A Guide to Wet Floodproofing Residential Structures

Course No: S03-018
Credit: 3 PDH

Allen Hughes, P.E.

CED engineering.com
PDH FOR THE PROFESSIONAL

Continuing Education and Development, Inc.

P: (877) 322-5800
info@cedengineering.com

Wet Floodproofing

Wet floodproofing can be defined as permanent or contingent measures applied to a structure and/or its contents that prevent or provide resistance to damage from flooding by allowing floodwater to enter the structure. The basic characteristic that distinguishes wet floodproofing from dry floodproofing is that it allows internal flooding of a structure as opposed to providing essentially watertight protection.

NOTE

Wet floodproofing is appropriate for basements, garages, and enclosed areas below the flood protection level.

Flooding of a structure's interior is intended to counteract hydrostatic pressure on the walls, floors, and supports of the structure by equalizing interior and exterior water levels during a flood. Inundation also reduces the danger of buoyancy from hydrostatic uplift forces. Such measures may require alteration of a structure's design and construction, use of flood-resistant materials, adjustment of building operations and maintenance procedures, relocation and modification of equipment and contents, and emergency preparedness for actions that require human intervention. This chapter examines:

- protection of the structure;

- design of openings for intentional flooding of enclosed areas below the DFE;

- use of flood-resistant materials;

- adjustment of building operations and maintenance procedures;

- the need for emergency preparedness for actions that require human intervention; and

- design of protection for the structure and its contents, including utility systems and appliances.

5W.1   Protection of the Structure

As with dry floodproofing techniques, developing a wet floodproofing strategy requires site-specific evaluations that may necessitate the services of a design professional. The potential for failure of various structural components (foundations, cavity walls, and solid walls) subjected to inundation is a major cause of structural damage. Some of the reasons a house would need to be wet floodproofed include the following:

- it is a pre-FIRM house located in an area below the BFE;

- it is an historic structure and elevating it is not an option;

- it has an attached garage;

- it is located in an area above the BFE where there is significant flooding potential; or

- it has accessory structures (e.g., detached garage or storage shed).

NOTE

FEMA strongly encourages that flood retrofits provide protection to the DFE (or BFE plus 1 foot, whichever is higher). However, in some situations a lower flood-protection level may be appropriate. Homeowners 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 home. The text and examples in this manual assume flood protection measures will be implemented to the DFE.

The following is an explanation of various building systems that can be wet floodproofed. Each section explains the typical building materials used to construct them and cautions the user about various methods.

In some locations, the use of ASCE 24 may be required by the building codes. This standard includes minimum requirements for wet floodproofing (Section 6.3), specifically the limitations of use for the space

and design load minimums; it also presents requirements for the utilities located below the minimum elevation requirements. Other sections of the standard discuss flood-resistant materials (Section 5.0) and minimum design elevations below which more stringent design requirements are required (Table 6-1 of ASCE 24).

While wet floodproofing offers an improved level of protection for a structure, extended floodwater inundation of areas subject to flooding could still cause damage to the materials. Additionally the areas above the wet floodproofing are still at risk of damage. This damage could result from higher than expected floodwater, contamination, or toxic materials in close proximity to the house, or growth of mold from extended inundation or higher than normal levels of humidity. There is remaining risk for the areas either wet floodproofed or above the wet floodproofing. This risk is referred to as the residual risk for the structure. While this remaining or residual risk can be financially minimized with the purchase of flood insurance, a homeowner living in a flood-prone area should be aware that some level of risk cannot be eliminated by either physical risk reduction measures like floodproofing or financial risk reduction measures like insurance. The extent of their selected level of protection should be consonant with their ability to absorb the implications of the residual risk. Many design guidance documents and design standards such as ASCE 24 incorporate freeboard, or additional elevation above the BFE, to serve as a risk reduction tool. However, the designer and homeowner should be aware that in some instances floodwater can exceed even freeboard elevations and determine methods of addressing this inherent residual risk.

5W.1.1   Foundations

The ability of floodwater to adversely affect the integrity of structure foundations by eroding supporting soil, scouring foundation material, and undermining footings necessitates careful examination of foundation designs and actual construction. Footings should be located deep enough below grade so that flood-related erosion does not reach the top of the footing. In addition, it is vital that the structure be adequately anchored to the foundation. A continuous load path is necessary due to uplift forces during a flood event, which are often great enough to separate an improperly anchored structure from its foundation should floodwater reach such a height. Foundation walls must be checked for lateral support to verify that any lateral forces imposed by floodwater can be resisted. Areas where cripple walls are used should be checked to verify that they are properly braced.

5W.1.2   Cavity Walls

Wet floodproofing equalizes hydrostatic pressure throughout the structure by allowing floodwater to enter the structure and equalize internal and external hydrostatic pressure. Thus, any attempt to seal internal air spaces within the wall system is not only technically difficult, but is also contrary to the wet floodproofing approach. Provisions must be made for the cavity space to fill with water and drain at a rate approximately equal to the floodwater rate of rise and fall. Insulation within cavity walls subject to inundation should also be a type that is not subject to damage from floodwater. The design of foundation openings to equalize hydrostatic pressure is covered in Section 5E.1.2.1. Following a flooding event, it may be necessary to remove one side of a cavity wall to allow the interior to properly dry. It is also necessary to verify that drainage or weep holes remain clear of debris. Although not always an indicator of water trapped within a cavity wall system, the presence of efflorescence (white staining) on a wall system may indicate that the wall may not be properly draining and that the cavity does not have sufficient drainage holes. This type of staining may be present in cavity walls and solid walls and indicate the significant transfer of moisture.

5W.1.3   Solid Walls

Solid walls are designed without internal spaces that could retain floodwater. Because these walls can be somewhat porous, they can absorb moisture and, to a limited degree, associated contaminants. Such intrusion could cause internal damage, especially in a cold (freeze-thaw) climate. Therefore, where solid walls are constructed of porous material, the retrofitting measures should include both exterior and interior protective cladding to guard against absorption. Some liquid products may be applied to each face of porous wall systems. It is possible for voids or cavities within solid wall systems to be open and not grouted and, therefore, retain additional moisture. These are difficult to grout as a retrofit, but it may be necessary to allow them to drain following a major flooding event.

5W.2   Use of Flood-Resistant Materials

In accordance with the NFIP, all materials exposed to floodwater must be durable, resistant to flood forces, and retardant to deterioration caused by repeated exposure to floodwater. Interior building elements such as wall finishes, floors, ceilings, roofs, and building envelope openings can also suffer considerable damage from inundation by floodwater, which can lead to failure or an unclean situation. The exterior cladding of a structure subject to flooding should be nonporous, resistant to chemical corrosion or debris deposits, and conducive to easy cleaning. Interior cladding should be easy to clean and not susceptible to damage from inundation. Likewise, floors, ceilings, roofs, fasteners, gaskets, connectors, and building envelope openings should be constructed of flood-resistant materials to minimize damage during and after floodwater inundation.

Generally, these performance requirements indicate that masonry construction is the most suited to wet floodproofing in terms of damage resistance. In some cases, wood or steel structures may be candidates, provided that the wood is pressure treated or naturally decay-resistant and steel is galvanized or protected with rust-retardant paint. A detailed list of appropriate materials can be found in NFIP Technical Bulletin 2-08, Flood-Resistant Materials Requirements for Buildings Located in Special Flood Hazard Areas in Accordance with the National Flood Insurance Program. Table 2 of Technical Bulletin 2-08 can be used as a guide for selecting structural (framing and some sheathing) and nonstructural (coverings,

CROSS REFERENCE

Detailed guidance is provided in FEMA's NFIP Technical Bulletin 2-08, *Flood-Resistant Materials Requirements for Buildings Located in Special Flood Hazard Areas in Accordance with the National Flood Insurance Program* (FEMA, 2008a).

CROSS REFERENCE

Additional information on these elements can be obtained from FEMA's NFIP Technical Bulletin 7-93, *Wet Floodproofing Requirements for Structures Located in Special Flood Hazard Areas in Accordance with the National Flood Insurance Program* (FEMA, 1993b).

WARNING

The use of wall coverings in flood-prone areas needs to be carefully researched. Standard gypsum board is not considered a flood resistant material. Water-resistant gypsum board, commonly referred to as "greenboard," is intended for areas where water may be splashed such as around bathroom sinks; however, it is not considered to be a flood-damage-resistant material. Only products such as cement board or proprietary products designed for submersion in water should be considered for use in areas subject to floodwater.

finishes, insulation, cabinets, doors, partitions, and windows) building components for use below the BFE. Some combinations of acceptable materials may result in unacceptable conditions; always refer to the manufacturer's specifications for more information. In addition to the material selection, Technical Bulletin 2-08 also explains the criteria for selecting connectors and fasteners for below the BFE. It should be noted, however, that the locally enforced building code may include more strict provisions than those stated in Technical Bulletin 2-08.

5W.3 Building Operations and Maintenance Procedures and Emergency Preparedness Plans

The operational procedure aspect of applying floodproofing techniques involves both the structure's functional requirements for daily use and the allocation of space with consideration of each function's potential for flood damage. Daily operations and space use can be organized and modified to minimize damage caused by floodwater.

5W.3.1 Flood Warning System

Because wet floodproofing will, in most cases, require some human intervention when a flood is imminent, it is extremely important that there be adequate time to execute such actions. This may be as simple as monitoring local weather reports, the NWS alarm system, or a local flood warning system.

