3 Dry Floodproofing Measures

The purpose of dry floodproofing a building is to make it watertight to floods of limited duration (a few hours) and depth (typically less than 3 feet). Dry floodproofing reduces the potential for flood damage by reducing the probability that the building interior will be inundated. It can be an appropriate alternative for flood mitigation when relocating or elevating buildings is not cost-effective or technically feasible.

> **Special Note**
>
> FEMA strongly encourages that flood retrofits provide protection to the DFE (the community's regulatory DFE). However, in some situations, lower flood-protection levels may be appropriate. Owners and design professionals should meet with a local building official to discuss the selected retrofit measure and the elevation to which it will protect the building.

The minimum performance requirement for dry floodproofing measures is a space that is protected by walls that are substantially impermeable and resistant to flood loads. As noted in Section 1, a substantially impermeable wall should limit water accumulation to a maximum accumulation of 4 inches in a 24-hour period with a sump pump to control seepage (USACE 1995). However, the minimum performance requirement can be exceeded with proper planning, design, and materials.

Incorporating flood damage-resistant materials into the dry floodproofing design up to the height of the dry floodproofing measure is recommended. Additionally, building systems such as walls and foundations may need to be strengthened to withstand direct flood forces and the loads imposed by floodproofing measures (e.g., shields, watertight doors), which are used to temporarily seal openings.

An effective dry floodproofing retrofit requires the following:

- Detailed site evaluation (see Section 3.1.2)
- Detailed building evaluation (see Sections 2.6.2 and 2.6.3)
- Careful evaluation of all of the dry floodproofing measures (see Sections 3.2 through 3.7), including a consideration of residual risk (see Section 1.3)
- Design by a qualified registered design professional
- Verification/testing that the constructed systems provide the desired floodproofing effectiveness
- Floodproofing Certificate for Non-Residential Structures for the dry floodproofing design (see Section 2.1.2)
- A plan for deploying any active dry floodproofing measures that require human intervention (see Section 2.5.4)
- Sufficient warning time to deploy active dry floodproofing measures and vacate the building
- Operations and maintenance plan (see Section 3.8)

Chapter 3 begins with a discussion of the design considerations for dry floodproofing projects followed by a discussion of the types of dry floodproofing measures, as follows:

- **Continuous impermeable walls.** Sealing the building's exterior walls using technologies that include impermeable waterproof membranes and potentially strengthening those walls
- **Flood resistance in interior core areas.** Critical core components and areas can be made flood resistant when dry floodproofing the entire building footprint is not needed or possible
- **Sealants for openings.** Protection of the building depends on sealing openings, such as doors, windows, and utility penetrations, and sealing walls and slabs, which are rarely designed to be watertight or resist flood loads
- **Flood shields for openings in exterior walls.** Watertight structural systems that close the openings in a building's exterior walls to the entry of water
- **Backflow valves.** Prevent floodwater flow into the building because of blockages in the sewage system
- **Internal drainage systems.** Primary method of removing water that may seep through small fissures and pathways in the protection system

Table 3-1 compares dry floodproofing retrofit measures to other flood mitigation retrofit measures.

Table 3-1. Advantages and Disadvantages of Dry Floodproofing Retrofits Compared to Other Flood Mitigation Retrofit Measures

Advantages	Disadvantages
• May be less costly than other retrofitting methods • Does not require the land that may be needed for levees and floodwalls • May be fundable under FEMA mitigation grant programs • May be used to bring Substantial Improvement/ Damage non-residential structures into compliance with the community's floodplain management regulations and codes • Can be used to protect against more frequent flooding even if it is not cost-effective to floodproof to the BFE/ DFE	• Active dry floodproofing measures require human intervention and adequate warning • Does not always minimize the potential damage from high-velocity flood flow or wave action • Requires ongoing maintenance • Flood shields may not be aesthetically pleasing (see Section 3.5) • Potential failure of the structure's walls and/or property damage if the flood event is greater than the level of protection to which the dry floodproofing measure was designed

3.1 Design Considerations for Dry Floodproofing Projects

Chapter 2 covers several planning and design issues that must be considered in a dry floodproofing project, including flood warning time, structural evaluation, and flood hazard evaluation. Because of the importance of these topics in relation to dry floodproofing, they are briefly revisited in Section 3.1.

3.1.1 Flood Warning Time

Installing active dry floodproofing measures, which require human intervention, takes time and requires sufficient warning. Active dry floodproofing measures are therefore not appropriate if the warning time is insufficient. For example, dry floodproofing is not appropriate in areas where floodwaters are known to rapidly rise, such as where flash flooding is common, because the rapid rise in water gives little or no warning time to install active measures. See Section 2.5.3 for additional information regarding flood warning time.

Building owners should rely on the community flood warning system unless there is easy access to NWS flood predictions (such as estimates of stream gage heights) and the owner knows how to compare that information to the building elevation. A plan based on the warning time provided by community flood warning system can be developed to ensure that there will be sufficient time for:

- Personnel responsible for installing dry floodproofing measures to travel to the building and install the measures
- Proper activation of all necessary floodproofing measures, which can include installing flood gates and shields, activating sump pumps, and closing manual valves
- Evacuation of the building and evacuation of personnel responsible for installing the floodproofing measures before the onset of flooding

The amount of time needed to install the measures depends on available personnel and the number of steps in the installation. See Sections 2.5.4 and 3.8 for more information on what the plan should include.

3.1.2 Site and Building Evaluation

The site and building need to be evaluated to determine whether dry floodproofing is appropriate. The site investigation will determine if the existing building can be cost-effectively retrofitted by looking at flood conditions needed to calculate the flood loads, such as depth of flooding and flood velocity. The site investigation will also determine whether the existing soil conditions and any existing fill under or around the building could resist scour and erosion during a design flood event.

The building should be evaluated by a structural engineer to determine whether the exterior wall and floor systems can resist the forces generated by the design flood event. Flood loads can cause wall systems to fail, possibly resulting in structural damage that is more severe than damage from inundation. A primary design consideration in dry floodproofing is therefore the determination of the ability of the foundation, floor system, and exterior walls to withstand the forces generated by the design flood event. If the building strength is found to be inadequate, decisions must be made about how to achieve the desired level of performance. Options include strengthening the existing wall systems or other types of mitigation (e.g., elevation, acquisition, mitigation reconstruction). The costs and obstacles associated with retrofitting an existing building to resist flood loads may indicate that other floodproofing measures are more appropriate. See Sections 2.4 through 2.6 for additional factors related to the site and building evaluation.

3.1.3 Building Standards and Codes

Section 2.1 covers a range of dry floodproofing regulatory requirements that vary based on which codes are in place in the project's jurisdiction. For example, some, but not all, jurisdictions require dry floodproofing to be designed and constructed in compliance with ASCE 24. Although most of the ASCE 24 requirements outlined in Chapter 2 were developed for new construction and may be required only for Substantial Improvement/Damage, ASCE 24 requirements should be considered in all dry floodproofing projects.

ASCE 24 should be relied on to determine the flood protection level and elements of a properly constructed dry floodproofed building. Utilities should meet the requirements in Section 7 of ASCE 24 to place utilities outside the dry floodproofed area either above a specified elevation or to be designed to resist flood loads to prevent the intrusion of floodwaters.

If required, Section 6 of ASCE 24, which provides minimum floodproofing elevations (see Table 3-2) can be used for determining the flood protection level of the dry floodproofing retrofits. Any critical core components or other building areas not protected by the dry floodproofing measure should be elevated to the applicable elevation specified in ASCE 24.

Table 3-2. ASCE 24 Structure Categories and Minimum Floodproofing Elevation in Zone A

ASCE Structure Category[a]	Minimum Floodproofing Elevation (Zone A)
I, II, and III	BFE + 1 foot or DFE, whichever is higher
IV	BFE + 2 feet or DFE, whichever is higher

Source: ASCE 24-05

[a] See Section 1.6 for information on the ASCE structure categories

When evaluating building systems, designers should refer to the requirements in the NFIP, building codes, and consensus standards (see Section 2.1) and other resources. For concrete and masonry walls, design professionals typically turn to American Concrete Institute (ACI) 318-08, *Building Code Requirements for Structural Concrete and Commentary* (ACI 2008), or ACI 530-11/ASCE 5-11/ The Masonry Society (TMS) 402-11, *Building Code Requirements and Specifications for Masonry Structures* (ACI/ASCE/TMS 2011). For wood-framed structures, designers may use American National Standards Institute / American Forest & Paper Association (ANSI/AF&PA) NDS2005, *National Design Standard for Wood Construction* (ANSI/AF&PA 2005).

If all the regulatory requirements discussed above and in Section 2.1 can be met and the retrofit is determined to be feasible, the designer should then consider the construction materials and products necessary to complete the project. The designer should specify the products and reference a standard the products must meet in order to provide a measure of certainty that both the constructed and purchased products will result in the desired level of protection. FM 2510, *Approval Standard for Flood Abatement Equipment*, was developed to certify certain products that provide floodproofing for conditions up to 3 feet of water.

> **Special Note**
>
> FM 2510, Approval Standard for Flood Abatement Equipment, can serve as a product standard for temporary flood barriers, opening barrier abatement equipment, backflow preventer flood abatement equipment, and sump pump flood abatement equipment.

The presence of an FM Approvals product certification/seal certifies that the product meets the requirements of FM 2510. However, compliance with FM 2510 for specific products does not, by itself, imply compliance with the design requirements in ASCE 24, nor does use of the products mean that the dry floodproofed area will be ASCE 24 or NFIP compliant. The designer should compare the specification requirements in ASCE 24 and FM 2510 to ensure that FM 2510-certified products are applicable for use on any given project. Some of the primary requirements that should be evaluated when selecting a product are as follows:

- Hydrostatic loads
- Hydrodynamic loads
- Wave loads
- Buoyancy requirements
- Debris impact loads
- Leakage
- Installation requirements
- Requirements related to material exposure

3.1.4 Verification and Testing of Systems

An often overlooked part of the design process deciding on a testing method for the effectiveness of the dry floodproofing. During the construction phase of the project, as wall systems are being retrofitted and installed, it is important to test them to verify that they can resist hydrostatic loads and the components are indeed waterproof. While some projects may protect such valuable resources that large-scale testing is cost-effective, in other situations, the testing of individual components such as flood shields protecting doors may be all that is necessary. Large-scale tests have entailed constructing large barriers around the outside of buildings and the area immediately around the building being flooded for a few hours. Smaller-scale tests may only require small barriers or forms to be constructed around individual components and those areas filled with water. The main reason for any type of test is ensure the designed hydrostatic load is achieved. The area must be filled with water to the designed flood protection level to develop the necessary hydrostatic load. Testing allows leaks to be identified under a controlled process and addressed prior to the completion of construction. However, designers and owners should bear in mind that these tests will only test the system for hydrostatic loads for a specific duration. Other loading factors such as buoyancy loads or the impacts of long duration flooding may be difficult or impossible to test.

3.2 Continuous Impermeable Walls

A continuous impermeable wall is substantially impermeable to the passage of water, and the structural components of the wall are capable of resisting hydrostatic and hydrodynamic loads and the effects of buoyancy. Two resources for dry floodproofing building wall assemblies to create continuous impermeable walls are *Flood Proofing Tests: Tests of Materials and Systems for Flood Proofing Structures* (USACE 1988) and the Southeast Region Research Initiative's (SERRI) *Floodproof Construction: Working for Coastal Communities* (ORNL 2011), referred to as the SERRI Report.

The designer should review the USACE report (which recommends dry floodproofing in many cases up to 3 feet) to determine whether the recommendations are consistent with the walls in the retrofit project. The USACE report contains information on tested systems and observed deflections. The SERRI Report focuses on new construction but may provide the designer with some ideas of building assemblies that proved to be impermeable in that research.

After the primary wall system and foundation have been strengthened to resist flood loads (if necessary), the building must be sealed and other portions of the building (e.g., windows, doors, utility points of entry) must be evaluated to determine how best to prevent floodwaters from entering the enclosed area. The three categories of measures that can contribute to making the primary wall system impermeable are protecting openings (closing, sealing, or shielding), waterproofing the walls, and using a flood wrapping system.

Special Note

The SERRI Report describes several wall assemblies including sealed CMU walls, cavity walls, unsealed CMU walls, Insulated Concrete Form Walls, metal stud walls, Structural Insulated Panel walls, sheet membranes over CMU walls, and a waterproof coating on a CMU wall. The report is available at: http://www.serri.org/publications/Pages/Reports.aspx.

