Dry Floodproofing: Planning and Design Considerations

Purpose and Intended Audience

The purpose of this Recovery Advisory is to provide guidance on the design of dry floodproofing measures to reduce flood damage and limit interruption of building services. This advisory incorporates observations made by the Federal Emergency Management Agency (FEMA) Mitigation Assessment Teams (MATs) in Texas and Florida after Hurricanes Harvey and Irma. It describes best design practices and successful implementation of dry floodproofing, as well as lessons learned from failures. The information in this advisory is directed toward existing and new non-residential facilities.

This guidance, along with other FEMA publications related to dry floodproofing, should be used by building owners and design professionals examining ways to reduce future risk. It will also be useful to communities and building owners preparing designs and proposals for FEMA Section 404 Hazard Mitigation grants and hazard mitigation elements included in recovery funding available through FEMA Section 406 Public Assistance. To improve resiliency in future flooding events, lessons learned and best practices from the MATs can be incorporated into retrofits when dry floodproofing measures are applied to existing buildings and when designing dry floodproofing systems for new buildings.

The audience for this advisory includes building owners, operators, and managers; architects; engineers; building officials; contractors; and local government officials responsible for public building planning, design, and maintenance.

Key Issues

The key issues identified by the MATs during field visits in Texas and Florida are shown in Table 1. A number of these key issues are discussed in detail in other FEMA publications (see the list of references and resources in this advisory) and not in this advisory. This advisory focuses on key issues to help fill information gaps or supplement guidance in other FEMA publications.

Dry Floodproofing

Dry floodproofing is a combination of measures that result in a structure, including its attendant utilities and equipment, being watertight, with all elements substantially impermeable to the entrance of floodwater and with structural components having the capacity to resist flood loads (ASCE 24; ASCE 2014).

The image below shows an example of dry floodproofing where a passive opening protection deployed to protect a below-grade loading dock was threatened by rising floodwaters.

Photograph courtesy of Andrew Hoyts, Hicks Ventures

FEMA Public Assistance Program Funding for Dry Floodproofing Projects

In addition to funding for repair and recovery projects, FEMA Public Assistance (PA) Program funding may be available for cost-effective hazard mitigation measures that increase resilience, such as dry floodproofing projects. For more information, refer to Chapter 2 Section VII.C., “Hazard Mitigation” of FEMA’s Public Assistance Program and Policy Guide (2018).
<table>
<thead>
<tr>
<th>Key Topic Areas</th>
<th>Discussed in this Advisory?</th>
<th>Additional FEMA Sources of Information</th>
</tr>
</thead>
<tbody>
<tr>
<td>Backup power</td>
<td>Yes</td>
<td>FEMA P-1019</td>
</tr>
<tr>
<td></td>
<td></td>
<td>FEMA P-348 (Chapter 5)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Iowa Floods of 2016 RA5</td>
</tr>
<tr>
<td>Building penetration elevations relative to base/design flood elevations</td>
<td>Yes</td>
<td>FEMA P-936 (Sections 2.6.3, 3.4, 3.9, and 3.10)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>FEMA P-259 (Chapter 5D)</td>
</tr>
<tr>
<td>Flood barrier penetrations and seepage control</td>
<td>Yes</td>
<td>FEMA P-312 (Chapters 7 and 8)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>FEMA P-936 (Section 3.4.3)</td>
</tr>
<tr>
<td>Issues with sewer system and stormwater systems (ejector pumps with back-flow</td>
<td>Yes</td>
<td>FEMA 259 (Sections 5D.10 and 5W.12)</td>
</tr>
<tr>
<td>preventers)</td>
<td></td>
<td>FEMA P-348 (Section 5.3)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>FEMA P-936 (Sections 2.2 and 3.7)</td>
</tr>
<tr>
<td>Rainfall behind the flood barrier</td>
<td>Yes</td>
<td>FEMA P-312 (Section 3.4.2; Chapters 7 and 8)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>FEMA P-936 (Sections 2.2.8 and 3.7)</td>
</tr>
<tr>
<td>Seepage disposal</td>
<td>Yes</td>
<td>FEMA P-936 (Sections 2.2.7 and 3.7)</td>
</tr>
<tr>
<td>Use of flood damage-resistant materials</td>
<td>Yes</td>
<td>FEMA TB 2</td>
</tr>
<tr>
<td></td>
<td></td>
<td>FEMA P-936 (Sections 3.2 and 3.9)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>See also *</td>
</tr>
<tr>
<td>Use of redundant systems and compartmentalization/layered protection</td>
<td>Yes</td>
<td>FEMA P-348 (Chapter 5)</td>
</tr>
<tr>
<td>Design flood elevation requirements</td>
<td>No</td>
<td>Hurricane Sandy RA5</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Iowa Floods of 2016 RA1</td>
</tr>
<tr>
<td>Hydrostatic forces and buoyancy</td>
<td>No</td>
<td>Hurricane Sandy RA2</td>
</tr>
<tr>
<td></td>
<td></td>
<td>FEMA P-936 (Section 2.2)</td>
</tr>
<tr>
<td>Performance of critical building systems</td>
<td>No</td>
<td>Hurricane Sandy RA2, RA4, and RA6</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Iowa Floods of 2016 RA3</td>
</tr>
<tr>
<td></td>
<td></td>
<td>FEMA P-348 (Chapter 5)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>FEMA P-936 (Section 2.6.3)</td>
</tr>
</tbody>
</table>