5W.3.2 Inspection and Maintenance Plan

Every wet floodproofing design requires some degree of periodic inspection and maintenance to ensure that all components will properly operate under flood conditions. Components of the system, including valves and opening covers, should be inspected and operated at least annually.

> **NOTE**
>
> Utility systems include heating and air conditioning systems, appliances, electrical/plumbing systems, and water service/sewer facilities.

It is advisable to consider adding more flood openings to ensure they are easily opened and will allow floodwater to enter the building as planned.

Homeowners and designers should consider developing a plan for elevating belongings in storage areas prior to the arrival of floodwater because, over time, contents may increase in this area and it may be difficult to quickly move tightly packed contents.

Some owners have used a line or marking on the wall to illustrate BFEs or historic floods as a reference/reminder of how high off the ground contents that would be damaged by floodwater should be stored.

5W.3.3 Emergency Operations Plan

This type of plan is essential when wet floodproofing requires human intervention, such as adjustments to or relocation of contents and utilities. A list of specific actions and the location of necessary materials to perform these actions should be developed.

5W.3.4   Protection of Utility Systems

The purpose of the retrofitting methods in this section is to prevent damage to building contents and equipment caused by contact with floodwater by isolating these components from floodwater. Isolation of these components can take the form of relocation, elevation, or protection in place (see Figure 5W-1).

Figure 5W-1.
Elevated air conditioning
compressor

Local codes may require the use of ASCE 24, which covers utilities in Section 7.0. The standard provides guidance on electrical; plumbing; sanitary sewer; mechanical; heating, ventilation, and air conditioning (HVAC) systems; and elevators. Depending on the building classification, Table 7.1 of ASCE-24 states minimum elevation requirements for utility and attendant equipment protection. Utilities and attendant equipment below this elevation will require increased loading and design requirements. Some of these requirements state minimum loading requirements, while others state use requirements during and immediately after a design flood event. Although utilities and attendant equipment may be located above the minimum requirements, these requirements also cover wires, pipes, lines, etc., that are located below the minimum elevation.

5W.4   Elevation

The most effective method of protection for equipment and contents is to elevate and/or relocate (permanently or temporarily) threatened items out of harm's way. The interior of the structure must be organized in a way that ensures easy access, facilitates relocation, and meets current building code requirements.

Both inside and outside of the flood-prone structure, elevation of key components may be achieved through the use of existing or specially constructed platforms or pedestals. Contingent elevation can be accomplished by the use of hoists or an overhead suspension system. Relocated utilities placed on pedestals are subject to wind and earthquake damage and must be secured to resist wind and seismic forces.

Conversion from a conventional water heater to a tankless water heater is another mitigation opportunity. Although there are conflicting reports on the expected savings to be gained by the conversion, the conversion allows the unit to be moved well above the BFE in many instances. Electrically heated units may have the option of being located inside the house, but liquid propane or natural gas units should be well ventilated and located on the exterior of the house or in a garage or other area. In some instances, energy tax credits may be available to assist in offsetting the higher purchase cost. Either type of unit should always be installed by a licensed plumbing or heating/air contractor.

CROSS REFERENCE

Refer to FEMA 348, *Protecting Building Utilities from Flood Damage: Principles and Practices for the Design and Construction of Flood Resistant Building Utility Systems* (FEMA, 1999a) for details on the protection of utility systems.

5W.5   In-Place Protection

Some types of utilities can be protected in place through a variety of options, such as:

- anchors and tie-downs to prevent flotation;

- low barriers or shields; and

- protective coatings.

The use of flood enclosures to protect utilities (see Figure 5W-2) should be considered an option of last resort and should not be considered a best practice. Floodwater exceeding the predicted height or failure of low barriers or shields can result in loss of the entire unit. This alternative should only be considered if there is no possible way to relocate the unit. Utility systems as used here are mechanical, electrical, and plumbing systems, including water, sewer, electricity, telephone, CATV, natural gas, etc. The recommendations presented in this section are intended for use individually or in common to mitigate the potential for flood-related damage.

WARNING

Regardless of the method of protection, any adjustments or modifications to retrofit building utility systems should be completed in accordance with local building code requirements.
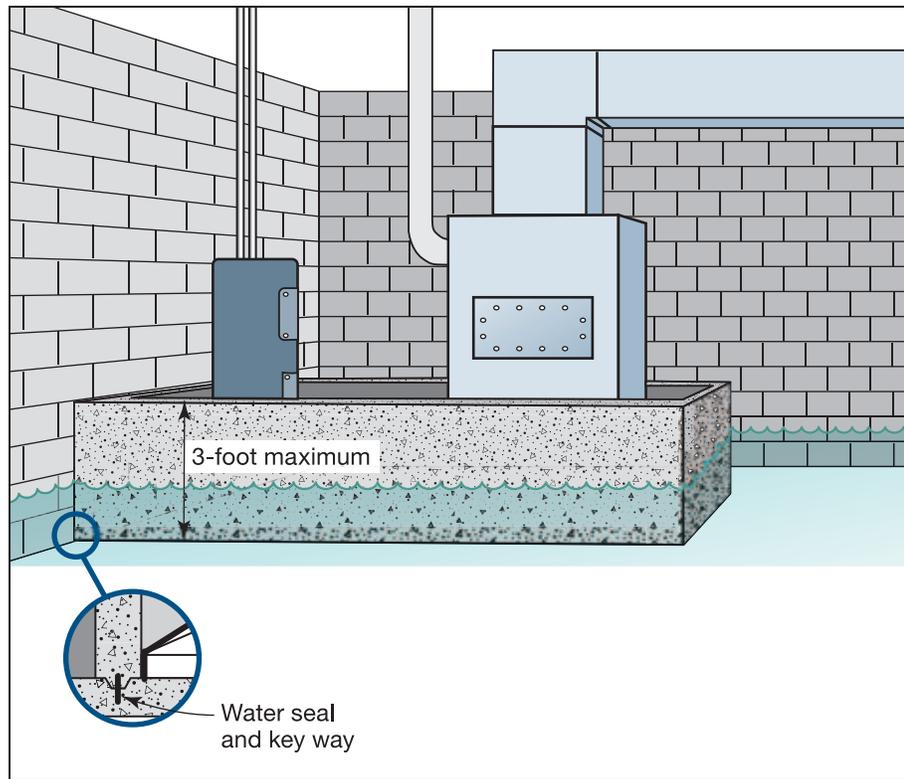
NOTE

Basic process for protection of utility systems:

- Field Investigation

- Design

- Construction

Figure 5W-2.
Flood enclosure protects
basement utilities from
shallow flooding
SOURCE: FEMA 348, 1999A

3-foot maximum

Water seal
and key way

Developing in-place protection should incorporate design elements into the solution. Walls should be designed with some factor of safety above the floodwater elevation. The wall should be designed to the DFE to incorporate a factor of safety into the protection. The protection measure should be able to resist the hydrostatic loads for the full height of the wall system. Maintenance access to the utility should be carefully considered. It is important to create a passive protection system. Under normal use, the utility should be protected from floodwater and accessible only during times of maintenance. This measure will ensure that the homeowner is not at risk when floodwater rises. Penetrations through the in-place protection should also be sealed to prevent the intrusion of floodwater. Finally the design should consider offset distances from the equipment. Utility systems requiring air flow or air circulation of safety or proper operation should not be enclosed by walls so tightly that it causes improper operation of the unit or causes a safety issue to develop.

5W.6 Field Investigation

Detailed information must be obtained about the existing structure to make decisions and calculations concerning the feasibility of using wet floodproofing. Use Figures 5-2 and 5-3 as a guide to record information.

Once this data is collected, the designer should answer the questions contained in Figure 5W-3, to confirm the measure(s) selected and develop a preliminary concept for the installation of wet floodproofing measures.

Once a conceptual approach toward wet floodproofing has been developed, the designer should discuss the following items with the homeowner:

■ previous flood history, flood depths, and equipment/systems impacted by the floods;

- plan of action as to what equipment can be relocated and what equipment will have to remain below the DFE;

- length of power outages, water shut-off, or fuel shut-off for work to be completed;

- specific scope of items to be designed; and

- any unsafe practices or code violations or exceptions to current codes.