In some instances, it may be more cost-effective or less invasive to building occupants during the retrofit process to construct a continuous impermeable wall on the outside of the existing wall system. Some wall systems, such as steel stud wall systems, may be too difficult to make impermeable, and in those instances a new wall system may be constructed along the perimeter of the existing wall to provide protection. In these instances, the load path to the foundation may be a primary concern for the designer.

3.2.1 Openings

The designer and owner should consider permanently closing any openings in the building's exterior if doing so would be inconsequential to functional use. Although filling in openings may affect the original or normal use of the building, filled openings limit the number of areas that require human intervention before a flood event. Openings similar to the one shown in Figure 3-1 must be evaluated individually in order to properly tie in the retrofit to the existing wall system and prevent a potential weak spot. Filled openings should be constructed so they match the full thickness of the wall system and are anchored properly into the surrounding wall system.

Permanently filling openings can be used in conjunction with deployable flood shields, which protect the remaining openings in exterior walls. Flood shields are used to temporarily seal openings from incoming floodwaters (see Section 3.5 for more information on flood shields).

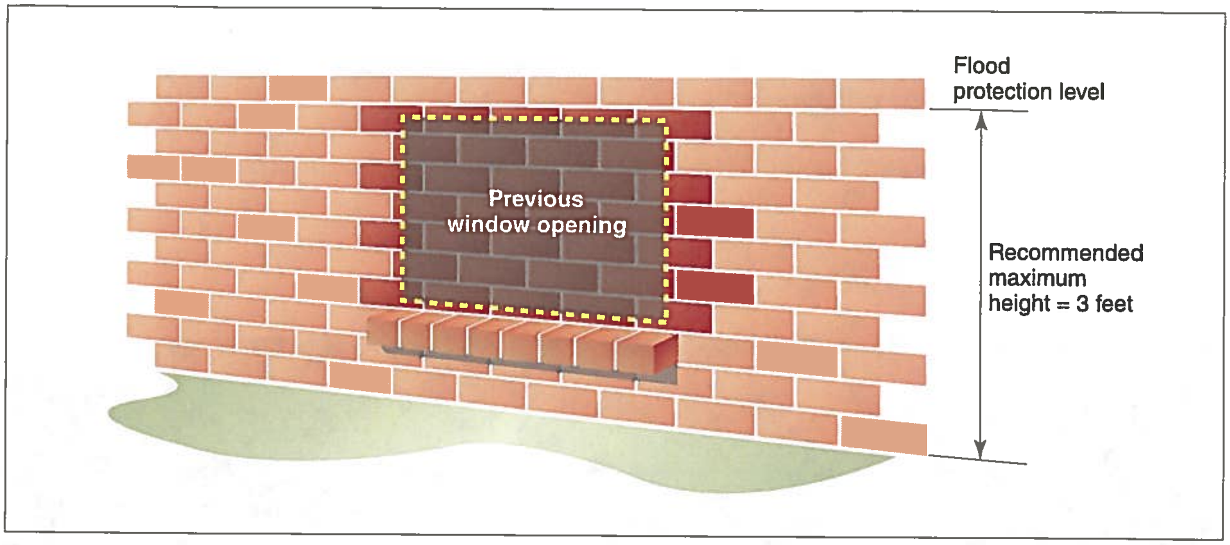


Figure 3-1. Filled window opening

3.2.2 Wall Systems

The decision to use sealants to waterproof a wall should include a consideration of the structural soundness of the building, including the walls and floor slab, and the building's ability to resist flood and flood-related loads. The structural systems should be evaluated when any type of dry floodproofing is under consideration.

The level of waterproofing that a wall system needs is highly dependent on the type of system. Systems such as poured concrete may require minimal waterproofing, while systems such as CMU may require filling cells with a flowable grout mix that contains a water-resistant additive. Retrofitting a CMU wall by grouting the cells requires creating openings at the top and bottom of the wall to ensure that the grout fills all the cells completely. Grout can be obstructed by mortar between courses of block or by debris left in the cell during construction of the wall. Drilled observation holes in the bottom course of a CMU block wall can be used to verify that grout flows through the entire wall and to inspect the connection between the wall and the floor slab to determine to what extent the connection can be relied on for shear load capacity.

Although Structural Insulated Panel (SIP) wall systems have been waterproofed successfully, waterproofing an existing SIP wall system is not recommended. This wall system can be waterproofed sufficiently to prevent almost all water from intruding, but the panel-to-slab anchors may be difficult to improve without installing vertical braces on the outside of the panels, and the panels may not be able to resist the buoyant forces.

Insulated Concrete Form (ICF) systems require minimal waterproofing. In addition, ICF systems have significant structural capacity and are likely to require little if any structural retrofits to withstand flood loads, but the slab-to-wall connection should be checked. The detailing of the exterior finish may require some thought depending on how the exterior of the ICF system is finished. The construction of the exterior face of an ICF building may make it difficult to prevent water from getting behind the exterior veneer, so drainage is important.

Creating a waterproof barrier in a section of wall to make it impermeable may require the use of sealants. Sealants include compounds that are applied directly to the exterior surface of the building to seal exterior walls and floors and typically fall into two categories (see Figure 3-2):

- **Positive-side sealant.** Applied to the wall exterior where the sealant acts as a barrier between floodwaters and the wall
- **Negative-side sealant.** Applied to the interior of a wall or floor where the water pushes against the sealant after it has passed through the wall or slab

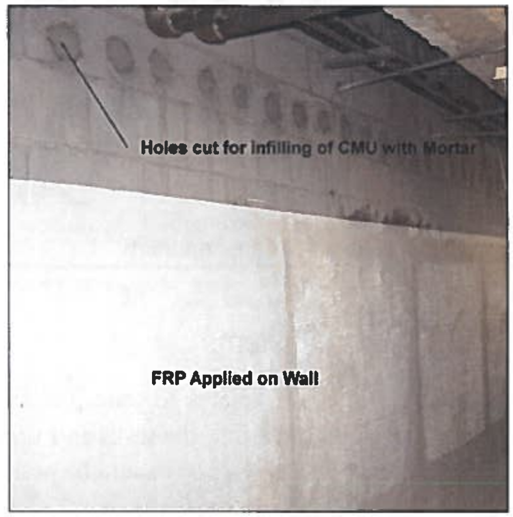


Figure 3-2. Application of a waterproof membrane on the exterior (positive side) of a wall (left) and fiber-reinforced polymer wrap applied to the interior (negative side) of a wall (right)

Above-ground walls can be sealed using either category of sealant because interior and exterior sides are both typically accessible while below-ground walls and floor slabs almost always require negative-side sealants.

Positive-side sealants also include wrap-style adhered membranes and spray-applied sealants, both of which can be applied to the exterior wall or foundation at or below the ground. Products such as elastomeric waterproofing material and self-adhering membrane sheets have been successfully used to prevent water intrusion for more than 24 hours. Temporary positive-side sealants called "flood wraps" can be attached to the wall above-grade during flooding. See Section 4.4.3 for more information on flood wrapping systems.

Negative-side sealants that are applied to a concrete slab or wall must be bonded directly to the slab or wall to prevent the sealant from pulling away from the surface. Negative-side sealants on slabs must be formulated and installed to withstand floor-related wear and must be applied across expansion joints common in concrete floor systems.

When the determination has been made that the building and foundation system can withstand the expected flood-related forces, selecting a sealant system is relatively straightforward. The decision centers on the compatibility of the sealant product with the expected duration and depth of flooding and the construction materials in the building. Materials such as brick veneers have been used in low-flood-height applications of dry floodproofing, but *Building Code Requirements and Specifications for Masonry Structures* (ACI/ASCE/TMS 2011), does not allow brick veneers to be included as part of the lateral load resistant system. The sealant should be selected using the decision process shown in Figure 3-3.

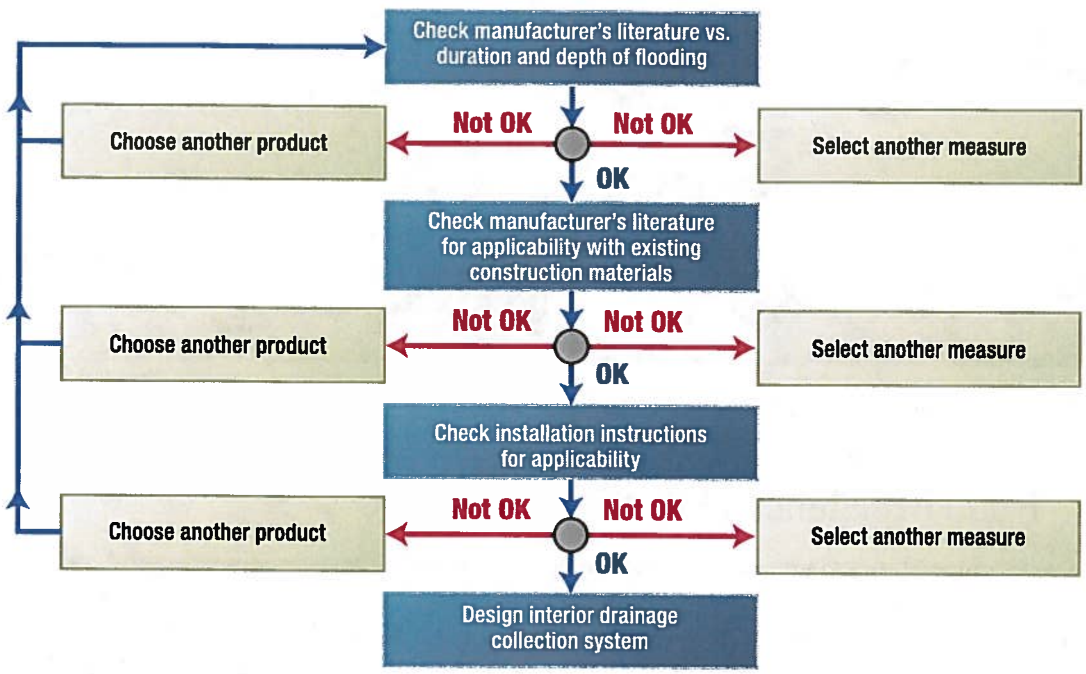


Figure 3-3. Decision process for selecting type of sealant

Even with sealants, a dry floodproofed building still requires a well-developed internal drainage system to collect the inevitable leaks and seepage that will develop (see Section 3.7). Many dry floodproofing systems still experience some water infiltration, and the owner will need a dewatering system capable of removing the water. Such a system may require establishing drains around footings and slabs (Figure 3-4) to direct seepage to a central collection point where it can be removed by a sump pump. Additionally, dry-floodproofed buildings usually need backflow devices and other measures designed to eliminate backwater flooding through waste and wastewater system components.

A particular area of concern in dry floodproofing non-residential buildings is the presence of adjacent buildings with shared walls or narrow gaps between walls. Although the only viable option for a shared wall may be to use a negative-side sealant, the shared wall may make dry floodproofing infeasible.

Adjacent walls also present a design challenge. Even if both buildings are to be dry floodproofed, it may not be possible to floodproof all areas of the adjacent walls. Sealants and filler material used to bridge these gaps have been used to protect these areas for short durations. If these areas are exposed to flooding for extended periods, water may migrate under the building foundations and flood the areas. The condition of adjacent buildings should be thoroughly investigated to ensure that the selected floodproofing measures will be effective.

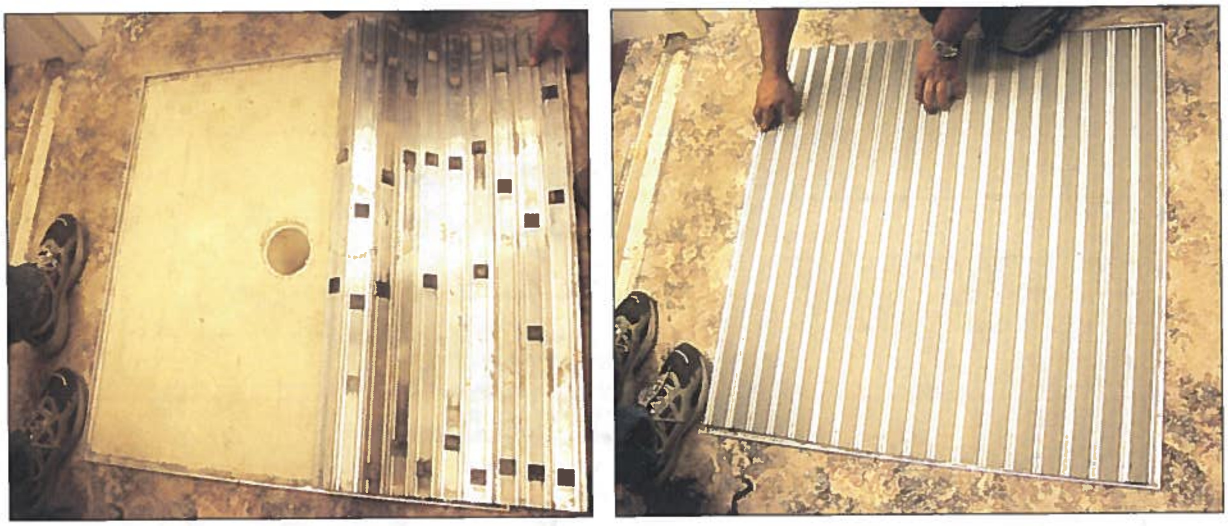


Figure 3-4. Internal drain in a dry floodproofed retail building

3.3 Flood Resistance of Interior Core Areas

Critical core components and areas can be made flood resistant even if dry floodproofing the entire building footprint is not needed or possible because of building occupancy type, geometry, function, or cost. Typical critical core areas contain utilities such as electrical distribution and switching areas, emergency generators, emergency fuel supplies, and other mission-critical components that cannot be moved or elevated. In many large complexes or campuses of buildings such as museums, universities, and large businesses, the utilities may be housed in a central building and linked to the other buildings via tunnels. Although the main utility building may not be at risk of flooding during a particular event, utility tunnels are often subject to more frequent flooding. The tunnels may need to be protected from floodwaters by watertight doors. Figure 3-5 is an example of a watertight door that would prevent flooding of a utility room.