Note: Complete titles and URLs for each publication are presented at the end of this advisory.

RA = Recovery Advisory; TB = Technical Bulletin

*Refer also to Floodproof Commercial Construction: Working for Coastal Communities (Oak Ridge National Laboratory 2011)

**This Recovery Advisory Addresses**

- Observations of dry floodproofing system failures
- Flood vulnerability assessments
- Planning and pre-design considerations
- Design considerations

A companion advisory, titled Dry Floodproofing: Operational Considerations (Hurricane Irma in Florida, FL-RA1, 2018) describes deployment considerations (deployment, operations, maintenance, testing) for dry floodproofing.
Dry Floodproofing Planning and Design Considerations

Observations of Dry Floodproofing System Failures

Hurricanes Harvey and Irma caused numerous failures in dry floodproofing systems used to protect non-residential buildings, which led to extensive damage to mechanical, electrical, and plumbing system components, as well as building and interior finishes, and occasionally structural components. Based on the observations of FEMA’s MATs deployed after the hurricanes, the performance of dry floodproofing measures was highly variable, ranging from effective to completely ineffective. Observed failures at dry floodproofed buildings included overtopping of flood walls or barriers, failure of the opening protections, structural failure of flood barriers, failure to identify lowest point of floodwater entry, seepage issues, and sanitary sewer and stormwater system issues.

As a result of these failures, critical building systems located in basements and first floors were damaged and rendered inoperable. Even where opening protection succeeded in holding back most of the floodwater, seepage through the flood barrier and water entry through penetrations resulted in significant damage to interior finishes and building systems. In addition to failures, there were numerous observations of “near misses” where dry floodproofing measures and human intervention prevented widespread flood damage. If flood levels had been only slightly higher or if building managers had not taken action before the onset of flooding, many observed successes would have become failures. This section describes the types of failure modes the MATs observed after Hurricanes Harvey and Irma.

Key Terminology

**Flood Barrier:** The physical barrier, composed of opening protection, floor slab, and wall system, that separates floodwater from the dry floodproofed portion of the building.

**Opening Protection:** A cover, shield, or door that covers a window, doorway, loading dock access, or other opening in a building wall or floor. Sometimes called “closure device.”

**Floodwall:** A constructed barrier of flood damage-resistant materials to keep water away from or out of a specific area. Floodwalls surround a building and are typically offset from the exterior walls of the building; some floodwalls can be integrated into the building envelope. Floodwalls are considered a component of the overall flood barrier.