Flood-Resistant Retrofitting Field Investigation Worksheet

Owner Name:_____ Prepared By:_____

Address: _____Date: _____

Property Location: _____

Design Flood Elevation (DFE) _____

HVAC System
Can equipment feasibly be relocated:

- To a pedestal or balcony above the DFE? ___ Yes ___ No
- To a higher level on the same floor level? ___ Yes ___ No
- To the next floor level? ___Yes ___No
- Is space available for the equipment in the alternate location? ___ Yes ___ No
- Can existing spaces be modified to accept equipment? ___ Yes ___ No
- Is additional space needed? ___ Yes ___ No
- Do local codes restrict such relocations? ___ Yes ___ No
- Can all equipment be protected in-place? ___Yes ___ No
- Is it feasible to install a curb or "pony" wall around equipment to act as a barrier? ___Yes ___No
- Is it feasible to construct a waterproof vault around equipment below the DFE? ___ Yes ___ No
- Can reasonably sized sump pumps keep water away from the equipment? ___ Yes ___ No

Fuel System
Can equipment feasibly be relocated:

- To a pedestal or balcony above the DFE? ___ Yes ___ No
- To a higher level on the same floor level? ___ Yes ___ No
- To the next floor level? ___Yes ___ No
- Is space available for the equipment in the alternate location? ___ Yes ___ No
- Can existing spaces be modified to accept equipment? ___ Yes ___ No
- Is additional space needed? ___ Yes ___ No
- Do local codes restrict such relocations? ___ Yes ___ No
- Can all equipment be protected in-place? ___ Yes ___ No
- Is the tank properly protected against horizontal and vertical forces from velocity flow and buoyancy? ___Yes ___ No
- Is it feasible to install a curb or "pony" wall around equipment to act as a barrier? ___ Yes ___ No
- Can reasonably sized sump pumps keep water away from the equipment? ___ Yes ___ No
- Is the meter properly protected against velocity and impact forces? ___ Yes ___ No
- Do local code officials and the gas company allow the meter to be relocated to a higher location? ___Yes ___No

Figure 5W-3. Flood-Resistant Retrofitting Field Investigation Worksheet

---

Electrical System

- Is it feasible to relocate the meter base and service lateral above the DFE? ___ Yes ___ No
- Is it feasible to relocate the main panel and branch circuits above the DFE? ___Yes ___ No
- Is it feasible to relocate appliances, receptacles, and circuits above the DFE? ___ Yes ___ No
- Is it feasible to relocate light switches and receptacles above the DFE? ___ Yes ___ No
- Can ground fault interrupter protection be added to circuits below the DFE? ___ Yes ___ No
- Can service lateral outside penetrations be sealed to prevent water entrance? ___ Yes ___ No
- Can cables and/or conduit be mechanically fastened to prevent damage during flooding? ___ Yes ___ No
- Can splices and connections be made water-resistant or relocated above the DFE? ___ Yes ___ No
- Do local code officials and electric companies allow the elevation of the meter? ___ Yes ___ No

Sewage Management System

- Can the on-site system be protected in-place? ___ Yes __ No
- Is it feasible to anchor the tank? ___ Yes ___ No
- Can the distribution box and leech field be protected from scour and impact forces? ___ Yes ___ No
- Can the supply lines be properly protected from scour and impact forces? ___Yes ___No
- Can backflow prevention valves be used to minimize flow of sewage into the building? ___ Yes ___ No
- Can equipment feasibly be relocated? ___ Yes ___ No
- Can the system be moved to a higher elevation on the property? ___ Yes ___ No
- Can the tank be relocated to a higher elevation or indoors? ___ Yes ___ No
- Can the drains and toilets be relocated above the DFE? ___ Yes ___ No
- Is space available for the equipment in the alternate location? ___ Yes ___ No
- Can existing spaces be modified to accept equipment? ___ Yes ___ No
- Is additional space needed? ___Yes ___ No
- Do local codes restrict such relocations? ___ Yes ___ No

Potable Water System

- Can the equipment feasibly be relocated? ___ Yes ___ No
- Can the well be moved to a higher elevation on the property? ___ Yes __ No
- Can the electric controls for the well be protected from inundation? ___ Yes ___ No
- Can the tank be relocated to a higher elevation or indoors? ___ Yes ___ No
- Can the taps be relocated above the DFE? ___ Yes ___ No
- Is space available for the equipment in the alternate location? ___ Yes ___ No
- Can existing spaces be modified to accept equipment? ___ Yes ___No
- Is additional space needed? ___Yes ___ No
- Do local codes restrict such relocations? ___ Yes ___ No
- Can the well be protected in-place? ___ Yes ___ No
- Is it feasible to install a curb or "pony" wall around equipment to act as a barrier? ___ Yes ___ No
- Is it feasible to construct a waterproof vault around equipment below the DFE? ___ Yes ___ No
- Can the wellhead and tank be protected from scour and impact forces? ___ Yes ___ No
- Can the supply lines be properly protected from scour and impact forces? ___ Yes ___ No
- Can backflow prevention valves be used to minimize flow of floodwater into the water source? ___ Yes ___ No

Figure 5W-3. Flood-Resistant Retrofitting Field Investigation Worksheet (concluded)

5W.7   Design Overview

This section presents the process of designing and implementing measures to retrofit existing building utility systems. Retrofitting may involve a combination of elevating and/or protecting in place. The general design process involved with wet floodproofing is shown in Figure 5W-4.

Elevation and protection in place alternatives for electrical systems, HVAC systems, fuel supply/storage systems, water systems, and sewer systems are discussed in Sections 5W.8 through 5W.12.
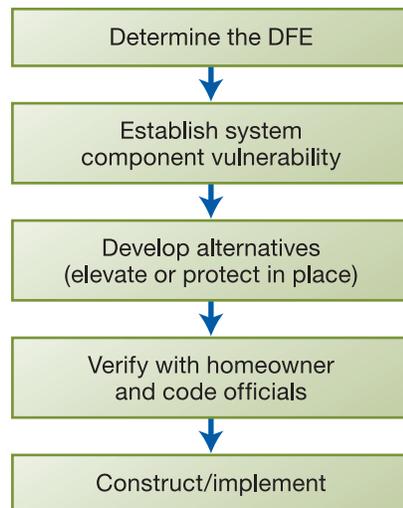
Determine the DFE

↓

Establish system component vulnerability

↓

Develop alternatives (elevate or protect in place)

↓

Verify with homeowner and code officials

↓

Construct/implement

Figure 5W-4.
Wet floodproofing of utilities design process

CROSS REFERENCE

Retrofitting measures, using techniques similar to those discussed in Section 5W.8, should be considered for telephone and cable TV exterior service lines, indoor wiring, outlet jacks, wall plates, etc.

5W.8   Electrical Systems

Electrical system components can be seriously damaged by floodwater when either active or inactive. Silt and grit accumulates in devices not rated for complete submergence and destroys the insulation of the device. Current circuit breakers and fuses are designed to protect the wiring conductors and devices from overload situations, including short circuit or ground fault conditions. Floodwater seriously affects operation of these devices.

Most houses were not designed to mitigate potential flood damage to electrical equipment; however, there are retrofitting steps that will provide permanent protection for the electrical system.

- The most important step is to raise or relocate equipment and devices above the DFE.

- A second step is to seal electrical equipment penetrations on outside walls, anchor cables and raceway, and mechanically protect the wiring system in flood-prone locations.

- A third step is to seal out moisture. Electrical system problems occur as moisture permeates devices and causes corrosion.

■ A fourth step necessary for retrofitting is the addition of Ground Fault Circuit Interrupter (GFCI) breakers, which deactivate circuits when excessive current leakage is encountered. This step ultimately assists life safety protection and may be required by local codes.

■ If it is possible, mount main service lines and the meter to the downstream side of the structure to limit the exposure to debris impact. If service from the distribution lines are underground, it is important to verify that they are buried to a sufficient depth to eliminate them being uncovered by erosion or scour. If possible, mount the meter to above the DFE and sufficiently secure it and the service lines below the DFE to resist flood loads.

Each residence presents the designer with a unique set of characteristics, including age, method of construction, size, and location. There are different combinations of systems that may need to be modified. When it is not feasible to elevate in place, the following information provides the design considerations and details that govern the retrofitting of electrical equipment and circuits below the DFE:

■ receptacles and switches should be kept to a minimum and elevated as high as is practical;

■ circuit conductors must be Underwriters Laboratories (UL) listed for use in wet locations;

■ wiring should be run vertically for drainage after being inundated;

■ new wiring should be underground feeder (UF) grade wiring to eliminate the need to replace large portions of wiring behind walls following flooding;

■ receptacles and switches should be installed in non-corrosive boxes with holes punched in the bottom to facilitate drying. The receptacles will have to be replaced after inundation by floodwater;

■ lighting fixtures should be connected via simple screw base porcelain lampholders to allow speedy removal of lamps or fixtures, and the lampholders can be cleaned and reused;

■ sump pumps and generators should have cables long enough to reach grounded receptacles above the DFE;

■ all circuits below the DFE should be protected by GFCI breakers;

■ circuits serving equipment below the DFE should be placed on separate GFCIs, clearly marked in the breaker box. This allows power to be turned off to circuits below the DFE without affecting the rest of the home; and

■ wiring splices below DFE should be kept to a minimum. If conductors must be spliced, use crimp connectors and waterproof with heat shrink tubing or grease packs over the splice.

CROSS REFERENCE

Additional information on these elements can be obtained from FEMA's NFIP Technical Bulletin 7-93, *Wet Floodproofing Requirements for Structures Located in Special Flood Hazard Areas in Accordance with the National Flood Insurance Program* (FEMA, 1993b).

5W.9   Heating, Ventilating, and Air Conditioning Systems

HVAC system equipment (i.e., furnaces, boilers, compressors) should be elevated/relocated above the DFE or protected within a watertight enclosure whenever possible. However, the protection of HVAC system equipment requires consideration of several factors. Some points to consider when evaluating potential retrofitting measures are:

- adequate space and structural support for relocated equipment;

- maintenance of required equipment clearances and maintenance access dictated by code and/or manufacturer;

- provision of adequate combustion air for fuel-burning equipment;

- modification and/or maintenance of proper venting of fuel-burning equipment;

- necessity of non-combustible construction materials;

- necessity of eliminating ductwork below the DFE whenever possible;

- suitability of protective partitions or vaults;

- reconfiguration of ductwork;

- consideration of duct construction material; and

- modification of hot water or steam circulation piping.