An important consideration in making a core area watertight is that floodwater levels may be higher than the height of typical dry floodproofing measures that protect the entire building, and additional anchorage may be needed to make sure the area does not become buoyant. Both the floor system and existing walls should be carefully studied and evaluated (see Section 3.1.2). Because these areas are typically designed to be fully resistant to high flood loads, additional anchoring or securing of the core area may be required to resist buoyancy forces.

Core areas can be made watertight by building infillwalls or retrofitting existing interior walls. Waterproofed walls may be constructed of cast-in-place concrete with sufficient detailing to make sure the walls are tied to the floor slab. Fully grouted reinforced CMU walls can also be used to construct the interior walls. CMU walls may require additional waterproofing to be considered fully impermeable. Special detailing should be done at the joint between the floor slab and wall because this is a common location for leaks.

Figure 3-5. Watertight door used to protect mechanical rooms subject to flooding

If access doors or hatches are necessary below the flood protection level, a hinged door is recommended so the area can be sealed quickly. Doors or hatches above the flood protection level may allow continuous access even during flood events, but require stairs or ladders. Although stairs or ladders may allow maintenance personnel to access the area during an event, they may limit the ability to move items in and out of the area. A pump system is still required in these areas to address any unidentified leaks.

3.4 Shields for Openings

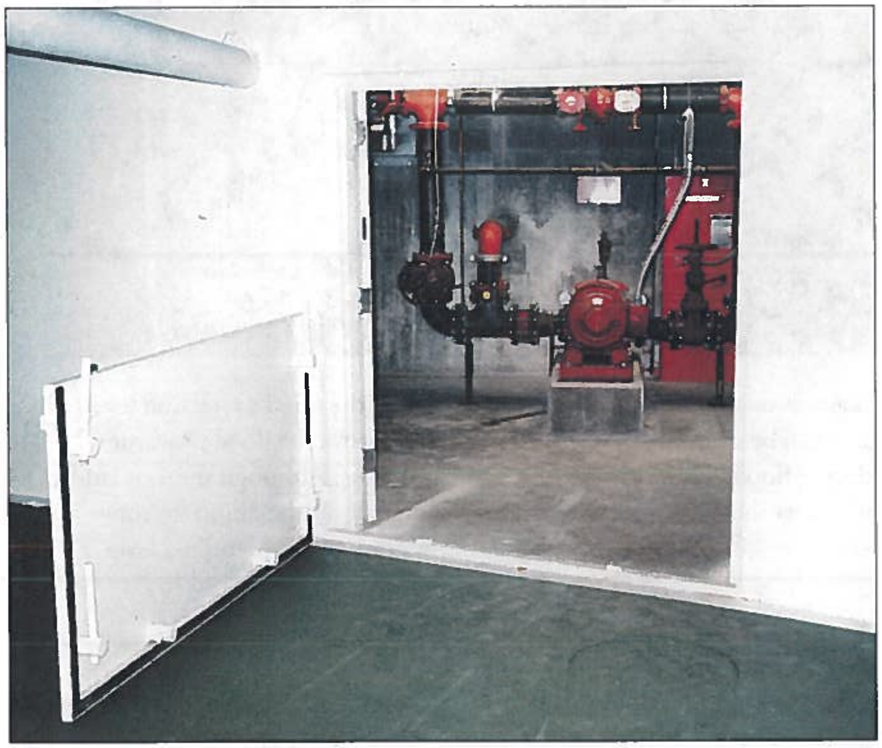
Dry floodproofing of wall systems is a complex undertaking because openings such as doors, windows, and utility connections are rarely designed to be watertight or to resist flood loads. When openings that must be maintained below the flood protection level are evaluated, a primary consideration should be the wall or foundation system's ability to resist the loads. Any system of flood doors, panels, or shields will depend on the transfer of the flood loads from the shields to the wall such that the load path is maintained. If the walls or foundation are structurally insufficient to carry these loads, they must be reinforced to maintain the load path (see Section 3.2.2).

Penetrations through walls for utilities have much narrower openings than those of doors or windows, so sealants are usually sufficient for preventing water intrusion at utility connections. However, if utility openings are not properly sealed from floodwaters, water can enter the building through these openings. Protecting water line penetrations properly and sealing electrical conduits can often minimize flood damage.

3.4.1 Doors

During flood conditions, doors typically present the largest openings requiring protection from water intrusion into the building. Most door openings vary from 3-foot-wide exterior doors to 16-foot-wide garage-type roll-up doors or cargo doors. Flood shields for doors (see Figure 3-6) must span these widths. The permanency of the shield may be dictated by the normal use of the opening, warning time available to install the shield, and the use of the door as a means of egress from the building. Emergency plans should identify the personnel who have been designated to close or install flood shields before a flood event and instructions on how to install the shields. Issues related to properly sealing the shield are discussed in Section 3.5.

Figure 3-6. Equipment room with watertight door (source: Presray Corporation)



3.4.2 Windows

Basement windows can be the first entry point for floodwaters. Window height can range from small basement windows that are 1 to 2 feet tall to full height windows. Removing a window and incorporating the opening into the wall system may be easier than retrofitting a window with watertight flood shields (see Section 3.2.1). The decision of whether to eliminate the window may depend on the following:

- Use of the window (e.g., provides light, means of egress, architectural feature)
- Location of the window on the building
- The ease with which the opening can be filled in and incorporated into the wall system

Basement windows may be good candidates for elimination, whereas windows higher on the building may only need to be shielded partially rather than eliminated. In areas where the flood protection level is higher than the elevation of the window, products such as submarine glass systems have been successfully used to replace standard windows. Replacing standard windows with submarine glass systems will render them inoperable, but the glass will still allow natural light into the area. If windows are used below the flood protection level, anchorage of the window frame, and attachment of mullions to the frame and the seals between the window and the frame must be considered because they are common places that fail or leak. Due to the loading requirements many of these window systems require oversized mullions in order to adequately distribute the loads.

3.4.3 Utility Connections

Where a utility enters the building or connects to the building's utility system usually depends on the type of utility. Overhead electrical lines may be attached near the roof system while buried water, electrical, gas, communications and sanitary line connections, and building penetrations are typically near or below the ground.

Floodwater can enter the building where the utility line penetrates the building through the wall or floor or directly through a line such as an electrical or sewer line. Gaps in the opening around the utility line should be filled with an expansive foam to create a waterproof seal. Sealants that are used to seal openings in walls or floors should be able to withstand being submerged for the anticipated duration of flooding.

Testing the waterproof seal may be difficult, but it should be done to make sure the seal is completely watertight for the expected hydrostatic pressures. Ideally, the floodproofing measure will only need to resist hydrostatic pressures as waters rise, but any utility that penetrates the building should be evaluated to determine whether the anchorage needs to be improved to prevent buoyancy forces, hydrodynamic loads, erosion, or scour from damaging the utility line or to prevent the line from damaging the seal around the wall penetration.

Nonresidential buildings may have ventilation shafts, exhaust fans, and louvered openings that should be protected with specially fitted flood shields. Placing the flood shields may require shutting down parts of the building or interrupting some of the building's critical utilities or mechanical systems. It may be feasible and cost-effective to reroute ventilation shafts, exhaust fans, or other utility openings above the flood protection level to avoid having to shut down some operations during a flood.

Older buildings may have openings into the basement that were used as coal chutes. As furnaces were updated for natural gas or electricity, these openings were sealed to prevent the loss of heat or animals from entering through them. The conventional methods used to fill in these opening were likely not designed to resist flood loads and rarely result in a waterproof covering or watertight seal. Attention is necessary to make sure they are sealed properly and do not present a weakness in the floodproofing system.

Even areas without wall penetrations, such as utility chases on exterior walls, can be subject to water infiltration. These areas may have electrical lines, plumbing, gas, communication, or ductwork running through them. Maintenance access points below the flood protection level can allow the infiltration of floodwaters that goes unnoticed and result in significant water entering the building.

3.5 Flood Shields for Openings in Exterior Walls

Flood shields or panels are watertight structural systems that bridge the openings in walls to prevent the entry of floodwaters. Flood shields work in tandem with waterproof barriers to resist water penetration.

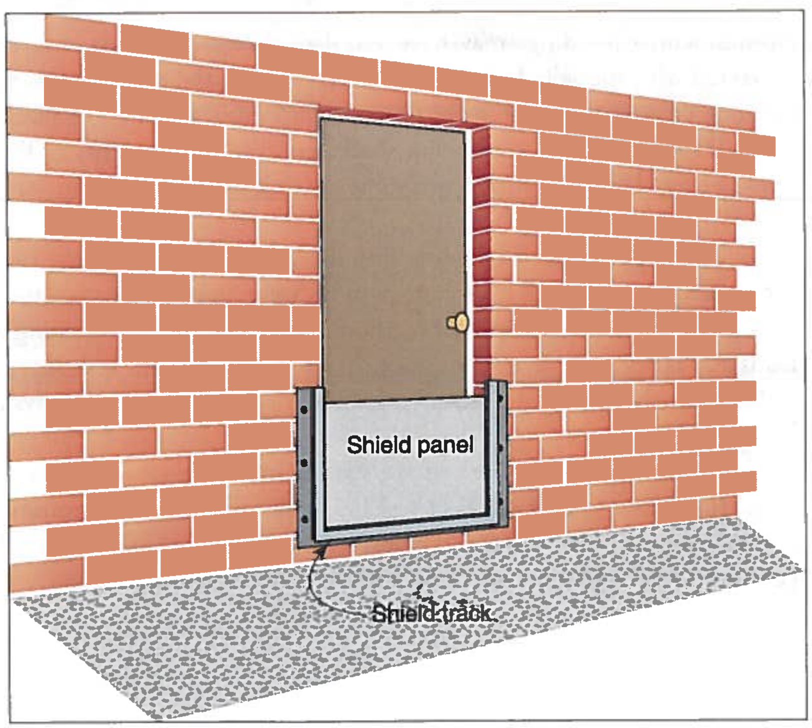
Although flood shields are most often temporary measures, they can also be used as a permanent floodproofing measure (e.g., hinged plate or door, mini-floodwall at a subgrade opening). Flood shields transfer flood-induced forces into the adjacent structural components and, like sealants, can overstress the structural capabilities of the building. Most flood shields are mounted against the exterior of the opening, allowing rising floodwaters to further compress the gaskets and seals between the flood shield and the wall system or frame of the opening. A number of vendors make special doors for permanent installation and drop-in panels or barriers that are designed to be watertight and installed as needed for flood protection.

For shallow and short-duration flooding, panel-style flood shields of sturdy material can be constructed to fit doorways and other openings to minimize the entry of floodwaters. Shields will only be watertight if a flexible gasket or sealant is provided and the mounting hardware is designed to apply even pressure on the gasket around the opening. Personnel must know where the materials are stored and be trained in their deployment (see Section 3.8).

3.5.1 Types of Flood Shields

The type of shield that is used depends on the size of the opening that needs to be protected and the duration of flooding. Examples of flood shields are shown in Figures 3-7 through 3-9.