**Flood Entry Point:** Any opening, joint, gap, crack, low point, or other location through or over which floodwater can enter the dry floodproofed area.

Overtopping

Floodwalls and opening protection were overtopped in locations where the water surface elevation (WSE) exceeded that of the top of the flood barrier.

Failure of Opening Protection

Opening protection failed either because it was not properly sealed against its frame or because hydrostatic or hydrodynamic forces exceeded the structural capacity of the barrier. Figure 1 shows a submarine door that failed at its midpoint due to hydrostatic forces.

Structural Failure of Flood Barrier

Flood barriers failed in locations where the hydrostatic forces exceeded the capacity of the wall system. Other failures occurred in areas where abandoned building openings were infilled with materials, typically unreinforced masonry, that could not resist hydrostatic forces.

Figure 1: Structural failure of a submarine door from hydrostatic forces; the door failed along a weld in the door panel adjacent to a stiffener (red circle)
Photograph courtesy of Carlos Gutierrez, CSF Consulting
Failure to Identify and Protect Lowest Point of Entry

Buildings were flooded when dry floodproofing measures were incomplete and did not adequately protect the lowest point of entry from floodwater. Figure 2 shows a building where the low point in the flood barrier was not identified or protected, allowing floodwater to overtop the low point in the flood barrier.

Failure to Maintain Structural Integrity of the Flood Barrier

Basements and other below-grade areas were flooded due to large openings being cut through the foundation walls during construction or capital improvement projects. These openings were sealed without re-establishing structural integrity or impermeability. Sealing these openings without making them substantially impermeable and not re-establishing an adequate structural load path left a weakness in the flood barrier, making it vulnerable to floodwater entry and flood damage when exposed to hydrostatic forces. Figure 3 shows a 6-foot by 6-foot opening cut into a foundation wall to provide access for a construction project. After construction was completed, the opening was filled in with timber framing and gypsum wall board. During Hurricane Harvey, the timber-framed infill wall failed and allowed floodwater to fill the building.

Substantially Impermeable

According to the U.S. Army Corps of Engineers (USACE), a wall is considered substantially impermeable if it limits water accumulation to 4 inches in a 24-hour period (USACE 1995). In addition, sump pumps are required to control any seepage, and flood damage-resistant materials must be used in all areas where seepage is likely to occur. This standard is the minimum requirement; it is possible to achieve lower seepage rates, which is strongly encouraged by FEMA, particularly in new construction.

Seepage Issues

The MAT observed several types of seepage issues, described below.
Failure to remove seepage through flood barriers. Numerous buildings experienced damage to interior finishes as a result of water seeping through the flood barrier. Buildings that were not equipped to remove the seepage had several near misses as water came within inches of critical building systems. In addition to damaging building finishes, water leaking into buildings required basements to be evacuated, caused failures in pump control panels for sump pumps and potable water supply pumps, and damaged elevator systems. Figure 4 shows an example of water seepage at a submarine door.

Unsealed penetrations through flood barriers. The MAT observed instances of improperly sealed or unsealed penetrations in flood barriers, such as for utilities, failing and allowing floodwater to enter buildings. Even buildings with extensive and redundant dry floodproofing systems were flooded because of penetrations for utilities passing through the flood barrier not being properly waterproofed and sealed. Figure 5 shows an example of unsealed penetrations that allowed floodwater to enter and flood a subgrade tunnel. Floodwater eventually filled the tunnel to the ceiling, causing 2 inches of water to leak into the basement of a connected building.

Another significant source of water infiltration was conduits from utility vaults or electrical pull boxes outside of the flood barrier that penetrated the flood barrier to interior spaces. Water from inside the vault or pull box was able to flow inside the conduit, often entering the building inside the electrical room or control room.