> **NOTE**
>
> In a post-flooding situation, the designer may recommend replacing old equipment with a new one that meets current codes, is more energy/cost-efficient, and fits in the desired location. In some cases, the old equipment may be replaced with lateral or in-line equipment, installed in the attic to protect it from flooding.

5W.10   Fuel Supply/Storage Systems

In conjunction with the retrofitting of HVAC equipment, the designer must consider rerouting and/or extending fuel supply lines (i.e., fuel oil, natural gas, and propane gas) when equipment is relocated. Floodwater can pull poorly anchored tanks off their foundations (see Figure 5W-5) and result in damages and the potential spill of toxic liquids. In order to prevent damaged fuel supply or storage tanks, the following should be considered with respect to fuel supply/storage systems:

- extension of fuel supply lines to relocated equipment;

- use of flexible connections;

- adequate support and anchorage to resist hydrostatic and hydrodynamic forces that act on tanks. This can be accomplished by:
    - elevating tanks on structural fill;
   - elevating tanks on a braced platform;

> **NOTE**
>
> Galvanized steel ductwork is less susceptible than ductboard or similar materials to damage from flooding. Generally, if flooded, ducts made of ductboard are not reusable.

- anchoring tanks to properly install and using designed ground anchors (Figure 5W-6);

- anchoring supply lines to the downstream side of structural members;

- relocating fuel tank because of equipment relocation; and

- using automatic cut-off valves.

Figure 5W-5.
An improperly anchored tank; tethered only by a supply line

Figure 5W-6.
Fuel tank anchored from two sides
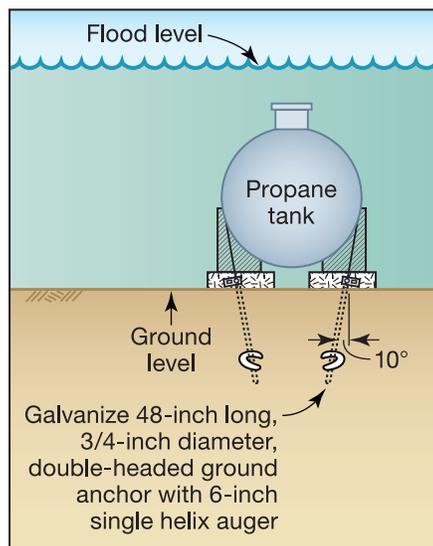
5W.11 Water Systems

The primary threats that floodwater poses to water systems are contamination and velocity flow damage. Contamination by floodwater may occur through infiltration into on-site water wells, public water supplies, open faucets, or broken pipes. In flood-prone areas that experience high velocity flow, damage may occur from the effects of the velocity, wave action, and/or debris impact. Some factors to consider when retrofitting water systems include:

- minimization of plumbing fixtures below the DFE;

- allowance of adequate space for elevating components;

- modification of lines and fixtures to prevent backflow;

- protection of system components from high velocity flow;

- suitability of protective partitions or vaults; and

- modification of the well top using watertight casing.

> **NOTE**
>
> Adequate protection of all fuel, water, sewer pipes, and tanks from damage caused by erosion, scour, buoyancy, debris impact, velocity flow, and wave action should be verified during the retrofitting design process.

5W.12 Sewer Systems

The main dangers associated with the flooding of sewer systems are backup of sewage, damage of system components, and contamination of floodwater. Because these dangers could result in serious health risks, preventive measures could help clean-up expenses and hazards. Retrofitting sewer systems to eliminate or minimize the dangers include the following possible options:

- relocation of collection components to a higher elevation;

- installation and/or maintenance of a check or sewer backflow prevention valve;

- installation and/or maintenance of combination check and gate valves (see Figure 5W-7);

- installation of an effluent ejector pump;

- provision of a backup electrical source;

- sealing of septic tank to prevent contamination; and

- adequate anchorage of septic tank to withstand buoyancy forces.

> **NOTE**
>
> Guidance concerning the anchoring of septic tanks is applicable to other types of underground storage tanks.

> **WARNING**
>
> When subject to flood forces, ruptured storage tanks containing natural gas, oil, or propane also pose the additional risk of explosion or environmental contamination.

It is important that sanitary sewage storage systems in flood-prone areas are able to prevent contamination during and immediately following a flooding event. In areas where ASCE 24 is enforced, Section 7.3.4 specifically outlines sizing requirements for sealed storage tanks during and after flood

events while the soil is saturated. The guidelines are intended to prevent contamination of the floodwater. Even if ASCE 24 is not a required design standard, it is an appropriate guidance document for sealed sanitary storage tank sizing requirements.
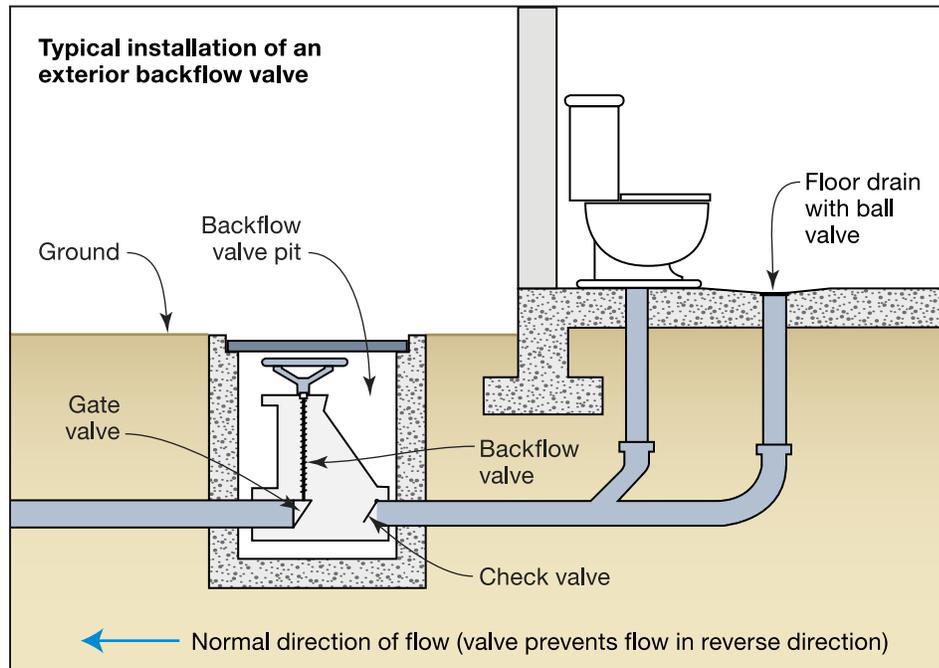
Typical installation of an exterior backflow valve

Ground

Backflow valve pit

Gate valve

Backflow valve

Check valve

Floor drain with ball valve

Normal direction of flow (valve prevents flow in reverse direction)

Figure 5W-7.
Backflow valve – a check valve and gate valve with an effluent pump bypass
SOURCE: FEMA 348, 1999A

5W.13 Calculation of Buoyancy Forces

The anchorage of any tank system consists of attaching the tank to a resisting body with enough weight to hold the tank in place. The attachment, or anchors, must be able to resist the total buoyant force acting on the tank. The buoyant force on an empty tank is the volume of the tank multiplied by the specific weight of water. It is usually advisable to include a safety factor of 1.3, as is shown in the net buoyancy force computation in Equation 5W-1.

NOTE

To minimize buoyancy forces, fuel tanks should be "topped off" prior to flooding.

CROSS REFERENCE

For a more detailed analysis of buoyancy forces, refer to FEMA 348, *Protecting Building Utilities from Flood Damage: Principles and Practices for the Design and Construction of Flood Resistant Building Utility Systems* (FEMA, 1999a)

EQUATION 5W-1: NET BUOYANCY FORCE ON A TANK

$$F_b = \left[0.134 V_t \gamma_w FS\right] - W_t \tag{Eq. 5W-1}$$

where:

F_b = net buoyancy force of the tank (lb)

V_t = volume of the tank (gal)

0.134 = factor to convert gal to ft³

γ_w = specific weight of flood water surrounding the tank (generally 62.4 lb/ft³ for fresh water and 64.0 lb/ft³ for saltwater)

FS = factor of safety to be applied to the computation, typically 1.3 for tanks

W_t = weight of the tank, calculated using an empty tank weight (lb)

The volume of concrete required to offset the buoyant force of the tank can be computed as shown in Equation 5W-2.

EQUATION 5W-2: CONCRETE VOLUME REQUIRED TO OFFSET BUOYANCY

$$V_c = \frac{F_b}{(S_c - \gamma_w)} \tag{Eq. 5W-2}$$

where:

V_c = volume of concrete required (ft³)

F_b = net buoyancy force of the tank (lb)

S_c = effective weight of concrete (typically 150 lb/ft³)

γ_w = specific weight of water (62.4 lb/ft³ for fresh water or 64.0 lb/ft³ for salt water)

To resist this buoyant force, a slab of concrete with a volume, V_c, is usually strapped to the tank to resist the buoyant load.

Sample calculations for the net buoyancy force on the tank and concrete volume required to resist buoyancy are available in Appendix C.