Figure 3-7. Door opening protected from low-level flooding by a flood shield



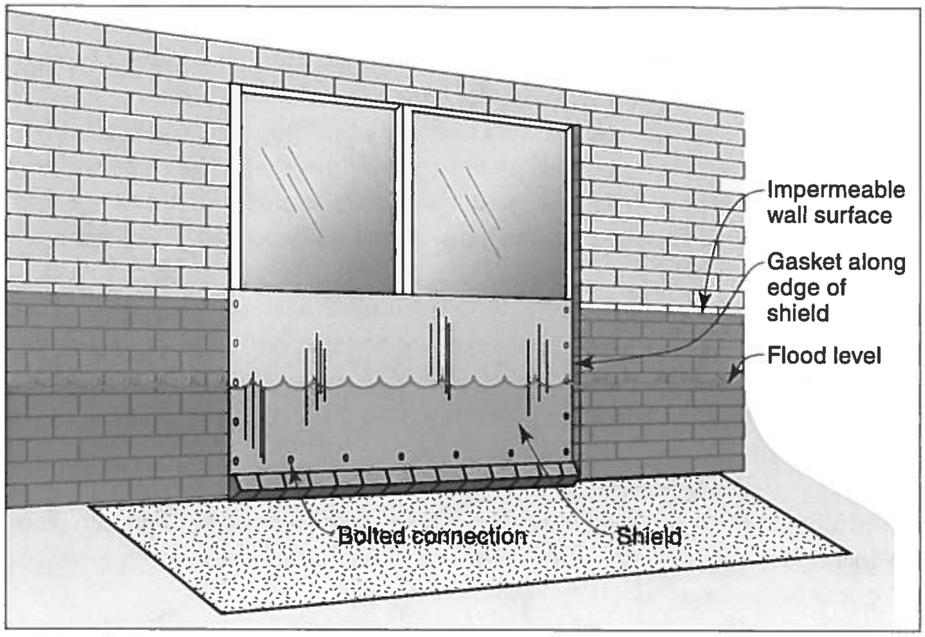


Figure 3-8. Window protected from low-level flooding by a flood shield and wall sealant

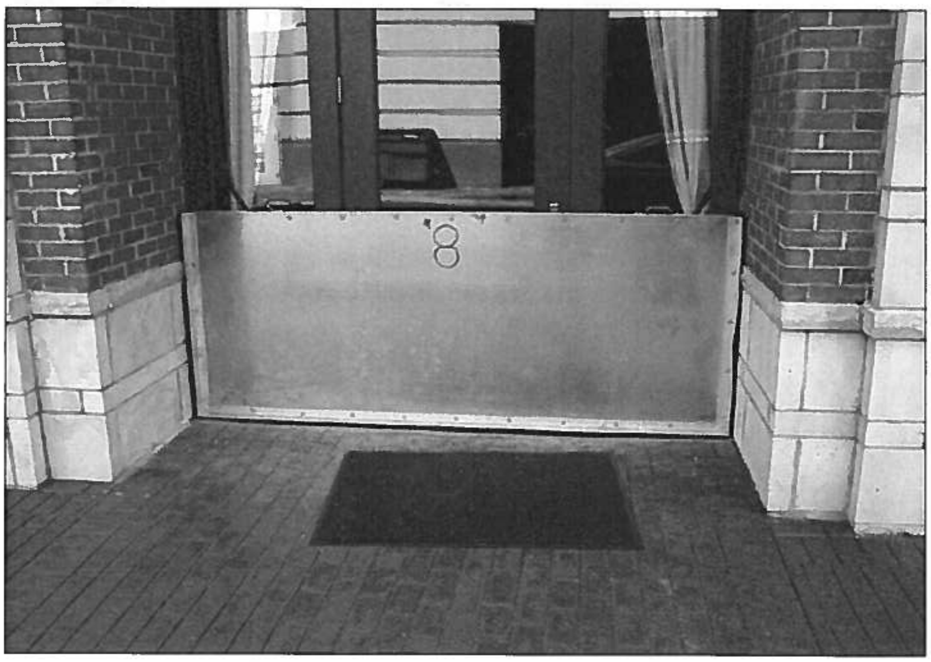


Figure 3-9. Aluminum flood shield used for flooding less than 3 feet deep

As noted above, longer and larger flood shields, such as for vehicle entrances, are normally constructed of steel plate or heavy aluminum plate. Because of the weight of the shield, it is usually best for the shield to be hinged so that it can swing into place (see Figure 3-10). Hinging can be along the bottom so the shield lies flat when not in use, or it can be placed along one side so the shield can fold back out of the way. Shields hinged on the bottom must fold into a recess so the surface of the entrance is smooth. Shields that fold into a recess require a design to make the shields and recess able to withstand the weight of the traffic over them. In addition, below-grade recesses can fill with water and debris, which increases maintenance and hinders rapid deployment.

Hinged and sliding flood shields (see Figure 3-10) only require the user to unlock and rotate or slide the flood shield and lock it into place. These flood shields may include pedestrian doors that are full-height doors with complex latching mechanisms for higher flood heights or lower half-door systems. Although hinged flood shields require human intervention, they can often be deployed by one person. Room must be available for the systems to swing or slide either beside or above the door when not in use.

Heavy flood shields for larger openings may require electrical or mechanical systems to move them into place. Designs should include a consideration of the fact that power may not be available following the event and that access through the opening may be necessary to restore power.

Passive (automatic) flood shields (see Figure 3-10) may be preferred to active flood shields, which require human intervention. Passive flood shields allow openings to be used until floodwaters reach a certain height. Rising floodwaters use a ballast system to push the flood shield closed. Ballast systems can be used in dry floodproofing and floodwalls when large shields are difficult to install quickly. Passive flood shield systems may require room under the opening to allow the flood shield to be stored when it is not in use.

Flood shields that must be moved into position prior to a flood event require the most time critical and labor intensive human intervention of any dry floodproofing measure. Although shield systems may be the most aesthetically pleasing, more than one person may be needed to carry and install them. A plan is needed to ensure that they will be installed efficiently, and the installers may need to have extensive training on proper installation (see Section 3.8).

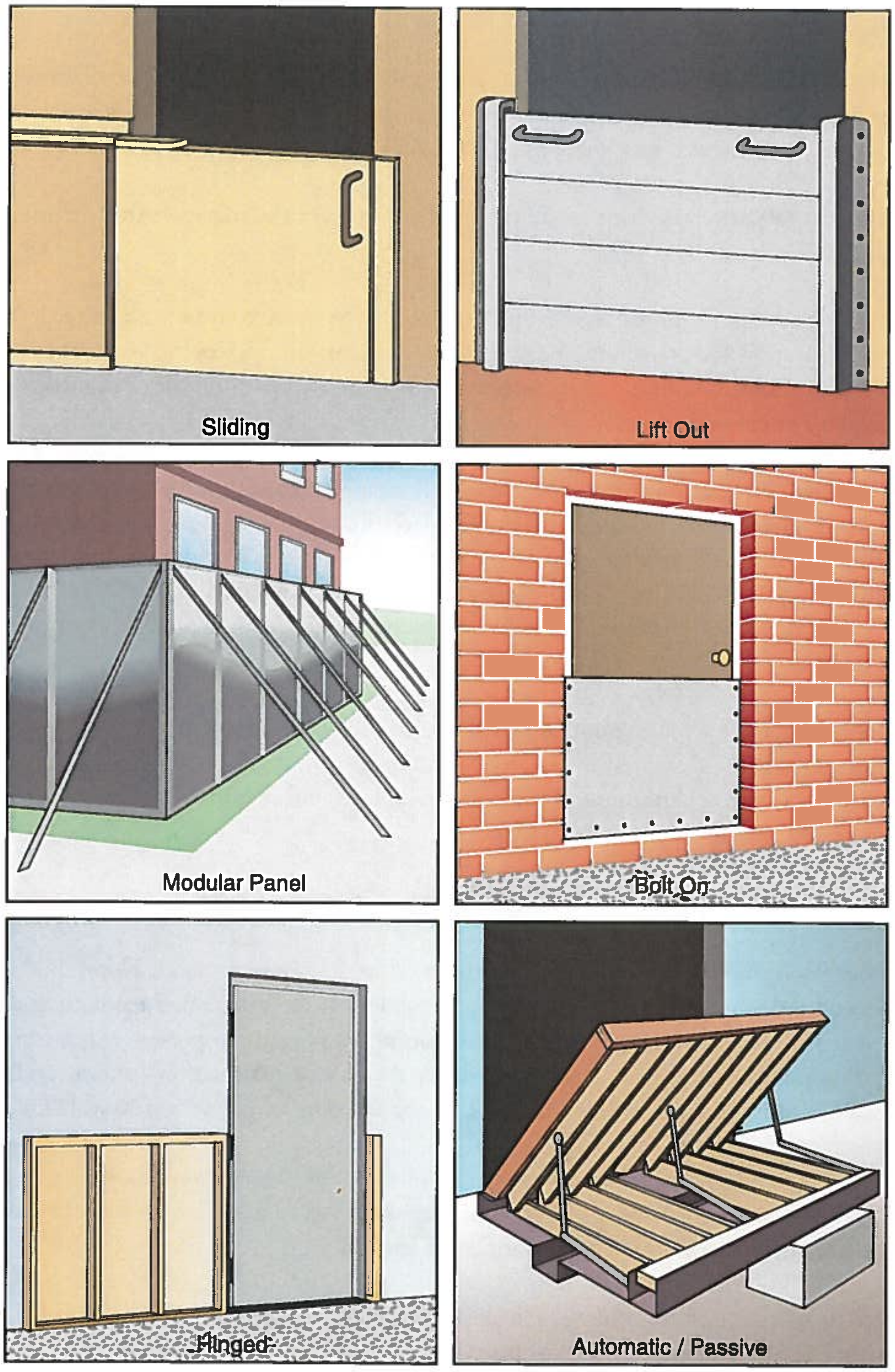


Figure 3-10. Types of flood shields

3.5.2 Flood Shield Materials

Considerations such as the size of the opening to be protected, the normal use of the openings, who will install the flood shields, and how quickly after the floodwaters recede the openings need to be available are important in determining the material to be used and also how the flood shield will be attached to the structure.

Steel, aluminum, and, in limited applications, marine-grade plywood are some of the materials that are used to fabricate shields, depending on loads.

For normal sized openings such as entrance doors, aluminum is probably the most common material. It is lightweight, allowing for easy fabrication and transport, and is resistant to corrosion. However, aluminum can buckle under large hydrostatic pressures, so additional reinforcement may be required. Shields designed for long-duration flooding are typically steel or aluminum.

For smaller openings such as windows with short-duration shallow flooding, marine-grade plywood is also commonly used. However, plywood is subject to warping if not properly stored. In addition, it will collapse under relatively low flood forces and usually requires significant reinforcement, which is usually some type of wood frame. Plywood flood shields are limited to short spans and low water heights. In addition, most plywood deteriorates when exposed to high moisture. Therefore, plywood flood shields should be examined periodically and replaced as necessary.

Longer and larger flood shields, such as for vehicle entrances, must be able to withstand significant flood forces and should therefore be constructed of a substantial material. This material is normally steel plate, which is protected against rust and corrosion. Heavy aluminum plate may also be used, although it will likely need to be reinforced.

3.5.3 Gasket and Seals

When leaks do occur into a dry floodproofed area, gaskets and seals are often the primary source. Flood shields depend on a variety of gasket and seal materials and configurations to prevent water intrusion. Pneumatic seals have been used successfully on some systems, but they rely on maintaining air pressure to prevent water from leaking past them. In long-duration flooding, it may not be possible to refill or maintain pneumatic seals. Self-sealing compression seals are more reliable and can be used in conjunction with pneumatic seals for a redundant configuration, which provides more protection.

Seals and gaskets can be monitored during a flood event by moisture monitors (e.g., water sensor, camera) inside the flood shield, and maintenance personnel can be notified of any leaks.

Seals and gaskets are subject to cracking or rot and need to be repaired or replaced periodically to be an effective watertight seal under flood conditions. Storage of flood shields and components outside can cause premature deterioration of seals and gasket materials.

3.5.4 Plate-Style Flood Shields

When it has been determined that the building can withstand the expected flood and flood-related forces, selecting a flood shield system is relatively straightforward. The decision hinges on the selected material's compatibility with the existing construction materials, and its ability to be constructed such that it can withstand the duration and depth of the expected flooding. Flood shields for standard size openings are available for purchase, but some openings may require flood shields to be designed for the opening.

The selection and design of a panel, or plate-style, flood shield should follow the process shown in Figure 3-11. If additional structural retrofitting is required to transfer loads from the flood shield to the wall system, the retrofit should be implemented in accordance with the guidance in Section 3.1. Similar steps are followed when a flood shield is purchased, but the manufacturer will provide most or all of the necessary design values.