Figure 4: Water seepage at a submarine door
Photograph courtesy of Facilities and Property Maintenance, Harris County Engineering Department

Figure 5: Unsealed conduit and utility penetrations through the flood barrier (yellow circles, left) allowed subgrade tunnel to fill with water (yellow arrow, right); the penetrations (shown on left image) are on the other side of the door at the end of the tunnel (shown on right image). The utility penetrations were sealed after the flooding, prior to the MAT visit
Photograph on the right courtesy of Facilities and Property Maintenance, Harris County Engineering Department
Failure to waterproof joints in the building envelope. The MAT observed numerous instances where significant water seepage originated from unsealed joints in the building envelope. Most water seepage through unsealed joints occurred where the concrete foundation wall stopped, typically 6 inches above surrounding grade, but significantly below the base flood elevation (BFE), design flood elevation (DFE), and WSE. Figure 6 shows an unsealed joint between the concrete foundation wall and the reinforced masonry wall with granite facade; if the joint is left unsealed, water can seep into the building. Another common area for water seepage was unsealed joints between the concrete foundation slab and foundation wall.

Sanitary Sewer or Stormwater System Flows

Failures associated with backflow from sanitary sewers and stormwater conveyance systems resulted in significant damage to building finishes and critical building systems throughout the areas affected by the hurricanes. While most of the buildings had some type of check valve or backflow preventer, the system configuration, pressure rating of the piping, age of the piping, and the building function all contributed to backflow issues. At one location, the issues were the result of occupants remaining in buildings and using its sanitary systems even after the check valves had been closed as a result of the main lines becoming surcharged by water pressure generated by floodwater. For buildings that did not have ejector pumps as part of the sanitary system, sewer water originating from within the building could not overcome the pressure in municipal lines and backflowed into the interior space.

Other damage occurred when there were no check valves installed on floor drains connected to stormwater drainage networks. When stormwater overwhelmed other components in the drainage network, water was able to backflow through floor drains and fill dry floodproofed areas from within the building.

Flood Vulnerability Assessments

Unless flood provisions were incorporated into their design, existing buildings are vulnerable to flooding if they are located in or near areas subject to flooding. Numerous buildings sustained flood damage as a result of building owners or managers not fully understanding the flood hazard for the building and/or failure to identify and protect all potential sources of water entry. Flooding can cause damage ranging from minor inconvenience to complete closure of and significant damage to the building. To reduce the likelihood of such damage in future events, building owners and managers should consider performing a flood vulnerability assessment to identify equipment and systems vulnerable to flooding and take actions to reduce their vulnerability to flooding. The information obtained during the flood vulnerability assessment, combined with building function and staff or tenant capabilities to deploy dry floodproofing measures, should be used to design the dry floodproofing measures. Prior to performing a flood vulnerability assessment, the floodwater source with corresponding 10-percent-, 2-percent-, 1-percent-, and 0.2-percent-annual-chance (10-, 50-, 100-, and 500-year) WSE and the enforced DFE should be identified for the building. The assessment should determine if the code minimum should

Vulnerability Assessments

Additional guidance on conducting flood vulnerability assessments is outlined in Appendix C of FEMA P-936, Floodproofing Non-Residential Structures.
be applied or whether a higher freeboard is cost effective and should be incorporated into the DFE. Assessments should account for the fact that once a floodproofing barrier is overtopped, a dry floodproofed building is impossible to keep dry and could negate all floodproofing efforts.

Vulnerability assessments should be conducted by a team of architects and engineers working closely with building managers, operators, and maintenance staff. It is highly recommended that a surveyor be incorporated into the team to identify the grades adjacent to the building and the elevations of all pertinent openings and entrances into the building, the first floor and subgrade floors, any utility penetrations into the building, and all critical building systems. The vulnerability assessment should identify the following:

- Locations and elevations of building entrances, such as personnel and overhead doors
- Locations and elevations of openings, such as windows, vents, and louvers
- Locations and elevations of utility (electrical, potable water, sanitary sewer, stormwater, chill water, steam, etc.) conduits entering or exiting the building
- Locations and elevations of any unsealed construction joints where water can enter
- The components of the sanitary sewer and stormwater systems, i.e., whether there is an ejector pump system or a gravity system, if there is a backflow preventer on the discharge piping, if the system is connected to backup power, and the location of the pump control panel. Additionally, it would be beneficial to determine the maximum surcharge level in the municipal system.
- Locations and elevations of the backup power systems, taking note of the building systems connected to backup power, size and location of fuel tank, and location of exhaust ductwork
- Locations and elevations of critical building systems, i.e., building electrical components, steam and chill water, electrical control panels, fire pumps, etc.