5W.14 Construction/Implementation

The retrofitting of utility systems, both elevating and protecting in place, must conform to the requirements set forth in local and state building codes, standards, floodplain ordinances, and equipment manufacturer's installation instructions. Building codes may include reference codes and standards. These reference codes typically address electrical, plumbing, and other utility items of work. It is important to verify compliance with each of these reference codes during the design phase and into the construction phase. For material or equipment substitutions, the technical bulletins, FEMA publications, and ASCE 24 referenced in this chapter should be consulted. All applicable permits and inspections should be completed prior to beginning the next phase of the construction.

The successful construction and implementation of wet floodproofing measures should include the use of flood-resistant materials and consider operations and preparedness planning in Section 5W.3.

6.3 Case Study #3: Residential Retrofit Outside of the Floodplain Using Dry or Wet Floodproofing

This case study exercise examines the retrofit of a residential building outside the floodplain by means of dry floodproofing or wet floodproofing. Details are provided in the subsections that follow.

6.3.1 Description of Property

Jorge Luis Borges
18 Chai Avenue
Memphis, TN 36549

The Borges family built their home in 1992. It is a one-story structure with a walkout-on-grade basement that serves as a garage. It is not in the floodplain but, due to the sloping terrain and the development in the area, water tends to collect in their backyard. Since living in the house, they've had water in their garage nearly every time it rains. On four occasions, they have had to conduct some repairs and replacements to damaged items and building materials. Mr. Borges estimated the amount of damage he incurred during each event (see Table 6-6). The main level does not have any flooding problems.

The Borges family does not live in the SFHA and, therefore, does not have flood insurance. However, the damage they incurred in 2011 encouraged them to retrofit their home to protect it against further damages.

6.3.2 Structure Information

18 Chai Avenue is a good quality, 1-story masonry house with a walkout-on-grade garage (see Figures 6-30 and 6-31).

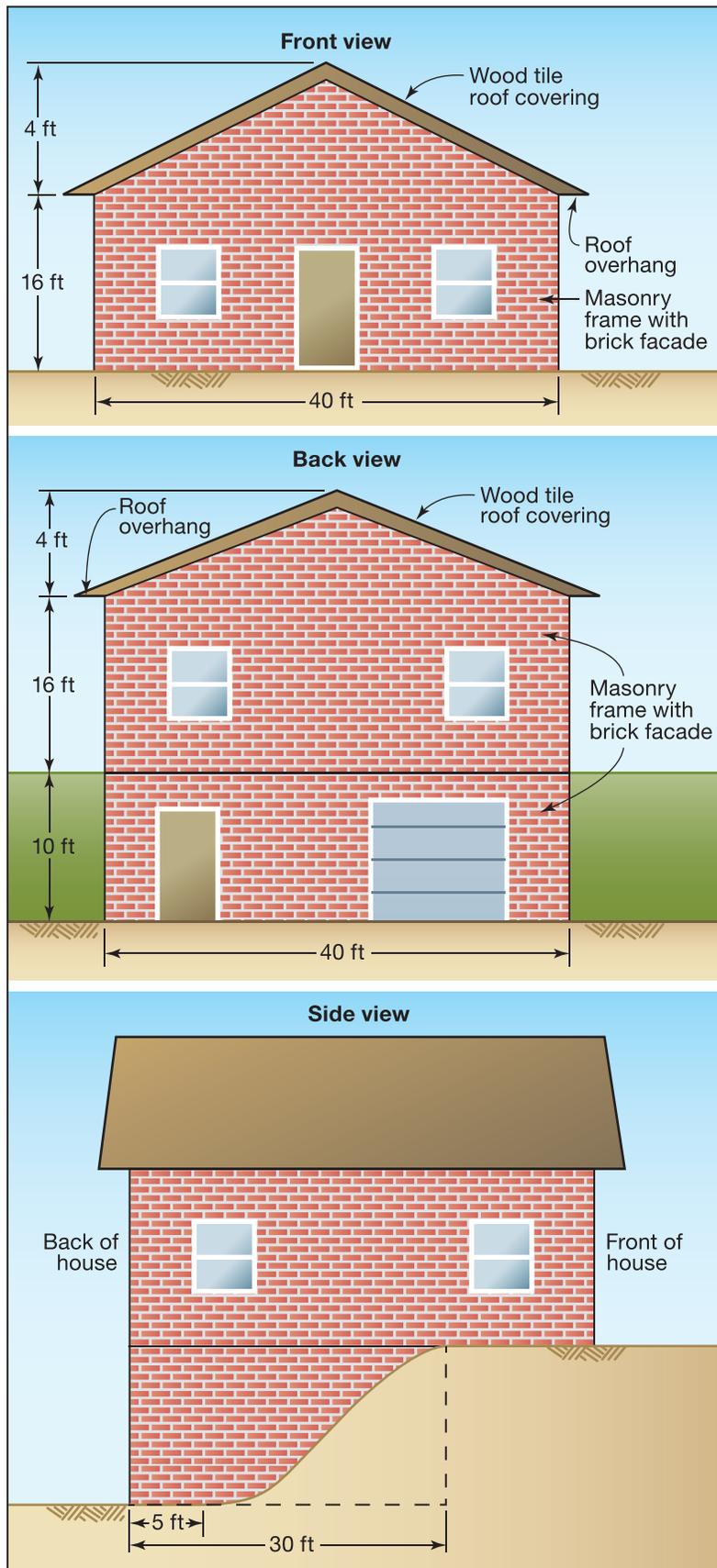**Figure 6-30.
Plan drawing for the
Borges house**
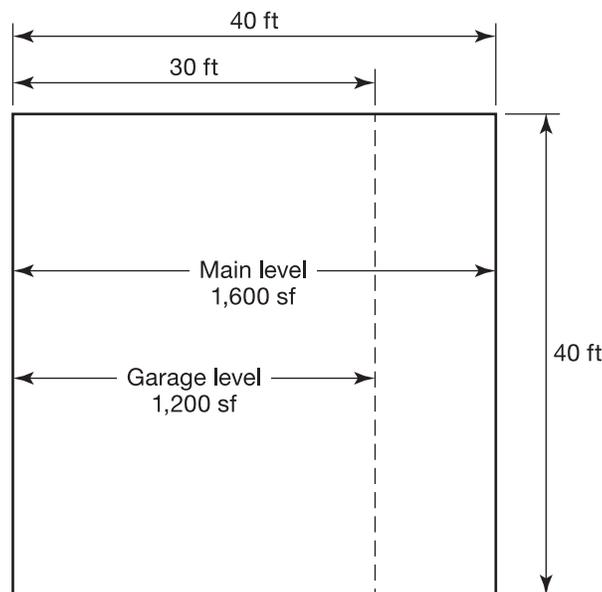
Figure 6-31.
Elevation drawings from the front, back, and side of the Borges house

Other structure information includes:

- Main floor (footprint): 1,600 square feet (40 feet x 40 feet)

- Garage: 1,200 square feet (30 feet x 40 feet)

- Foundation:
  - Garage walls are reinforced and grouted CMU block, 8 inches thick, supported by a 2-foot-wide x 1-foot-thick concrete wall footer with a 6-inch-thick interior concrete slab.
  - Main floor over garage is supported on 2-inch x 8-inch joists spaced at 16 inches on center. Main floor not over garage is 4-inch-thick concrete slab supported by a 2-foot-wide x 1-foot-thick concrete wall footer.
  - Approximately 5 feet of the side garage walls are exposed at grade level.
  - Below-grade walls have an existing drainage system to control hydrostatic pressures below ground.

- Structure:
  - Main structure: Concrete block with common brick veneer
  - Garage: Concrete block with common brick veneer
  - Wood-frame interior walls with gypsum board sheathing

- Roof:
  - Gable roof with 1-foot overhangs over main structure
  - Asphalt shingle roof covering over entire roof

- Interior:
  - Wood stud interior walls with gypsum board sheathing
  - Hardwood floor coverings

- Entrances:
  - The garage has two entrances: a single pedestrian door (3-feet wide) and a standard garage door (8-feet wide)
  - There are no other windows or entrances in the garage

Plot

No part of the Borges' plot is in the floodplain. The site soils are primarily poorly graded gravel (Soil Type GP).

Building Assessment

An updated tax card is included at the end of this case study as an alternate source of the building replacement value as well as to verify the building square footage data.

Additionally, an engineer's estimate is that the Borges' home has a building replacement value of approximately $100.00 per square foot, based on popular cost estimating guides.

Flood Hazard Data

Because 18 Chai Avenue is not in the floodplain, there is no BFE for the structure. However, Mr. Borges has kept records of flood events that required some repairs. Flood depths are in inches from the top of the garage floor (see Table 6-6).

Table 6-6. Summary of Damages for the Borges House

Damage Year	Flood Depth (inches)	Damages (2011 dollars)
1994	6	$2,500
1999	1	$500
2003	2	$800
2011	8	$5,000

Based on this history of flooding, Mr. Borges would like to protect his house from up to 2 feet of flooding.

6.3.3   Retrofit Options Selection

During an initial interview with the Borges family, potential retrofit options were discussed (Figure 6-32). Initially, relocation was quickly ruled out because the Borges family was not willing to move. Floodwalls and levees were also ruled out, because there is not sufficient space on the property to undertake those methods. Although elevation was considered, it is not required and the costs were unreasonably high for the required level of protection.

Based on the retrofit option screening matrix, the two most viable options are dry floodproofing and wet floodproofing.