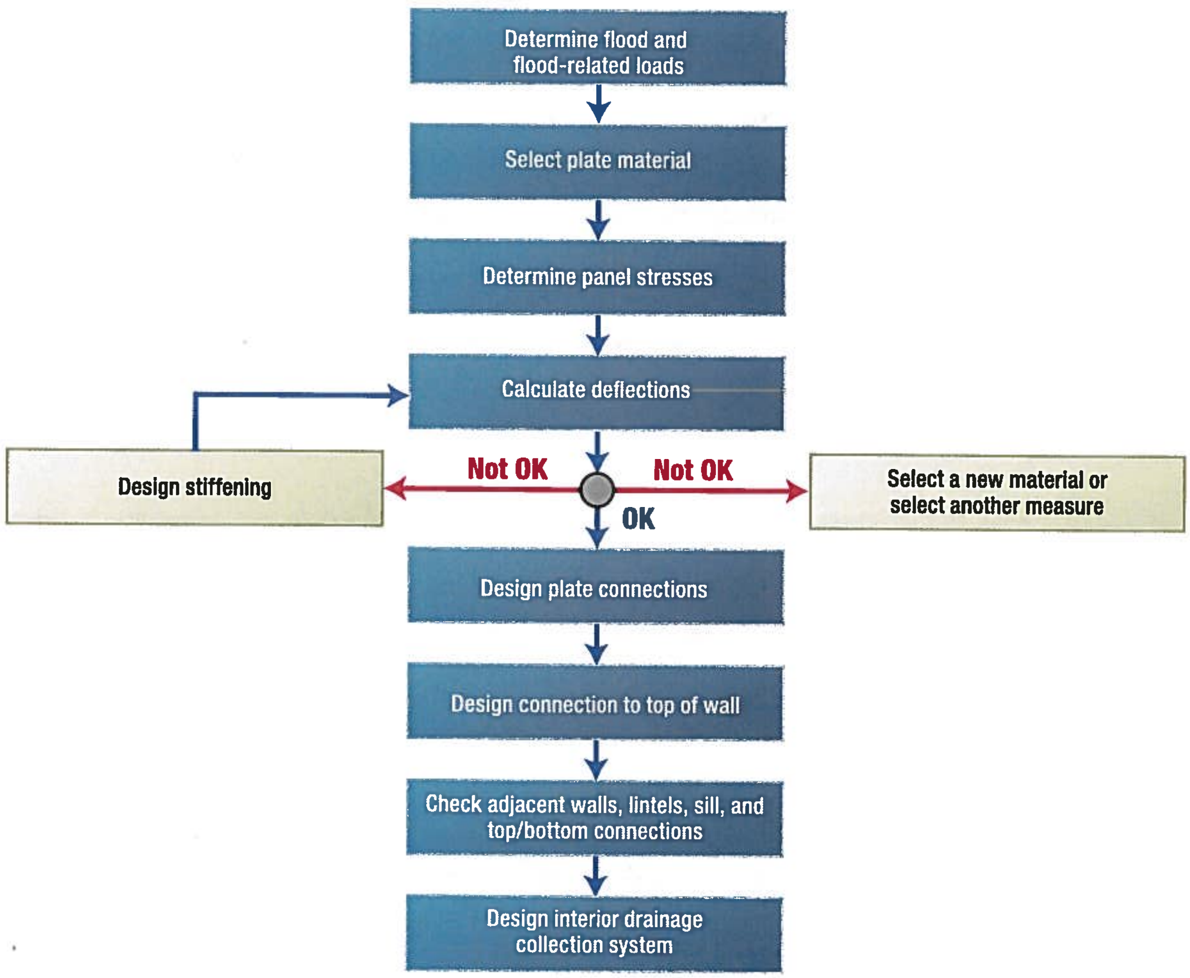


Figure 3-11. Selection/design of plate-style flood shields

The process for selecting and designing plate-style flood shields is as follows:

Step 1. **Determine the flood and flood-related loads.** Loads calculated in Chapter 2 should be used to determine the flood loads acting on the shield. The height of the flood protection level (the depth as it relates to the panel) and the related flood loads calculated per linear foot should be applied over the entire width of the area to be protected by the shield.

Step 2. **Select the plate shield material.** Material selection is driven by the size of the opening and duration of flooding. Factors to consider are:

a. Flood duration: Select steel or aluminum materials for long-duration flooding and consider marine grade plywood materials for short-duration, shallow flooding.

b. Size of opening: Select steel and aluminum materials with stiffeners for larger openings and shored marine grade plywood with appropriate bracing for small openings.

c. Installation: Should be quick and require minimal effort to minimize personnel needs.

Step 3. **Determine panel stresses.** The designer should check the flood shield panel either as a plate or a horizontal/vertical span across the opening, as follows:

a. Using end conditions and attachments to determine how the panel will work, calculate stresses based on bending of the plate. In larger shield applications, also compute the end shear. b. Compare these stresses to the allowable stresses from a material design value source.

c. Address shields that have a free end at the top or other unusual configuration on a case-by-case basis.

d. Adjust the plate thickness to select the most economical section. If the shield does not work for larger thicknesses, add stiffeners.

e. Refer to the American Institute of Steel Construction (AISC) 325, *Steel Construction Manual,* for steel plate design (AISC 2011); the Aluminum Association's (AA's) *Aluminum Design Manual* for aluminum design (AA 2010); the ANSI/AF&PA *National Design Specification for Wood Construction* for plywood design (ANSI/AF&PA 2005); and applicable codes and standards.

Step 4A. **Check deflections.** A shield that is acceptable for stresses may not be acceptable for deflection. Deflection may be controlled by using alternative plate materials. Check deflections as follows:

a. Calculate deflections for the shield and evaluate on the basis of connections and sealants.

b. If the stresses are such that the loads will permanently deflect the shield or cause leakage around the gasket material, the deflection should be considered unacceptable and stiffeners should be added.

c. Refer to the AISC 325 for steel plate design (AISC 2011), the *Aluminum Design Manual* (AA 2010) for aluminum design, the ANSI/AF&PA *National Design Specification for Wood Construction* for plywood design (ANSI/AF&PA 2005), and applicable codes and standards.

Step 4B. Design stiffeners as required. Plate overstress or deflection may be solved by using stiffeners. Design the stiffening as follows:

a. Select the section to be used as a stiffener. Angles may be used for steel or aluminum shields and wood stock for plywood shields.

b. Calculate the stresses and deflection based on the composite section of stiffener and plate.

c. Calculate the horizontal shear between the sections, and design the connections to carry this load.

d. Keep plate connections and frame in mind when detailing stiffeners.

e. Refer to the AISC 325 for steel plate design (AISC 2011), the *Aluminum Design Manual,* (AA 2010) for aluminum design, the ANSI/AF&PA *National Design Specification for Wood Construction* for plywood design (ANSI/AF&PA 2005), and applicable codes and standards.

Step 5A. Design the connections and hardware. Plate connections must be easy to install and able to handle the loads from the plate into the frame and surrounding wall.

a. Determine the type of connection (e.g., hinged, free top, bolted, latching dogs).

b. Consider ease of installation and aesthetics. Any hardware that can be permanently attached to walls systems or the shields will eliminate the potential to lose hardware.

c. Design the connection to operate in conjunction with gasket or sealant to prevent leakage.

d. Design the connection to be capable of resisting live loads in the direction opposite of surges.

e. Refer to the AISC 325 for steel plate design (AISC 2011), the *Aluminum Design Manual* (AA 2010) for aluminum design, the ANSI/AF&PA *National Design Specification for Wood Construction* for plywood design (ANSI/AF&PA 2005), and applicable codes and standards.

Step 5B. Select the gasket or waterproofing. Gaskets or waterproofing materials, which form the interface between shields and the existing structure, are vital elements of the dry floodproofing system. They should be flexible, durable, and applicable to the specific situation.

a. Determine the type of gasket or waterproofing required. Gasket/waterproofing must be able to withstand expected forces and able to function during climatic extremes.

b. Consider ease of installation and ability to work with plate/connections as a single unit.

c. Refer to the manufacturer's literature and check against duration/depth of flooding, the applicability to selected building materials, and storage requirements. Some gasket materials can be damaged by extended exposure to sunlight or other weather conditions. Vulnerability to sunlight or weather may affect the selection of the gasket or waterproofing material.

Step 6. Check adjacent walls, lintels, sills, and top/bottom connections. Resistance of structural components adjacent to the shield such as walls, lintels, sills, and top/bottom connections should be checked against maximum loading conditions. Different methods of attachment may load the adjacent wall differently. These support areas will be depended on to maintain the load path from the shield and to the wall system.

Walls adjacent to the shield should be anchored into the footing to resist base shear. Lintels/sills should be checked for biaxial bending resulting from lateral loading. Connections, if used, should be evaluated for shear resistance and ability to transfer loads to the horizontal diaphragm above.

When removable shields are used, a flood emergency plan should be developed and posted in at least two conspicuous locations in the building. The plan should specify, at a minimum, the following:

- Storage location(s) of the shields and hardware (storage in outside locations can cause premature deterioration of gaskets and waterproofing materials)
- Methods of installation
- Conditions activating installation
- Maintenance of shields and attachment devices (check for deterioration)
- Cleaning of any permanently mounted channels or gaskets
- Periodic shield installation practice
- Testing of backflow valves
- Testing sump pumps and other measures associated with the internal drainage collection system
- Inspecting material and equipment required to implement the dry floodproofing measure

A maintenance plan is an important part of a floodproofing system that includes flood shields. Flood shields, hinges, hoists, latches, channels, and seals should be inspected periodically for damage. Typically, the time between the flood warning and the flood event is not sufficient to repair any damage to shields or seals. See Section 3.8 for more information on operations and maintenance plans.

3.5.5 Case Study: Retrofit Dry Floodproofed Building, New Castle, DE

A machine shop located in northern Delaware was badly damaged by flooding in 2003 and 2004. Although the owner received several hundred thousand dollars in claim payments from the NFIP, the time required to recover meant significant loss of business. Despite wanting to relocate his business, the owner was unable to find an alternative site outside of the SFHA because the surrounding area is so densely developed. Instead, he worked with the New Castle Conservation District and the State of Delaware to pursue a mitigation grant from FEMA.

Without any guarantee of Federal assistance, the owner paid to have a structural engineer evaluate the building to determine whether it was feasible to retrofit. The engineer computed flood loads, evaluated options, and developed a retrofit floodproofing solution. The engineer also prepared a probable cost estimate. Federal grant funds were awarded to the State of Delaware, and to the District as a subgrant applicant, which worked with the owner to construct the floodproofing measures.

A key aspect of the project's feasibility was the fact that stream gages are installed throughout the upper watershed, including one placed in Pennsylvania by the State of Delaware. The gages are part of a warning system that transmits text messages and pages to property owners and businesses throughout the flood-prone lower reach of Red Clay Creek. Because of the short warning time, business owners who implement floodproofing measures that require human intervention agree to deploy those measures when buildings are vacant, such as overnight and on weekends.

The structural engineer determined that the machine shop's concrete masonry walls that form the main part of the building and the metal walls that form the rear portion would not resist anticipated flood loads, prompting design of supplementary walls. The main part of the shop building has two exit doors and a garage door at the front that were retrofit with drop-in aluminum panels with inflatable gaskets (see Figure 3-12). The exit door at the back of the building was protected with a permanent, hinged aluminum panel (see Figure 3-13).

The Delaware Department of Natural Resources and Environmental Control, as the State agency administering the Federal grant, required submission of an emergency operation plan that specified how flood threats are monitored and identified which personnel are responsible for specific actions. A flood in 2007 affected the area, but the machine shop was not damaged.