In addition to determining flood entry points, the team should consider the effects of water entry. Specifically, if the flood barrier is penetrated, what areas of the building or building systems would be exposed to floodwater. Clarifying the path floodwater will take upon entering the building will identify optimal locations for installing drains to collect water seepage or submarine doors to form a redundant barrier. The use of flood damage-resistant materials in these areas, and below the DFE, will help minimize damage and reduce downtime after the floodwater recedes.

Figure 7 is an illustration of an existing building with examples of the types of openings and penetrations that should be identified during a flood vulnerability assessment.

---

**Freeboard**

Freeboard is a factor if safety, usually feet above a flood level, used to compensate for unknown factors that can contribute to flood heights greater than calculated heights. Providing freeboard in excess of code minimums is often a cost-effective means of limiting future damage. FEMA National Flood Insurance Program (NFIP) regulations require a minimum of 1 foot of freeboard. The American Society of Civil Engineers (ASCE) 24-14, Standard for Flood Resistant Design and Construction, and Hurricane Sandy Recovery Advisory 5 provide additional guidance and considerations related to flood risk and determining how much freeboard to incorporate into a design.

**National Flood Barrier Testing and Certification Program**

This program, a partnership among the Association of State Floodplain Managers, U.S. Army Corps of Engineers, and FM Approvals, currently tests and certifies four types of products to meet ANSI/FM 2510: temporary (perimeter) barriers, closure devices (opening protection), backwater valves, and mitigation (flood abatement) pumps. Testing and certification standards are currently being developed for semi-permanent barriers and sealants. A list of certified products can be found at www.nationalfloodbarrier.org.
Component

1 Building entrance
2 Windows
3 Access ramp to loading dock
4 Electric service equipment room
5 Building central plant equipment room
6 Construction joint
7 Water service
8 Sewer line
9 Utility power
10 Ventilation grill
11 Sump pit with sump pump
12 Stormwater drain
13 Waste line
14 Floor drain
15 Access tunnel to adjacent building
16 Submarine door
17 Backup generator with fuel tank
18 Fuel line

Figure 7: Example of an existing building with multiple openings and penetrations below the BFE and DFE; blue numbered circles indicate a small sample of the types of openings and penetrations that should be identified during a flood vulnerability assessment and protected by the flood barrier

Planning and Pre-Design Considerations

After the flood vulnerability assessment and prior to design, each identified opening should be evaluated to determine the appropriate method of opening protection. Opening protection systems should come from a reputable manufacturer and be compliant with a testing standard such as ANSI/FM 2510 that includes, among other requirements, performance standards for hydrostatic test strength, impact and wear resistance, system leakage (seepage), environmental corrosion, abrasion resistance, and tear and puncture resistance. If the system is not tested in accordance with ANSI/FM 2510, opening protection systems should, at a minimum, have a demonstrated ability to resist hydrostatic forces associated with the DFE. Homemade barriers should not be used. After the components of the flood barrier have been installed, it is highly recommended that they be tested to ensure water tightness.

Key considerations. The pre-design process for flood protection systems should be comprehensive, ensuring that all opening protection components for the entire building can be installed based on the implementation timeframe used in the building’s emergency operations plan (for more information, refer to the companion FL-RA1, Dry Floodproofing: Operational Considerations). Key considerations should include, but not necessarily be limited to:

- The timing and rate of anticipated floodwater rise, availability of staff and equipment to install the opening protection, building occupancy classification, daily use of the openings, and maintenance requirements.
The amount of traffic, whether vehicular or pedestrian. Traffic may affect the selection of opening protection systems, since gaskets on shields or doors may need to be protected against damage during day-to-day use.