Dry Floodproofing

The purpose of dry floodproofing is to keep the water out of the garage. Refer to Table 1-3 for the advantages and disadvantages of dry floodproofing. This would involve:

- applying a waterproof sealant to the exterior of the CMU block walls, approximately $12/linear foot for a 2-foot flood depth (note that the sealant need only be applied to exposed walls because there is an existing drainage system for below-grade walls); and

- installing metal flood shields over the two doors, approximately $250/linear foot for a 2-foot flood depth.

Note that other dry floodproofing measures such as check valves, sump pumps, and drainage are not considered because there is no plumbing in the garage.

Preliminary Floodproofing/Retrofitting Preference Matrix

Owner Name: Jorge Juis Borges   Prepared By: Jane Q. Engineer

Address: 18 Chai Avenue   Date: 9/1/2011

Property Location: Memphis, TN

Floodproofing Measures

Considerations	Elevation on Foundation Walls	Elevation on Fill	Elevation on Piers	Elevation on Posts and Columns	Elevation on Piles	Relocation	Dry Flood-proofing	Wet Flood-proofing	Floodwalls and Levees
Note the measures NOT allowed						X			X

Homeowner Concerns

Aesthetic Concerns	X	X	X	X	X				
High Cost Concerns	X	X	X	X	X				
Risk Concerns	X	X					X	X	
Accessibility Concerns	X	X	X	X					
Code Required Upgrade Concerns									
Off-Site Flooding Concerns	X	X					X		
Total "X's"	5	5	3	3	3	NA	2	1	NA

Instructions: Determine whether or not floodproofing measure is allowed under local regulations or homeowner requirement. **Put an "x" in the box for each measure which is not allowed.**

Complete the matrix for only those measures that are allowable (no "x" in the first row). For those measures allowable or owner required, evaluate the considerations to determine if the homeowner has concerns that would affect its implementation. A concern is defined as a homeowner issue that, if unresolved, would make the retrofitting method(s) infeasible. If the homeowner has a concern, place an "x" in the box under the appropriate measure/consideration. Total the number of "x's". The floodproofing measure with the least number of "x's" is the most preferred.

Figure 6-32. Preliminary Floodproofing/Retrofitting Preference Matrix for the Borges house

The exposed areas of the CMU wall are:

Back wall: 40 ft – 3 ft – 8 ft = 29 ft

Side walls: 2 x 5 ft = 10 ft

Therefore, the total cost of sealant is (10 ft + 29 ft) x $12/lf = $468

Refer to Figure 5D-3 in Chapter 5D for details of sealant systems.

Metal closures would require 3 ft + 8 ft = 11 ft of closure.

Therefore, the total cost of closures is (11 ft) x $250/lf = $2,750

Refer to Figures 5D-5 and 5D-6 in Chapter 5D for closure details.

The total cost of dry floodproofing is $3,218. Additionally, an additional $75 per year will be needed to maintain the floodproofing sealants and shields.

Using this cost estimate, a preliminary BCA yields a BCR of 1.39. Therefore, this project would be cost effective.

This technique may be effective for a few inches of water, but it could lead to far more significant damages for greater levels of flooding. Dry floodproofing may not work for water levels that are sufficient to cause uplift against the underside of the garage slab, leading to cracking and water intrusion into the garage. See Section 6.3.4 for calculations related to the slab of the house. The hydrostatic forces associated with 2 feet or more of water on the slab would likely cause the slab to crack, allowing water into the garage and resulting in severe damage to the foundation of the house. This option is included here to illustrate its use; however, it is strongly recommended that the wet floodproofing option be used over the dry floodproofing option. Refer to the buoyancy check calculations in Section 6.3.4 for further information.

Wet Floodproofing

The purpose of wet floodproofing would be to allow water into the garage to equalize hydrostatic forces. Refer to Table 1-4 for the advantages and disadvantages of wet floodproofing. This would involve:

■ elevating all stored contents above the floodproofing depth (2 feet);

■ elevating all utilities above the floodproofing depth (2 feet); and

■ installing flood vents along back wall and sides of house (see Figure 5E-15).

Note that wet floodproofing often includes replacing interior finishes with flood damage-resistant materials. Because the wet floodproofed area is a garage, there are no interior finishes. Additionally, concrete block walls and floors are considered to be flood damage-resistant under NFIP Technical Bulletin 2-08, *Flood Damage-Resistant Materials Requirements for Buildings Located in Special Flood Hazard Areas in accordance with the National Flood Insurance Program* (FEMA, 2008a).

It is expected that the cost of wet floodproofing will be approximately $3,600, with an additional $50 a year budgeted to maintain the project, including clearing flood vents. A preliminary BCA yields a BCR of 1.41. Therefore, this project would also be cost effective.

6.3.4   Load Calculations

The paragraphs that follow provide calculations for flood loads, dead loads, live loads, and load combinations, as well as bearing capacity, sliding, uplift, and overturning checks associated with the dry and wet floodproofing options.

Load Calculations: Flood Loads

The first step is to calculate hydrostatic forces (Figure 6-33). As determined above, the floodproofing depth H is 2 feet. The house is slab-on-grade, so the saturated soil depth is 0 feet (again, these calculations are for the exposed walls only; there is an existing drainage system for the buried walls). Note that, for dry floodproofing, the hydrostatic forces act on the house in both the horizontal and vertical directions. For wet floodproofing, however, the hydrostatic forces are equalized, so the equivalent hydrostatic force (vertical and horizontal) is 0 pounds.

Because the source of flooding is surface runoff rather than a water body, the flow velocity is considered to be 0 ft/sec and there are no hydrodynamic or flood-borne debris impact forces.

Flood Force Summary:

Horizontal Force:
   f_{comb} = 124.8 lb/lf
   F_i = 0 lbs

   The total flood force acting on the back wall is:
   F_{sta} = (124.8 lb/lf x 40 ft) = 4,992 lbs (dry floodproofing)

Vertical Force:
   F_{bouy} = 149,760 lbs (dry floodproofing)

Load Calculations: Dead Loads

The dead load is the self-weight of the structure. Case Study #1 illustrates a detailed calculation of the dead load. For this case study, assume a dead weight of approximately 40 lb/ft² over 1,600 square feet for the main level, plus approximately 40 lb/ft² over 1,200 ft² for the garage.
   D = 40 lb/ft² x (1,600 ft²) + 40 lb/ft² x (1,200 ft²) = 112,000 lbs

Load Calculations: Live Loads

Live Load (Vertical)

   Per ASCE 7-10, assume a live load of:
   L = 40 lb/ft² x (1,600 ft² + 1,200 ft²) = 112,000 lbs

Hydrostatic Force Computation Worksheet

Owner Name: _____Jorge Juis Borges_____ Prepared By: _____Jane Q. Engineer_____

Address: _____18 Chai Avenue_____ Date: __9/1/2011__

Property Location: _____Memphis, TN_____

Constants

γ_w = specific weight of water = 62.4 lb/ft³ for fresh water and 64.0 lb/ft³ for saltwater

Variables

H = floodproofing design depth (ft) = 2 ft

D = depth of saturated soil (ft) = 0 ft

S = equivalent fluid weight of saturated soil (lb/ft³) = 75 lb/ft³

Vol = volume of floodwater displaced by a submerged object (ft³) = 1,200 ft² x 2 ft = 2,400 ft³

P_h = hydrostatic pressure due to standing water at a depth of H (lb/ft²), $P_h = \gamma_w H$ = 124.8 lb/ft²

Summary of Loads

f_{sta} = 124.8 lb/ft

f_{dif} = 0 lb/ft

f_{comb} = 124.8 lb/ft

F_{bouy} = 149,760 lbs

Equation 4-4: Lateral Hydrostatic Force

$$f_{sta} = \frac{1}{2}P_h H = \frac{1}{2}\gamma_w H^2 = (1/2)(62.4 \text{ lb/ft}^3)(2 \text{ ft})^2 = 124.8 \text{ lb/ft}$$

Equation 4-5: Submerged Soil and Water Force

$$f_{dif} = \frac{1}{2}(S - \gamma_w)D^2 = 0 \text{ lb/ft}$$

Equation 4-6: Combined Lateral Hydrostatic Force

$$F_{buoy} = \gamma_w(Vol) = 124.8 \text{ lb/ft} + 0 \text{ lb/ft} = 124.8 \text{ lb/ft}$$

Equation 4-7: Buoyancy Force

$$dh = \frac{C_d V^2}{2g} = (62.4 \text{ lb/ft}^3)(2,400 \text{ ft}^3) = 149,760 \text{ lbs}$$

Figure 6-33. Hydrostatic Force Computation Worksheet for the Borges house (Refer to Figure 4-9)

Roof Live Load (Vertical)

Per ASCE 7-10, assume a roof live load of 20 lb/ft². The roof live load acts on the horizontal projected area of the roof:
L_r = 20 lb/ft² x (1,600 ft²) = 32,000 lbs

Snow Load (Vertical)

Assume a conservative snow load of 20 lb/ft², per ASCE 7-10. The snow load also acts on the horizontal projected area of the roof.
S = 20 lb/ft² x (1,600 ft²) = 32,000 lbs

Wind Load (Horizontal)

Appendix C contains a detailed discussion of wind load calculations, including a detailed example. Refer to Appendix C for wind load calculations; this case study uses a simplified approach. Using a simplified wind load, assuming that the structure is fully enclosed, assume a worst case scenario wind load acting perpendicular to the structure (i.e., on the entire face of the structure facing the river). Therefore, assume a wind pressure of 30 lb/ft² acting uniformly over the entire aboveground structure:

    Area = Exterior Wall area + Vertical Roof area
$$\Rightarrow A = (40 \text{ ft})(10 \text{ ft}) + (40 \text{ ft})(16 \text{ ft}) + (1/2)(4 \text{ ft})(40 \text{ ft}) = 1{,}120 \text{ ft}^2$$
$$W_H = 30 \text{ lb/ft}^2 \times (1{,}120 \text{ ft}^2) = 33{,}600 \text{ lbs}$$

Wind Load (Vertical)

With a 1-foot overhang, assume that the only vertical wind force is acting upwards on the horizontal projected area of the overhangs (a simplification).