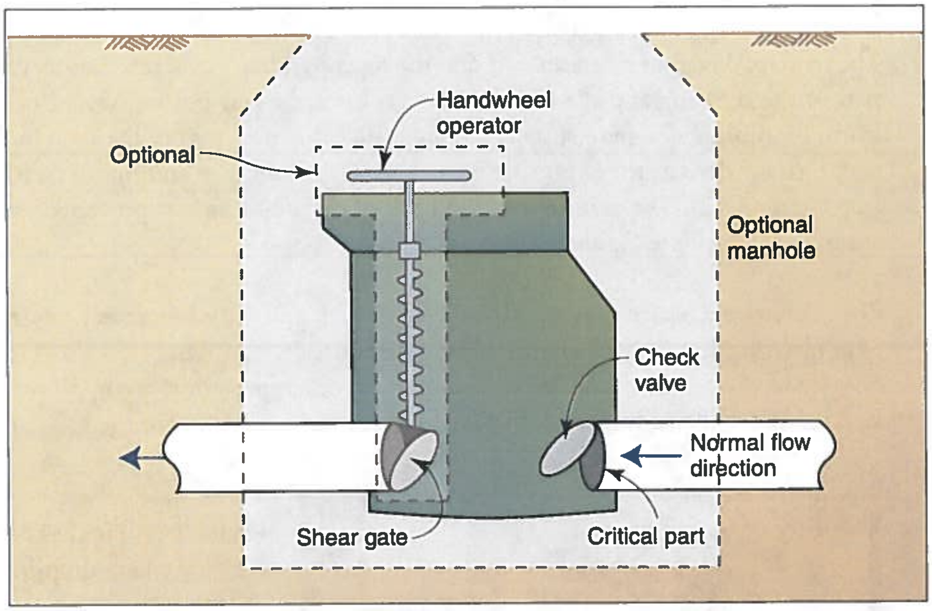
Figure 3-12. Front of retrofit dry floodproofed building where drop-in flood shields protect doors

Figure 3-13. Rear of retrofit dry floodproofed building with permanently installed flood shield

3.6 Backflow Valves

A backflow valve is similar to a check valve used in water systems (see Figure 3-14). It has an internal hinged plate that opens in the normal direction of flow, and if flow is reversed, the hinged plate closes over the inlet to cover the pipe opening. The valve generally has corrosion-resistant internal parts and a cast-iron body with a removable cover for access. Valves are available in sizes from 2 to 8 inches in diameter.

Figure 3-14. Backflow valve



Backflow valves can help prevent water flowing from the exterior to the interior of the building through the sanitary sewer and/or water drainage systems and should be considered for sanitary sewer drainage systems with fixtures below the flood protection level. Combined sewers (sanitary and storm) may present the greatest need for backflow valves because the valves can prevent both a health and a flooding hazard. However, the effectiveness of a backflow valve can be reduced if its internal mechanism is fouled by soil or debris. Periodic maintenance and testing is required to maintain functionality.

Special Note

Alternatives to backflow valves include retrofitting sewer lines and standpipes so that they are overhead or to install a gate valve which must be closed manually.

Some manufacturers add a shear gate mechanism that can be manually operated to close the drain line when backflow conditions are anticipated. The valve remains open during normal use. When manually operated backflow valves are used, the time necessary to close the valves should be factored into the emergency operations plan. A second type of backflow valve is a ball float check valve (see Figure 3-15) that can be installed on the bottom of outlet floor drains to prevent water from flowing up through the drain. This type of valve is often built into floor drains or traps in newer construction.

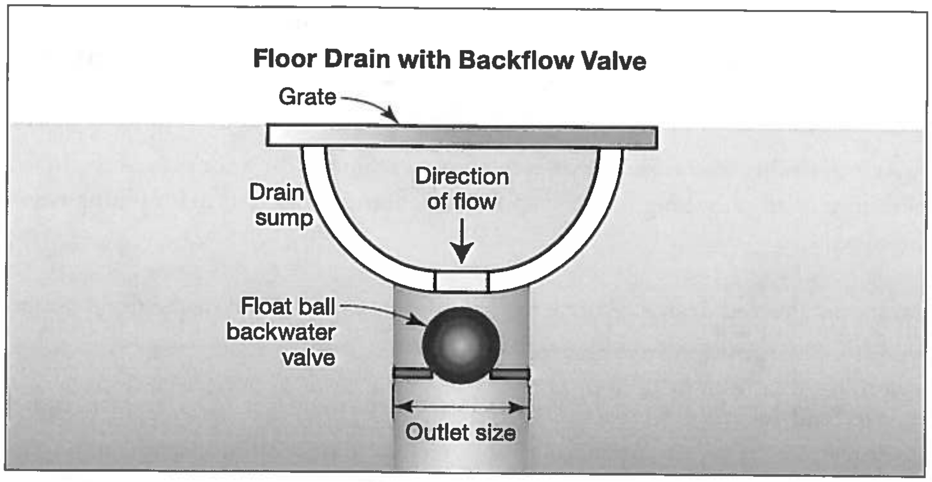


Figure 3-15. Floor drain with a backflow valve with a ball float check valve

Advanced backflow valve systems have ejector pump attachments to pump sewage around the backflow valve, forcing it into the sewer system during flooding. This system is useful for maintaining normal operation of sanitary and drainage system components during a flood.

Detailed information must be obtained about the existing building and the location of sanitary and drain lines to determine whether using backflow valves is feasible. Once the design data are collected, the designer should follow the process shown in Figure 3-16 to develop a preliminary concept for the installation of the backflow valve.

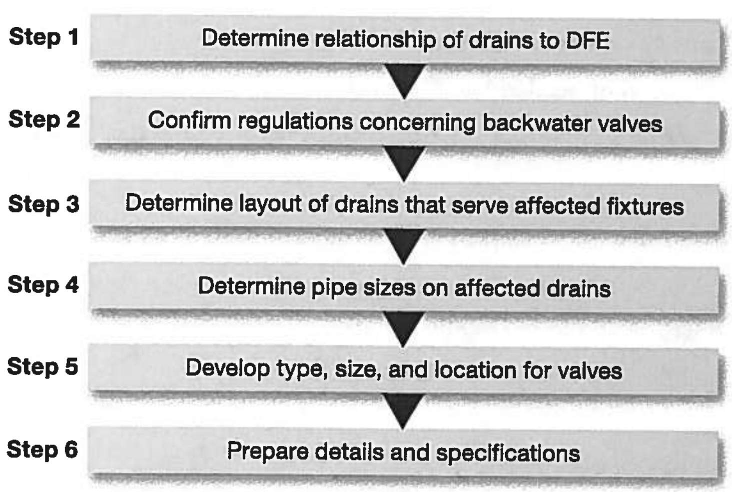


Figure 3-16. Backflow valve selection process

The elements of the backflow valve selection process are as follows:

Step 1. **Determine relationship of drains to flood protection level.** If any drain or pipe fixture is below the flood protection level, backflow valves should be installed. If all drains and fixtures are above the flood protection level, backflow valves are not necessary.

Step 2. **Confirm regulations on backflow valves.** Based on information collected during the field investigation, confirm the local code or governing regulations allow the use and installation of backflow valves.

Step 3. **Determine the layout of drains that serve the affected fixtures.** Sketch the floor plan of the building showing the location of all plumbing fixtures, appliances, floor drains, and drain piping below the flood protection level.

Step 4. **Determine pipe sizes on affected drains.** Obtain the size of drainage lines below the flood protection level from the field investigation or construction drawings.

Step 5. **Determine type, size, and location for valves.** Determine type, size, and location of backflow valves required, paying attention to any special conditions related to installation. Factors to be considered are:

- Clearance for access and maintenance
- Cutting and patching of concrete floors
- Indicating on the floor plan sketch the tentative location(s) of the backflow valve(s) to verify they do not conflict with other utility lines or equipment

At this point, the designer should confirm the preliminary design with the owner, discussing the following items:

- Verify that proposed locations of backflow valves are feasible
- Verify existing conditions at location of proposed backflow valves
- Confirm the size and location of needed backflow valves
- Confirm special considerations regarding existing conditions affecting design and installation of backflow valves

Step 6. **Prepare details and specifications.** The final plans and specifications should include the following items:

- Floor plan or site plan with location of backflow valves
- Details, notes, and schedules:
  - Backflow valve detail
  - Wall, floor, and wall penetration details
  - Installation notes
  - Equipment notes (or schedule)
- Specifications governing the installation of:
  - Pipes and fittings
  - Insulation
  - Hangers and supports
  - Valves

The designer should coordinate the backflow valve plans with any other floodproofing retrofit measures that may be proposed for the same building.

3.7 Internal Drainage

Internal drainage systems serve two primary functions in dry floodproofing projects. First, they remove water that has seeped through small openings in the sealant system or through the gaskets of shields that are protecting openings. Additionally, internal drain systems may be used to remove water collected from underdrain systems in the below-grade walls and floors of the building. See Section 2.2.7 for additional information.

3.7.1 Sump Pumps

Other than the piping system, sump pumps are the most common piece of equipment in an internal drainage system (see Figure 3-17). In dry floodproofing applications, sump pumps are used to prevent accumulation of water in the building and handle the inevitable small leaks that occur around shields and sealed openings and the leaks from the buildup of hydrostatic pressure against walls. Sump pumps may be used with other floodproofing methods to protect areas around mechanical equipment and other systems that may be located in lower building levels that are subject to flooding. If the building has excessive seepage or a significant inflow of water from below the floor slab, or it is totally inundated by overtopping, the pumping capacity of sump pumps will likely be exceeded.

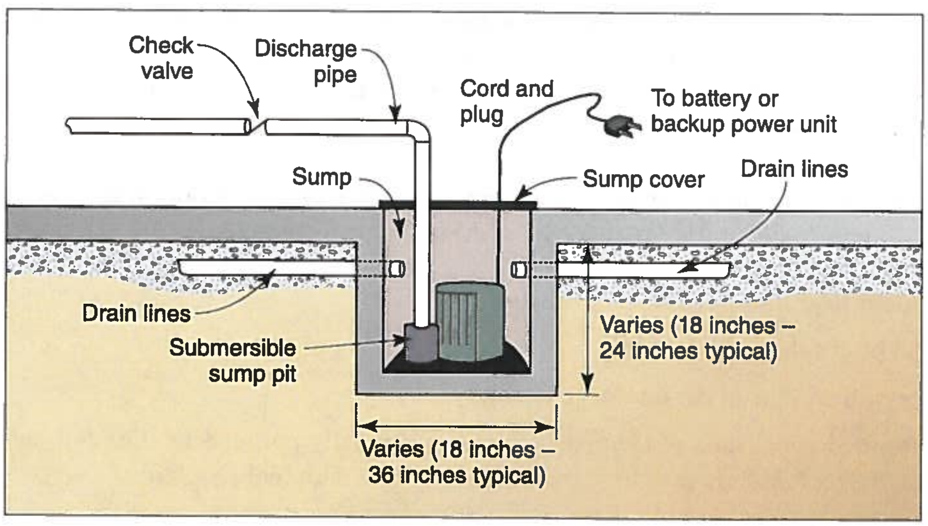


Figure 3-17. Typical sump detail

Before designing a sump pump system, the designer should verify that electrical power will be available for the pump system during and after a flood event. A generator may be required. When sizing the generator system, the designer should account for the pump's electrical load on startup. An electrical engineer should be consulted to make sure the generator is sized properly. Additionally the designer should consider whether the fuel source for the generator can be relied on during a flood event.

Sump pump and pit systems are constructed so that the bottom of the pit is below the base of the floor slab. Water in the areas adjacent to the walls and floor migrate toward the pit along the lines of least water flow resistance. If the pit is located properly, water will flow toward and into the sump pit.

To remove water that has seeped into the dry floodproofed area, the floor slab should be sloped toward the sump pit(s). The slope will reduce the potential for water to accumulate before it reaches the sump pit. Placement of any equipment, storage items, or other potential obstructions should be considered so drainage is not impeded.

A path of reduced resistance may need to be constructed for water that has collected in the backfill material next to and adjacent to the building so that it can travel to the sump pit. Short pipe segments are inserted into holes drilled through the foundation walls into the backfill adjacent to the foundation wall. These pipe segments are connected to larger diameter pipes running along a gravel-filled trench or cove area in the basement floor that leads to one or more sumps. Although a sump system is effective in areas with low water tables, it may be overwhelmed by high water tables.

Two commonly used types of sump pumps are the submersible and pedestal. The submersible type has a watertight motor connected directly to the pump casing and is installed at the bottom of the sump. Pedestal sump pumps have an open motor supported on a pipe column with the pump at its base and a long shaft inside the column connecting the motor to the pump impeller.

Submersible pumps are preferred for smaller applications because they continue to operate if the water level exceeds the height of the pump. In larger or commercial applications, a pedestal floor-mounted pump is preferred. Larger pumps require greater maintenance because of the larger volume of water they are designed to move. Larger pumps must therefore be mounted above the water collection pit for accessibility.

When selecting a sump pump for floodproofing applications, the designer should consider the advantages of each pump type and select a pump based on the requirements of the building. Considerations are as follows:

- Pump capacity (gallons per minute or gallons per hour)
- Pump head (vertical height the water is lifted)
- Frictional resistance of fluid flow in the discharge piping system
- Electrical power required (small non-residential buildings are usually powered by 120/240 volt, single-phase AC, but larger buildings may have three-phase systems with higher voltages)
- Type of pump activation switch system

The pump activation switch is an important component of the sump pump system. Many pumps use one of four types of switches: diaphragm, vertical action float, tethered float, or electronic free float. Although all of these switches are viable, the strengths and reliability of each one must be understood. Table 3-3 provides a comparison of the pump activation switch types.