The type of gasket—inflatable or compression—should be considered when selecting opening protection systems. Inflatable gaskets tend to be composed of thinner material and are generally more susceptible to cracking under prolonged exposure to weather and sunlight.

**Active versus passive protection.** The rate of floodwater rise and anticipated amount of advance warning are often the most important considerations in determining whether to use active (requiring human intervention) or passive (automatic) opening protection (see text box).

Openings at elevations that can flood during frequent flood events (e.g., 10-percent-annual-chance [10-year] flood events or strong downpour) may require passive opening protection (see Figure 8). Another important consideration is the presence of 24/7 on-site support staff—owners of buildings without continuous support staff should also consider passive opening protection since there may not be enough time for a contractor crew to arrive and install active opening protection systems. On the other hand, passive opening protection measures require regular maintenance, as their components are exposed to the elements.

If active protection is selected, designers need to determine if the opening protection will be permanently attached (using hinges or rails) or detached (such as bolted-on shields or flood logs). It is recommended that brackets or stanchions for active opening protection systems be incorporated into the design of the exterior of the building to reduce installation time. The lack of availability of equipment or staff to move flood protection measures into place in a timely manner can render the flood protection ineffective and leave the building vulnerable.

---

**Figure 8: Example of passive opening protection installed to protect openings in the floodwall constructed around an existing building to establish a flood barrier with minimal openings below the DFE.**

---

**Active and Passive Opening Protection**

Active: A dry floodproofing opening protection system that requires human intervention to install the physical barrier. These systems are effective only if there is enough warning time to mobilize the labor and equipment necessary to implement them and then safely evacuate.

Passive: A dry floodproofing opening protection system that does not require human intervention to deploy the physical barrier.
Design Considerations

A successful dry floodproofing systems design should start with a flood vulnerability assessment and should consider building use, maintenance considerations, and operational requirements before, during, and after an event (refer to previous sections of this advisory). The design should take a comprehensive approach that addresses all possible points of water entry and allows the building to maintain flood protection effectiveness for the life of the building.

Dry floodproofing design is discussed in detail in FEMA P-936, Floodproofing Non-Residential Structures (2013), and Section 6 of the American Society of Civil Engineers (ASCE) 24, Standard for Flood Resistant Design and Construction (2014). Design considerations are discussed in Chapter 2 of FEMA P-936. Specific dry floodproofing details are addressed in Chapter 3; the introduction of Chapter 3 provides readers with a list of building retrofitting recommendations.

NFIP Floodproofing Certificate. The requirements of the NFIP Floodproofing Certificate are described in FEMA P-936 and should be understood before starting design. The NFIP Floodproofing Certificate requires compliance with ASCE 24 and is both a design and construction certification. Professional engineers and architects should read the Floodproofing Certificate in its entirety and the applicable sections of ASCE 24, FEMA P-936, and Technical Bulletin 3, Non-Residential Floodproofing (FEMA 1993), prior to signing it.

Improving reliability of floodproofing measures. Based on the performance of dry floodproofing retrofit mitigation measures observed by the MATs after Hurricanes Harvey and Irma in Texas and Florida, additional attention must be paid to specific items to improve the reliability of floodproofing measures. The MATs recommend that the measures described in Table 2 be considered to help avoid the types of system failures observed.

Combining Flood Risk Reduction Measures

For new buildings, the design height of dry floodproofing can be reduced by using fill material to raise the building site. The image on the right shows where the designer elevated the building on fill, thereby reducing the height of the dry floodproofing system for the building.

Reducing the height of dry floodproofing measures allows more flexibility in the design, reduces flood loads, reduces the potential for leakage, and can minimize any loss of function.

The image on the right shows a dry floodproofed building that was constructed on approximately 3 feet of fill. The building incorporated 1.5 feet of freeboard into floodproofing design, and the flood level during Hurricane Harvey used up 1.0 of the 1.5 feet.