The horizontal projected area is taken to be 1 foot as a conservative estimate.

The upward wind force acts on the length of the overhang (40 feet) on each side of the house. Therefore, the total horizontal area is:

    $\Rightarrow A = 2 \times 1 \text{ ft} \times 40 \text{ ft} = 80 \text{ ft}^2$

Assuming a vertical wind load of 20 lb/ft², the total vertical wind load is:

    $W_V = 20 \text{ lb/ft}^2 \times (80 \text{ ft}^2) = 1{,}600 \text{ lbs}$

Earthquake Load

Earthquake forces are assumed to be negligible for this location, because the project is located far from the New Madrid fault. Therefore, for the purposes of this case study, $E = 0$.

Load Combinations

To determine the worst-case horizontal and vertical loading scenarios, ASCE 7-10 load combinations are used (Allowable Stress Design).

Load Summary:

Horizontal Loads
    $D = L = L_r = S = E = 0$
    $F_a = F_{sta} = 4{,}992$ lbs (dry floodproofing); $F_a = 0$ lbs (wet floodproofing)
    $W = 33{,}600$ lbs

Vertical Loads
    $D = 112{,}000$ lbs ($\downarrow$)
    $L = 112{,}000$ lbs ($\downarrow$)
    $L_r = 32{,}000$ lbs ($\downarrow$)
    $S = 32{,}000$ lbs ($\downarrow$)
    $W = 1{,}600$ lbs ($\uparrow$)
    $E = 0$
    $F_a = F_{buoy} = 149{,}760$ lbs ($\uparrow$) (dry floodproofing), $F_a = 0$ (wet floodproofing)

Table 6-7 presents a summary of the horizontal and vertical loads for the Borges house.

Table 6-7. Summary of Horizontal and Vertical Load Combinations for the Borges House Combination

	Horizontal (lbs)	Vertical (lbs)
1. D	0	112,000
2. $D + L$	0	224,000
3. $D + (L_r$ or S or $R)$	0	144,000
4. $D + 0.75L + 0.75(L_r$ or S or $R)$	0	220,000
5. $D + (0.6W$ or $0.7E) + 0.75F_a$	23,904 (dry) 20,160 (wet)	-1,280 (dry) 111,040 (wet)
6a. $D + 0.75L + 0.75(0.6W) + 0.75(L_r$ or S or $R) + 0.75F_a$	18,864 (dry) 15,120 (wet)	106,960 (dry) 219,280 (wet)
6b. $D + 0.75L + 0.75(0.7E) + 0.75S + 0.75F_a$	3,744 (dry) 0 (wet)	107,680 (dry) 220,000 (wet)
7. $0.6D + 0.6W + 0.75F_a$	23,904 (dry) 20,160 (wet)	-46,080 (dry) 66,240 (wet)
8. $0.6D + 0.7E$	0	67,200

Bearing Capacity Check

$$P_{max} = A_{bearing} S_{bc}$$

$S_{bc} = 2,500$ lb/ft² (see Table 5-2)

The bearing area is taken to be the area of the footer under the garage:
$A_{bearing} = 2$ ft x $(2$x40 ft $+ 2$x30 ft$) - (4$ ft x 2 ft$) = 272$ ft²
$P_{max} = (2,500$ lb/ft²$)(272$ ft²$) = 680,000$ lbs

Maximum vertical load:
436,000 lbs $< P_{max}$ ✓

Sliding

Lateral forces are resisted by the walls of the structure, buried footers, and the slab. An analysis of resistance to sliding on foundation walls is included in Case Study 1. Additional sliding resistance will be provided by the slab.

Note that, although the home is unlikely to slide, the garage walls are susceptible to cracking due to lateral hydrostatic forces.

Uplift and Overturning

Resistance to uplift and overturning will be provided by the footers, the slab, and the soil below grade. An analysis of uplift resistance provided by footers is included in Case Study 1, and that additional resistance is provided by the slab. Note that, although the structure is unlikely to float out of the ground, the slab is susceptible to cracking (see below).

Slab Check

For dry floodproofing, it is necessary to check that the slab can resist the vertical and horizontal flood forces. This is done by checking the uplift forces against the dead load of the slab, as well as by checking the bending moment at the slab-to-wall connection. This analysis is a simplified comparison of vertical forces to the dead weight of the slab and does not account for steel reinforcement inside the slab. A slab that is both bottom- and top-reinforced may be able to resist uplift forces without cracking.

For this check, the dead load is the weight of the slab only (not including the rest of the structure):

$D = 1,200 \text{ ft}^2 \times 6 \text{ in.} \times 1 \text{ ft}/12 \text{ in.} \times 150 \text{ lb/ft}^3 = 90,000 \text{ lbs}$

The vertical and horizontal flood forces are the same:

$F_V = 149,760 \text{ lbs}$
$F_H = 4,992 \text{ lbs}$

The worst case loading scenario for both the uplift and moment checks will be $0.6D + 0.75F_a$.

Uplift:

$0.6D = 0.6(90,000 \text{ lbs}) = 54,000 \text{ lbs}$
$0.75F_V = 0.75(149,760 \text{ lbs}) = 112,320 \text{ lbs} > 54,000 \text{ lbs}$ **NOT ACCEPTABLE (dry floodproofing)**

The buoyancy forces are greater than the resisting force of the slab, causing the slab to crack or even rise out of the ground.

Bending:

For this check, the pivot point is the connection of the slab to the back wall and only the flood and slab weight forces are included, as shown in Figure 6-34.

$0.6M_D = 0.6(15 \text{ ft})(90,000 \text{ lbs}) = 810,000 \text{ ft-lbs}$

$0.75M_{Fa} = 0.75(15 \text{ ft})(149,760 \text{ lbs}) + 0.75(2/3 \text{ ft})(4,992 \text{ lbs}) = 1,687,296 \text{ ft-lbs} > 810,000 \text{ ft-lbs}$
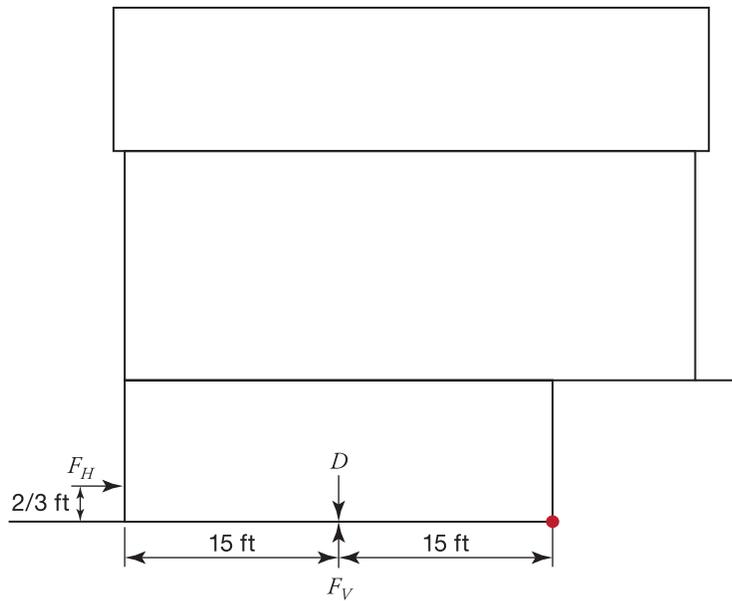**NOT ACCEPTABLE (dry floodproofing)**

Figure 6-34.
Moment diagram for the Borges house, slab only

The moment resulting from the flood forces is significantly greater than the resistive force of the slab, causing the slab to crack.

Dry floodproofing the existing garage is therefore not an option, because a flood depth of 2 feet would cause the slab to fail, allowing water into the house and requiring expensive repairs. The Borges family can either opt to use wet floodproofing, or they can install a thicker, better reinforced slab.

6.3.5   Supporting Documentation

This section includes additional information about the Borges house. The following maps and documents provide backup documentation for the values used in the Case Study 3 calculations, including:

■ topographic map showing the location of the plot and ground elevation (Figure 6-35);

■ FIRM excerpt showing the location of the Borges house, outside of the 100-year floodplain (Figure 6-36);

■ elevation certificate showing the first floor elevation (Figure 6-37);

■ tax card providing building value and square footage (Figure 6-38); and

■ BCA report excerpt summarizing the cost effectiveness of dry and wet floodproofing (Figure 6-39).

