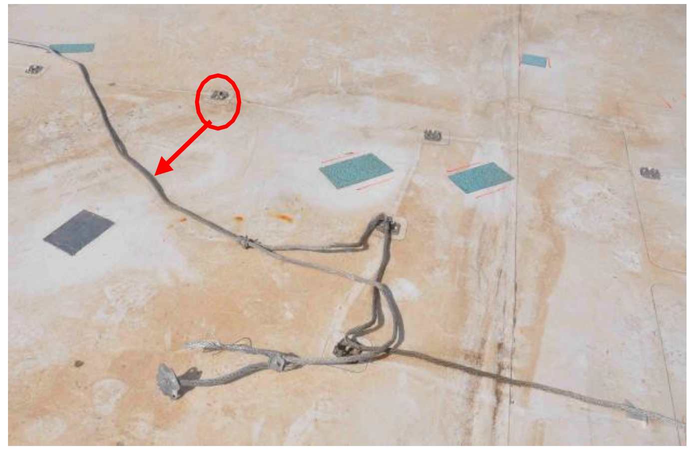

Figure 17. Detached LPS at an airport terminal. Temporary patches had been made after the hurricane.

Figure 18. Enhanced LPS attachment, using intermittent roof membrane flashing strips. From FEMA P-424 (Figure 6-114).

Seismic Considerations

Seismic hazard is also an important consideration for the USVI. The following publications provide general information on fasteners and edge distances:

- *Installing Seismic Restraints for Mechanical Equipment* (FEMA 412, 2002)
- I*nstalling Seismic Restraints for Electrical Equipment* (FEMA 413, 2004)
- *Installing Seismic Restraints for Duct and Pipe* (FEMA 414, 2004) References and Resources

ASCE 7-16

Previous editions of ASCE 7 did not provide load criteria for equipment on roofs greater than 60 ft. above grade. The 60 ft. limit has been eliminated in the 2016 edition. The criteria in sections 29.4.1 and 30.10 now apply to all roof heights.

The 2016 edition also provides new information regarding loads on equipment screens in Section C29.4.1.

Roof-mounted Communication Towers/Antennae

Collapse of communication towers mounted on the roof or penthouse walls is common during high-wind events. These failures often result in complete loss of communication capabilities. In addition to the disruption of communications, collapsed towers can puncture roof membranes. FEMA P-424 provides guidance on determining design wind loads and determining wind resistance of existing towers.

References

American Society of Civil Engineers (ASCE). 2017. *Minimum Design Loads and Associated Criteria for Buildings and Other Structures.* ASCE/SEI 7-16. https://www.asce.org/structural-engineering/asce-7-and-sei-standards/

FEMA. 2002. *Installing Seismic Restraints for Mechanical Equipment.* FEMA 412. https://www.fema.gov/media-library/assets/documents/2142

FEMA. 2004. *Installing Seismic Restraints for Electrical Equipment*. FEMA 413. https://www.fema.gov/media-library/assets/documents/843

FEMA. 2004. *Installing Seismic Restraints for Duct and Pipe.* FEMA 414. https://www.fema.gov/media-library/assets/documents/848

FEMA. 2010. *Design Guide for Improving School Safety in Earthquakes, Floods, and High Winds, Second Edition*. FEMA P-424. https://www.fema.gov/library/viewRecord.do?id=1986

FEMA. 2017. *Safer, Stronger, Smarter: A Guide to Improving School Natural Hazard Safety*. FEMA P-1000. https://www.fema.gov/media-library/assets/documents/132592

FEMA. 2018. *FEMA Public Assistance Program and Policy Guide*. FEMA PAPPG. https://www.fema.gov/media-library/assets/documents/111781

Resources

American National Standards Institute (ANSI), American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE). 2017. *Method of Testing for Rating Seismic and Wind Restraints.* ANSI/ASHRAE 171-2017. https://webstore.ansi.org/RecordDetail.aspx?sku=ANSI%2FASHRAE+Standard+171-2017

FEMA. 2007. *Design Guide for Improving Hospital Safety in Earthquakes, Floods, and High Winds*. FEMA 577. https://www.fema.gov/library/viewRecord.do?id=2739

FEMA. 2007. *Design Guide for Improving Critical Facility Safety from Flooding and High Winds.* FEMA 543. https://www.fema.gov/library/viewRecord.do?id=2441

Useful Links

FEMA. 2018. *FEMA U.S. Virgin Islands.* FEMA U.S. Virgin Islands Recovery Facebook Page. https://www.facebook.com/FEMAUSVirginIslands

Note to readers: This page was created for the Hurricanes Irma and Maria recovery process and is regularly updated with useful information.

For more information, see the FEMA Building Science Frequently Asked Questions Web site at https://www.fema.gov/frequently-asked-questions-building-science.

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