Photograph courtesy of Kati Southern
<table>
<thead>
<tr>
<th>Item</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Backflow preventers</td>
<td>Install backflow prevention valves for any piping in the building below the flood protection elevation or that connects to other piping networks that extend below the flood protection elevation. Backflow prevention systems can be either passive or active.</td>
</tr>
<tr>
<td>Building system locations</td>
<td>Locate building systems (e.g., mechanical, electrical, and plumbing components; communication systems; potable water supply pumps; fire suppression equipment) above the DFE. Consider relocating critical building systems above the flood protection elevation. If relocating is not possible, consider installing redundant protection systems and protecting these systems to a higher-severity flood event than the rest of the dry floodproofed area.</td>
</tr>
<tr>
<td>Design forces</td>
<td>Flood load calculations should address both lateral hydrostatic and vertical buoyancy forces, as well as velocity, debris impact, and wave forces, if applicable. Wall and floor systems may need to be modified or sections completely reconstructed to resist flood loads or to ensure that water cannot penetrate the wall or floor. Additional reinforcement may be required in some areas, and connections between floors and walls may need to be improved to resist lateral and uplift loads. In some instances, this modification may require constructing a new wall around the existing exterior wall to achieve the desired strength or waterproofness.</td>
</tr>
</tbody>
</table>
| Design of a substantially impermeable system | Design and construction criteria for dry floodproofing require both walls and floors to be “substantially impermeable.” Some things to consider for wall systems are:  
  - Deciding whether to build a new floodwall or modify the building envelope.  
  - Sealing existing construction joints and injecting cracks in concrete walls.  
  - For new construction:  
    - The construction joint in and between the foundation slab and walls should contain a waterstop.  
    - Design concrete walls below the flood protection elevation in accordance with American Concrete Institute (ACI) 350, *Code Requirements for Environmental Engineering Concrete Structures*, instead of ACI 318, *Building Code Requirements for Structural Concrete*. ACI 350 has additional requirements that minimize the possibility of water seeping through a concrete slab or wall.  
    - Use a concrete admixture that will limit the porosity of the concrete or a silica admixture.  
Refer to FEMA P-936 (2013) for additional information. |
| Ejector system              | Incorporate ejector systems to prevent the accumulation or backflow of sanitary (wastewater) or stormwater into protected buildings.  
  - Install ejector systems for stormwater with back-flow prevention  
  - Drain fixtures below the maximum surcharge level into a sump, and pump effluent out to a municipal line  
  - Design and size pipelines for the maximum anticipated surcharge pressure conditions associated with ejector pumps  
For buildings that must be occupied when municipal lines are surcharged, collect sanitary sewage from all fixtures below the surcharge level (not just those below the level of the sanitary sewer lateral) into a sanitary sewage sump equipped with an ejector pump and check valve. Ensure the ejector pump has adequate capacity to discharge with anticipated sewage flow rates against the maximum anticipated head of the surcharged lines. |
### Table 2. Dry Floodproofing Design Considerations (concluded)