Table 3-3. Comparison of Types of Pump Activation Switches

Float Switch Type	Description	Strengths	Considerations
Diaphragm switch	Activated by water pressure	Well suited for most pit situations; works well in small sump pits	Most expensive; not always the most reliable: not adjustable
Vertical action float switch	Attached to a vertical rod, which activates the switch as it rises along with the water level	Inexpensive; relatively reliable	Not ideal for a deep sump pit because there may not be sufficient adjustment for the pit depth
Tethered float switch	Works similar to the vertical action float but is tethered by a line instead of a vertical rod	Inexpensive	Subject to operational problems; easily shut off by trapped debris; requires space in the sump pit
Electronic float free switch	Uses a wire that senses contact with water; may include an audible alarm	Few moving parts to fail	Relatively expensive

If a pump system is to be depended on for dry floodproofing, the pump(s) must be periodically checked to ensure that they are working properly. One of the most common causes of failure is the malfunction of the switch. The owner must be familiar with the proper procedure for replacing the switch. Although the switch can be an inexpensive part, the malfunction of a switch can negate the effectiveness of other floodproofing measures. Other common problems are an improperly working float (tells the sump pump when to operate), blocked intake, and blocked impeller. Although not directly connected to the pump, the discharge system should incorporate a check valve to make sure that backflow does not occur along the discharge pipe. Check valves should be inspected periodically for proper operation, and owners should be aware that debris in the discharge pipe can prevent proper operation. Sump pumps should be incorporated into the operations and maintenance plan for the building along with other floodproofing measures.

Larger buildings and critical facilities require large internal drainage systems, which may be significantly different from small systems. Large systems require more careful design, layout, and significantly higher power requirements. Many large systems require three-phase electric motors and are applicable only where the feed to the building is 3-phase.

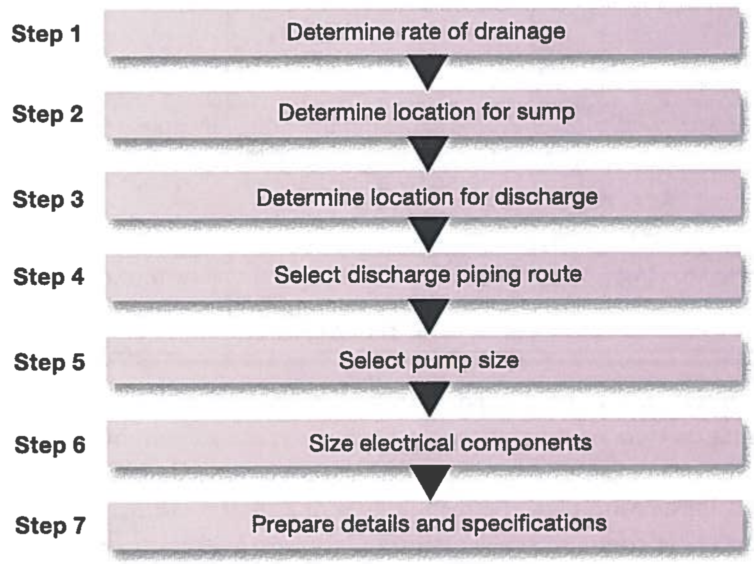
Pumping systems typically fall into two categories: a constant speed pump or a variable speed pump. A constant speed pump may be the only viable option when the project is under cost constraints because a constant speed pump is less expensive than a variable speed pump.

During a flooding event, the slow rise of floodwaters may result in low flows of water into the water collection pit. A constant speed sump pump will likely cycle on and off several times to empty the water collection pit until the flood protection level is reached, when the pump will likely need to accommodate a more constant flow of water into the collection pit.

A variable speed sump pump can be adjusted to address the variability in the flow rates into the collection pit. The more consistent operation of a variable speed pump will likely reduce the size of the generator system needed to compensate for the startup electrical draw required for the pump system. A large commercial application using large constant speed sump pumps could require either the installation of a larger generator system or reductions in the number of other types of equipment that can be run on a smaller generator system.

Once the sump pump type is determined, the design should follow the procedure shown in Figure 3-18.

Figure 3-18. Sump pump design process



Step 1. Determine the rate of drainage. This is covered in Section 2.2.7, Internal Building Drainage.

Step 2. Determine the location for the sump pump. Consider the following:

- Verify there is adequate room for the sump.
- Assess whether the subfloor conditions (i.e., structural footings) would interfere with the sump pump installation.
- If penetration of the floor is not recommended, consider using a submersible pump design for use on any flat surface.
- If other floodproofing measures are being considered, such as placing a flood barrier around heating equipment or plumbing appliances, locate the sump pump or provide piping to it to keep a protected area dewatered. Sketch a preliminary location for the sump pump, discharge piping, and electrical receptacle for the pump.
- Coordinate the sump pump location with the design of the drainage collection system.

Step 3. Determine the location for the discharge. Check with local officials about the discharge of clear water wastes. In most jurisdictions, it is not acceptable to connect to a sanitary drainage system, nor may it be desirable because of the potential for backflow under flood conditions. If allowable, the desirable location for the discharge is a point above the flood protection level at some distance away from the building. The discharge point should be far enough away from the building that water does not infiltrate back into the building. From the information obtained during the field investigation, tentatively lay out the route of the discharge piping and locate the point of discharge.

Step 4. Select the discharge piping route.

- Minimize the length of pipe between sump and discharge point
- Avoid utility and structural interferences along the route
- Attach the discharge pipe to the structure as required by code
- Protect the discharge point against erosion and install a downspout discharge block under the sump pump pipe discharge

Step 5. Select the pump size. Sump pumps for non-residential use generally have motors from 1/6 to 3/4 horsepower and pumping capacities from 8 to 60 gpm. In selecting a pump, the designer needs to estimate the rate of flow of floodwater that will infiltrate into the space (gpm or gallons per hour [gph]). Additionally, the total dynamic head for the sump discharge must be determined. The total dynamic head equals the vertical distance from the pump to the point of discharge plus the frictional resistance to flow through the piping, the fittings, and the transitions. The head loss from pipe friction can be obtained from hydraulic engineering data books and depends on the pipe material and pipe length.

Other pump size considerations may be:

- Physical size of the sump pump given the area available to place the pump
- Recommendations of the sump pump manufacturer regarding pump cycling or other constraints

The designer should take these considerations into account in locating the sump and configuring the sump pump discharge.

Step 6. Size the electrical components.

- Obtain horsepower and full load amperage rating
- Select a ground fault interrupter circuit, as required by code
- Size minimum circuit ampacity and maximum fuse size
- Size maximum circuit breaker size
- Obtain recommended fuse size or circuit breaker size from manufacturer and compare to above maximum and minimum National Electrical Code sizes

At this point, the designer should prepare a floor plan sketch showing the location of the sump pump, routing of the discharge line, location of the discharge point, and the preliminary specifications for the sump pump, sump pit, piping, and appurtenances and confirm the preliminary design with the owner or facility management, covering the following items:

- Verify that the proposed location of the sump pump and pit is feasible
- Verify electrical availability for the sump pump

- Verify existing conditions along the proposed routing of discharge piping and at the discharge pipe termination
- Confirm selection and size of the sump pump
- Confirm size and location of the sump pit
- Confirm special considerations regarding existing conditions affecting design and installation of the sump pump and sump pit

Step 7. Prepare details and specifications.

Prepare final plans showing:

- Floor plan with locations of sump and backflow valves
- Routing of discharge pipe and location of discharge point
- Sump pump detail
- Wall, floor, and wall penetration details:
  - Sump construction details
  - Installation notes
  - Equipment notes (or schedule)
- Specifications (on drawing or as a specifications booklet):
  - Pipe and fittings
  - Insulation
  - Hangers and supports
  - Valves (including backwater valves)
  - Sump pumps
  - Coordinate plans with the work of others on additional floodproofing measures that may be proposed at the same building

3.7.2 Pressure Relief Systems

If flooding exceeds the level of protection and water fills the building, pumping out an area before the floodwater has receded can cause the walls to collapse if hydrostatic pressure from the floodwater exceeds the structural resistance of the foundation walls and the floor slab. Incorporating a pressure relief system is recommended to avoid structural damage to the building.

Pressure relief systems are similar to wet floodproofing measures in that they allow floodwaters into an area rather than risking damage by hydrostatic pressures. The systems allow for some level of dry floodproofing and then release the hydrostatic pressure if water levels exceed a specific height. A pressure relief system provides an added degree of protection against structural failure of a new building or for an existing structure that cannot be modified to reduce uplift pressures.

Installing some type of pressure relief system is generally desirable. For floor systems that are not thick enough or sufficiently reinforced to resist buoyancy forces, the system may be a series of relief valves equally spaced across the floor slab. If floodwaters begin to collect in the soil under the slab, the relief valves will allow the water to percolate through the floor slab, eliminating the buoyancy forces. Dry floodproofing protection will not be achieved, but this is preferable to losing the structure.

3.8 Flood Emergency Operations Plan and Inspection and Maintenance Plan

All dry floodproofed buildings must maintain a Flood Emergency Operations Plan and an Inspection and Maintenance Plan. The complexity of these plans depends largely on whether the dry floodproofing measures are passive or active and how much human intervention the active measures require. If ASCE 24 is required to be followed for the retrofit design, these plans will need to be approved by the Authority Having Jurisdiction. Both the Flood Emergency Operations Plan and the Inspection and Maintenance Plan should be drafted and submitted as part of the building permit application. More information on the minimum requirements for operations, maintenance, and inspection plans is available in Sections 2.5.4 and 2.5.5. The following paragraphs describe in more detail the typical components of a dry floodproofing measure that would be inspected and what common failures an inspector might see.

When performing routine inspections of dry floodproofing measures, gaskets and attachment hardware should be evaluated to determine whether they are still in good condition. Missing or deteriorated gaskets (see Figure 3.19) should be replaced with materials that are designed for use with the dry floodproofing shields. Shields and anchorage hardware should be installed at least annually to verify that all necessary hardware is available. A recommended practice is for owners to test their dry floodproofing components when renewing their flood policy each year. Emergency power sources and sump pumps should also be tested to verify that they are also in good working order. Sump pumps should be tested using the emergency power source rather than using the normal power source. Some dry floodproofing measures incorporate the use of leak detectors, which should also be tested. An inspection of the exterior of the building is also necessary to verify that no additional penetrations have been made below the DFE to which the dry floodproofing measure protects. Plumbing, electrical, mechanical, communications, or other penetrations can be installed over time and render the dry floodproofing ineffective if not properly sealed. Although sealing these penetrations is the building owner's responsibility, the design professional should make it clear to the building owner that failure to maintain the dry floodproofing measures can result in either greater water intrusion than the sump pump system was designed for or, in a worst case scenario, water infiltration to a degree that renders the dry floodproofing measures useless.

Figure 3-19. A deteriorated flood shield gasket (see red circle) that must be replaced for the shield to seal and function properly (Ocean City, NJ)

3.9 Dry Floodproofing in New Construction

Although this chapter focuses on retrofitting existing buildings, similar methods are used for designing and constructing new buildings that are dry floodproofed. Depending on which codes are locally enforced, ASCE 24 will likely be the required standard for flood-resistant design and construction of a new building and is recommended as a standard of practice even if not required. ASCE 24 will be used to establish the elevation of the floodproofing measure, and ASCE 7 will be followed for the design loads that should be considered.

Special Note

New construction must comply with the locally enforced BFE/DFE and/or IBC (ASCE 24 by reference).

Being able to design the layout of the site and building is a benefit of new construction that can avoid many of the design challenges in a retrofit project. If permitted by floodplain management regulations, the site can be graded to reduce portions of the building that need to be dry floodproofed. Additionally, laying out the building to minimize or eliminate openings and points of egress below the required elevation will reduce construction details and the human intervention that may be necessary to prevent the intrusion of floodwaters. Higher ceiling heights can allow windows to be located above the required elevation and still allow sunlight to reach the lower floors, which can create flexibility in the use of the lower floors. Mechanical systems and electrical systems can also be located on higher floors, eliminating the need to protect them during a flood event.

Careful consideration should be given to the placement of critical building systems (including, but not limited to, MEP components, gas installations, communications systems, and fire suppression equipment) that are essential to the functionality of a building. Flood damage to critical building systems can cause the building to be closed for weeks or months, resulting in building loss of function similar to structural damage. There is substantial residual risk associated with relying on dry floodproofing measures to protect critical building systems. Designers should relocate the systems above the DFE or, at a minimum, provide additional protective measures. For example, a building may be designed with an emergency connection for temporary heat or power in case the primary source is compromised. Aside from the residential use limitation, there are very few restrictions on occupancy categories of dry floodproofed areas. Designers must consider flood damage implications to areas below the DFE as well as the impacts to building inhabitants because other parts of the building may need to be occupied immediately following the flood event.