<table>
<thead>
<tr>
<th>Item</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Flood barrier penetrations</strong></td>
<td>Do not penetrate the flood barrier unless no other options exist and do so only when absolutely required. All penetrations below the DFE should be sealed to resist flood forces and render the flood barrier substantially impermeable. For chill water lines and steam lines, consider removing a small section of insulation and casing around the insulation, since some of those materials can prevent a watertight seal from being made.</td>
</tr>
<tr>
<td><strong>Flood damage-resistant materials</strong></td>
<td>Consider wet floodproofing behind dry floodproofed barriers. In the event of seepage through walls or shield systems, the incorporation of flood damage-resistant materials will reduce the amount of damage to the building. The MATs found that damaged drywall behind the flood barrier still had to be replaced in numerous dry floodproofed buildings, which resulted in sections of the building being unusable while repairs were made.</td>
</tr>
<tr>
<td><strong>Labeling of the flood barrier</strong></td>
<td>The location of the flood barrier and DFE should be indicated on the building drawings, similar to how fire walls are labeled. Additionally, the walls and slabs that create a dry floodproofed area should be labeled with “Flood Barrier: No Penetrations Below This Level” with a demarcation of the DFE.</td>
</tr>
<tr>
<td><strong>Peer review</strong></td>
<td>Perform a peer review on plans and specifications for dry floodproofed systems to help ensure that failure points have been properly identified and addressed.</td>
</tr>
<tr>
<td><strong>Pump control panel locations</strong></td>
<td>Relocate pump control panels above the DFE and away from perimeter walls. The MAT observed buildings where water seeping through cracks in the perimeter wall entered pump control panels, resulting in their malfunction.</td>
</tr>
<tr>
<td><strong>Sealing inside flood barrier penetrations</strong></td>
<td>Seal the inside of electrical conduits, as the interior of electrical conduits can convey water even if the wall penetration is properly waterproofed.</td>
</tr>
<tr>
<td><strong>Seepage</strong></td>
<td>Regardless of the type of dry floodproofing incorporated into the system, the approach should plan for seepage. All dry floodproofing systems required to comply with ASCE 24 or the NFIP must have a sump pump system sufficient to adequately drain seepage in the dry floodproofed area. It is recommended that the sump pumps be connected to a standby power source. Redundancy in the system should be considered and leak detection alarms incorporated into the design. Internal drainage systems should have a discharge point above the flood protection elevation.</td>
</tr>
<tr>
<td><strong>Standby power</strong></td>
<td>Provide standby power for critical building systems, which includes sump pump systems, building mechanical systems, and electrical systems. Standby power systems should be sized to meet the start-up power loading requirements of equipment. Design should consider the possible loss of power for extended times when critical building systems may need to function for days or weeks until power is restored. Fuel sources and how to replenish supplies should be considered, as well as how many redundant generators should be installed.</td>
</tr>
<tr>
<td><strong>Stormwater</strong></td>
<td>Rainfall behind the flood barrier should be considered. Sump pumps should be sized to handle the additional water, and the use of redundant or additional pumps should be considered when designing systems that remove rainfall from behind the flood barrier. When designing for rainfall events behind the flood barrier, the design rainfall should be consistent with the design level of protection, so protection for a 0.2-percent-annual-chance (500-year) flood event should accommodate a 0.2-percent-annual-chance (500-year) rainstorm or rainfall of record.</td>
</tr>
<tr>
<td><strong>System redundancy</strong></td>
<td>Consider providing redundancy in the overall flood protection system, compartmentalization, or a series of gates or shields. This redundancy is especially important in tunnels and below-grade areas, where the potential for a single point of failure can be reduced by such measures. Over the years, MATs have observed many single points of failure that have resulted in excessive damage that could have been reduced had redundant systems been in place.</td>
</tr>
</tbody>
</table>
References and Resources

References


Resources


Recovery Advisories for Hurricane Sandy listed below are available at [https://www.fema.gov/media-library/assets/documents/30966](https://www.fema.gov/media-library/assets/documents/30966).

- FEMA. 2013. *Designing for Flood Levels Above the BFE After Hurricane Sandy.* Hurricane Sandy RA5.

Recovery Advisories from the 2016 Fall Flooding in Iowa listed below are available at [https://www.fema.gov/media-library/assets/documents/130555](https://www.fema.gov/media-library/assets/documents/130555).


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

If you have any additional questions on FEMA Building Science Publications, contact the helpline at FEMA-Buildingsciencehelp@fema.dhs.gov or 866-927-2104.


To order publications, contact the FEMA Distribution Center:

- Call: 1-800-480-2520 (Monday–Friday, 8 a.m.–5 p.m., EST)
- Fax: 240-699-0525
- Email: FEMA-Publications-Warehouse@fema.dhs.gov

Additional FEMA documents can be found in the FEMA Library at [https://www.fema.gov/media-library/resources](https://www.fema.gov/media-library/resources).

Please scan this QR code to visit the FEMA Building Science Web page.