In some cases, critical building systems, such as fuel tanks for emergency power, are required by building codes to be placed on the lowest floor (including basement). This location, while ideal for reducing the risk of fire associated with large volumes of flammable liquids, may be the most vulnerable to flooding. As a result, elevating the system above the flood level may not be feasible, but it may be possible to protect it by placing it in a dry floodproofed enclosure (see Section 3.3). These enclosures, often considered vaults, are typically constructed of reinforced concrete because its inherent mass helps counteract buoyancy and, with proper reinforcement, concrete can be constructed to resist hydrostatic pressures (see Figure 3-20). Because rooms containing building systems require access and ventilation, they should be equipped with specially designed, impermeable doors and ventilation equipment (see Figure 3-21). Also, because barriers used for dry floodproofing are rarely 100 percent watertight, a system to prevent seepage and infiltration is required. Sump pumps powered by emergency power sources are recommended. Note, these enclosures are not intended to be occupied when flooding is imminent.

A large building area with a floor slab deep below the flood protection level can experience significant buoyancy loads. A retrofitted building must rely on its dead load and any foundation connections from the original design to resist buoyancy, but the foundation of a new building can be designed to resist buoyancy. Deep foundations or large, robust foundation elements can be necessary to achieve the required resistance.

Figure 3-20. Dry floodproofed fuel pump room adjacent to generator fuel tank vault

Figure 3-21. Door to a dry floodproofed generator fuel tank vault servicing multiple generators in a high-rise building

Walls and floor slabs are subject to the loads described earlier in Section 2.2, but the cost of constructing walls and slabs sufficient to resist these loads can be minimized in new construction. Floor slabs can be properly reinforced and sufficiently thick to prevent buoyancy forces from cracking them. Additionally, sufficient waterproofing can be applied to the slab and joints during construction to eliminate or minimize the potential for water intrusion and seepage. Perimeter and underdrain systems can be drained to a location outside the main building to eliminate the need for sump pits, which is another location where water can infiltrate the building.

Floor slabs and walls can be detailed to allow a sufficient connection between them in order to maintain the load path. The connection can be further detailed to minimize the potential for water migrating through the wall-to-slab connection. The wall-to-slab connection is often an area of weakness for water intrusion in dry floodproofing projects.

Walls can be floodproofed by minimizing cold joints and properly detailing them to minimize pathways for water intrusion. Excavation for below-grade walls will allow for the proper application of a waterproofing membrane or coating. The designer may have a wider selection of products to choose from because of accessibility to the walls. Wall penetrations can be located above the required elevation or detailed and tested to prevent water intrusion.

The SERRI Report referenced in Section 3.2 suggests that simple wall systems can be successful and that dry floodproofing increases the cost of construction by 15 percent. Although cast-in-place concrete walls are commonly limited to industrial structures, wall assemblies may be appropriate for many other non-residential and commercial buildings requiring dry floodproofing measures. The SERRI Report indicates that if detailed properly, an ICF system and metal SIPs are capable of being substantially impermeable. A CMU block wall with filled cells and an exterior membrane (see Figure 3-22) was also successful in meeting the requirements for substantially impermeable buildings. The SERRI Report indicates that multi-layered polymer sealants and liquid-applied asphaltic membranes are both successful. Prior to using these systems, the designer should review the SERRI Report to evaluate the appropriateness of a particular wall system and to evaluate the construction details under which the systems were found to be substantially impermeable.

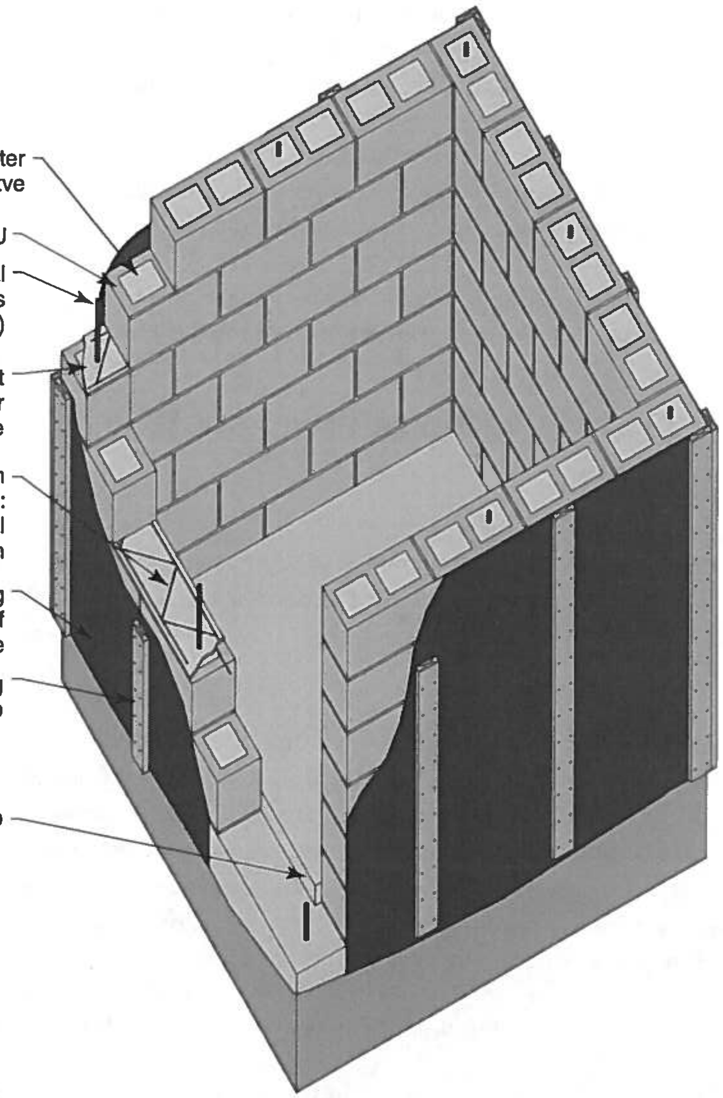


Figure 3-22. Cross section of the test mock-up used for the SERRI tests of a substantially impermeable CMU wall system (SERRI Report) – Not intended for design purposes

Doors, windows, and other openings below the required elevation should be detailed to eliminate the need for flood shields if possible, but at a minimum, permanently installed flood shields should be incorporated. New construction allows for more passive flood shields than in retrofits because the shields and shield supports can be incorporated into the design. Windows that cannot be situated above the required elevation should use materials such as submarine glass systems and seals that eliminate the need for a flood shield. Door frames and window mullions are particular areas of concern, and field testing to verify proper installation is important. Door and window frame anchorage should also be carefully checked and verified during installation. If flood shields are required, see Section 3.5.

Plumbing systems and mechanical systems should be run inside the building as much as possible in new construction. Properly waterproofing wall penetrations is often a challenging process. If lines running into the building are located above the required elevation, many of the common points of water entry during flood events can be eliminated. If plumbing and mechanical systems are located in utility chases along interior walls, the potential for water intrusion through an unnoticed leak in a chase can be eliminated. Utility chases along exterior walls may need to be grouted after utilities are routed to prevent the potential for water intrusion. Moving lines above the required elevation will also allow backflow valves to be located above floodwaters.

A Flood Emergency Operations Plan and a Maintenance and Operations Plan should be drafted (see Sections 2.5.4, 2.5.5, and 3.8). These plans need to meet the same requirements as a retrofit project, but the amount of human intervention required to successfully implement the plan should be lower.

The final step in designing a dry floodproofing project is to provide a Floodproofing Certificate for Non-Residential Structures, which needs to meet the requirements discussed in Section 2.1.2.

3.10 Case Study: University of Texas Perimeter Wall and Dry Floodproofing Project

In 2001, Tropical Storm Allison left the Medical School Building (MSB) at the Texas Medical Center in Houston, TX, with a flooded first floor and basement and losses of more than $205 million. The first floor and basement housed mechanical equipment, gross anatomy classrooms, the morgue, and research laboratories.

To reduce the potential for future flooding, the first floor and basement were dry floodproofed to the 0.2-percent-annual-chance (500-year) flood elevation plus 1 foot. The floodproofing did not affect the function of the spaces. The flood elevation requirements resulted in large portions of the first floor having to resist flood loads for depths of 7 feet. The project also needed to be designed to minimize the impacts to existing trees and landscaping to be aesthetically pleasing with measures unobtrusively incorporated into the building and landscaping. Additionally, operations at the MSB needed to continue during construction, which required dividing the project into 11 phases.

The total project cost was approximately $12 million. The floodproofing included:

- Reinforcing or replacing existing concrete walls and constructing sections of new concrete floodwalls
- Installing flood doors at key locations to maintain points of egress (see Figure 3-23)
- Retrofitting windows with aquarium (submarine) glass and creating a floodproof window system
- Installing isolation (backflow) valves on sanitary water system and sewer lines
- Retrofitting the basement to resist flood loads and buoyancy
- Replacing exterior stairways below the level of flood protection
- Waterproofing connections between buildings

Figure 3-23. Flood doors incorporated into the existing building façade (source: Walter P. Moore)

Because some sections of the original first floor walls were curtain walls, they could not be properly retrofitted to resist the flood loads. The curtain walls were replaced with reinforced concrete walls. One area of the main building required that the concrete walls be constructed offset from the building to maintain the continuity of the wall system.

Nine flood doors were added to maintain points of egress. Some of the flood doors have dual inflatable gaskets to provide redundant protection. The flood door seal pressures and closure bolts are monitored from a remote and secure location during a storm event and are on an independently powered building automation system.

Retrofitting windows was a particular challenge because of the flood elevation requirements. Aquarium (submarine) glass was used to allow natural light to enter the first floor. The retrofit consisted of replacing the conventional window wall system with laminated glass panels and oversized mullions to resist flood loads.

Plumbing systems (sanitary water systems and sewer lines) were protected with isolation valves that act as backflow prevention devices. Loss of power tips the devices and prevents potential floodwaters from entering the building.

Ross Sterling Avenue, a public street that passes under the MSB, provides access to other areas of the medical center (see Figure 3-24). Local authorities would not allow floodgates to be placed across the road, so the road was raised to create a berm that provides protection to the level of the base flood. Because Ross Sterling Avenue passes under the second floor of the building, all penetrations through the walls were waterproofed, and the mechanical chases were grouted to seal the area between the chase and the ductwork and pipes inside the chase. The waterproofed areas allow Ross Sterling Avenue to flood without compromising the building.

In the portion of the basement that is under Ross Sterling Avenue, the existing pan joist system of the basemtent ceiling was strengthened with fiber-reinforced polymer materials to minimize space consumption relative to existing and future equipment. Because of the potential buoyancy forces acting on the basement slab, some areas were retrofitted with beams and tie-down plates, and some equipment required additional anchoring. All existing expansion joints and wall cracks were filled with a urethane grout to allow some movement in the walls without compromising the floodproofing measures. To maintain continuity of operation during a flood event, the MEP equipment room was further floodproofed as a backup measure in case the dry floodproofed exterior walls fail. Portions of the equipment room were located over the basement, and the floor systems of these areas were upgraded to resist buoyancy forces.

Figure 3-24. Ross Sterling Avenue was raised to protect the MSB to the level of the base flood (source: Walter P. Moore)

Areas of particular concern were sections of the stairwell that originally had doors to exit at grade, but were below the flood protection level. The doors were walled in, and eight new doors and elevated platforms were constructed from the emergency stair landing between floors to maintain points of egress above the flood protection level (see Figure 3-25).

Connections between buildings presented a considerable design challenge because there were limited options for floodproofing. In some areas, the tight spaces between buildings were filled with expansion joint material, which was then waterproofed to prevent floodwater infiltration.

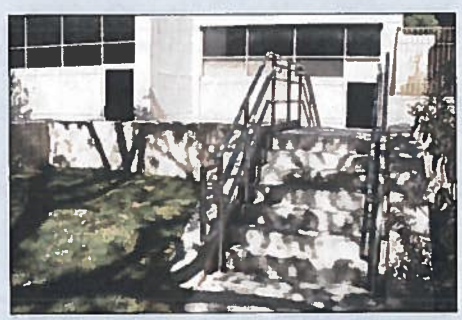


Figure 3-25. Three sets of stairs that provide building egress during the design flood event, but still allow normal use of the building (source: Walter P. Moore)