Figure 6-35.
Topographic map
showing the location of
the Borges house (circled
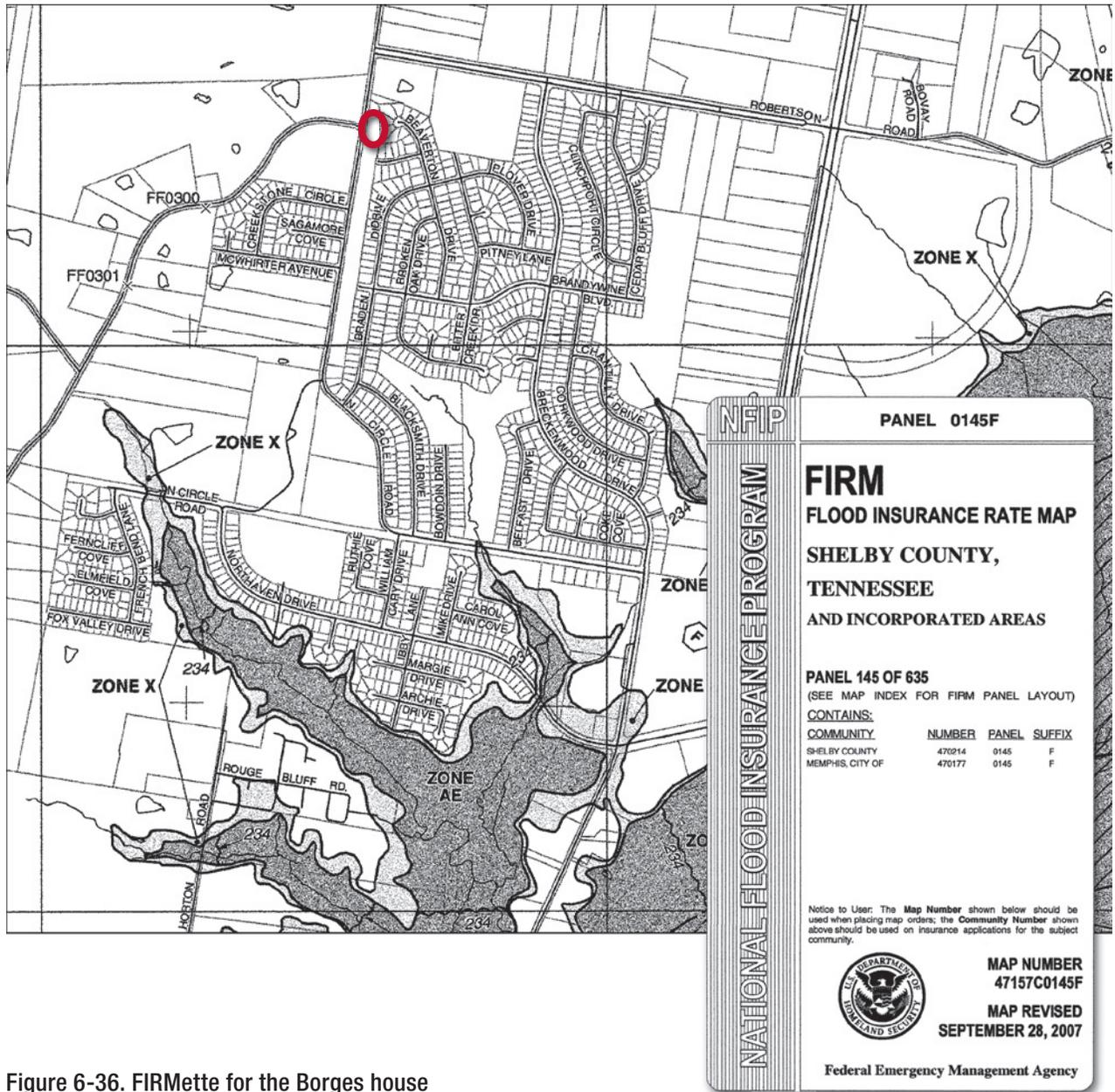in red). Please note these
are 10-foot contours.
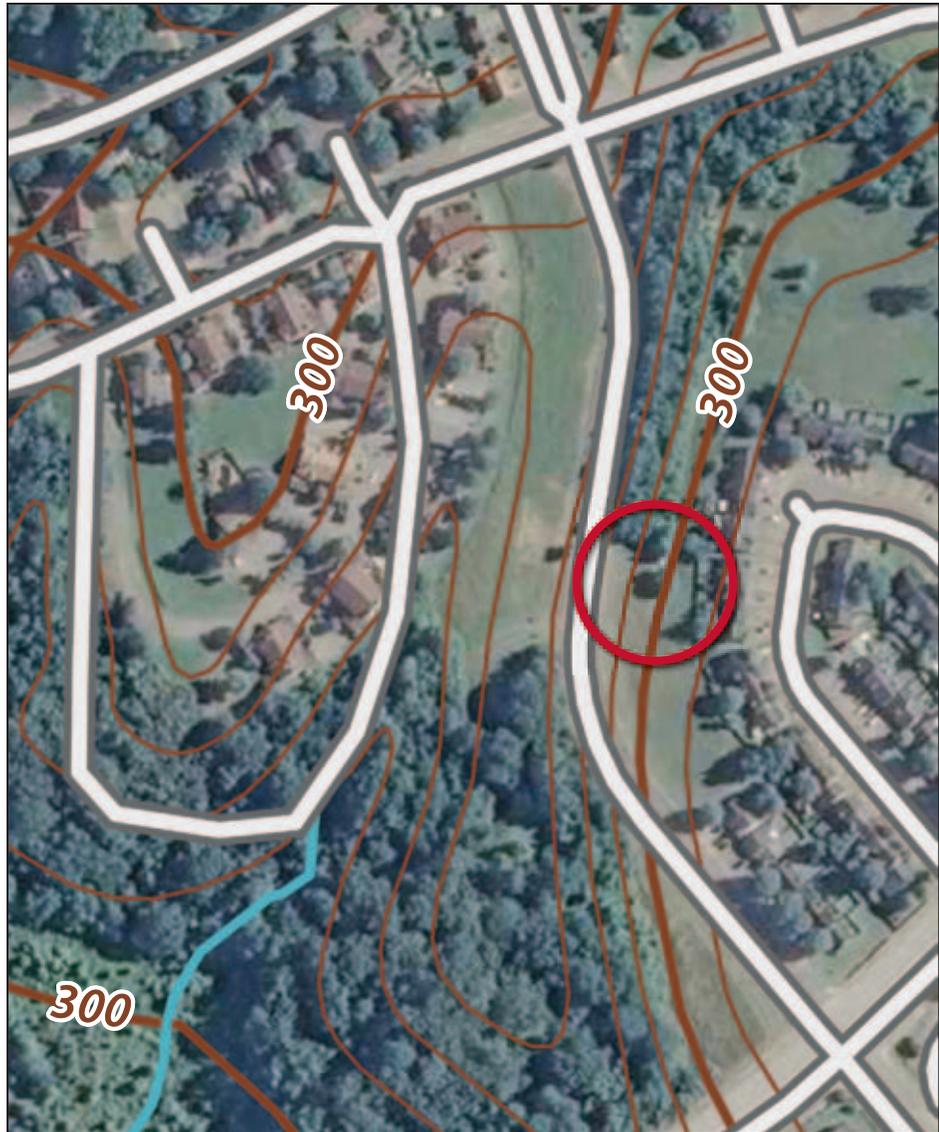
Figure 6-36. FIRMette for the Borges house

U.S. DEPARTMENT OF HOMELAND SECURITY
Federal Emergency Management Agency
National Flood Insurance Program

ELEVATION CERTIFICATE

Important: Read the instructions on pages 1-9.

OMB No. 1660-0008
Expires March 31, 2012

SECTION A - PROPERTY INFORMATION

For Insurance Company Use:

A1. Building Owner's Name   Jorge Luis Borges

Policy Number

A2. Building Street Address (including Apt., Unit, Suite, and/or Bldg. No.) or P.O. Route and Box No.
18 Chai Avenue

Company NAIC Number

     City   Memphis   State   TN   ZIP Code   36549

A3. Property Description (Lot and Block Numbers, Tax Parcel Number, Legal Description, etc.)

A4. Building Use (e.g., Residential, Non-Residential, Addition, Accessory, etc.) Residential
A5. Latitude/Longitude: Lat. _____ Long. _____   Horizontal Datum: ☐ NAD 1927 ☐ NAD 1983
A6. Attach at least 2 photographs of the building if the Certificate is being used to obtain flood insurance.
A7. Building Diagram Number _____
A8. For a building with a crawlspace or enclosure(s):   A9. For a building with an attached garage:
   a) Square footage of crawlspace or enclosure(s) _____ sq ft   a) Square footage of attached garage   1200   sq ft
   b) No. of permanent flood openings in the crawlspace or   b) No. of permanent flood openings in the attached garage
     enclosure(s) within 1.0 foot above adjacent grade _____   within 1.0 foot above adjacent grade   0
   c) Total net area of flood openings in A8.b _____ sq in   c) Total net area of flood openings in A9.b   0   sq in
   d) Engineered flood openings? ☐ Yes ☐ No   d) Engineered flood openings? ☐ Yes ☐ No

SECTION B - FLOOD INSURANCE RATE MAP (FIRM) INFORMATION

B1. NFIP Community Name & Community Number Memphis, 47147	B2. County Name Shelby	B3. State TN

B4. Map/Panel Number 0145	B5. Suffix F	B6. FIRM Index Date 9/28/2007	B7. FIRM Panel Effective/Revised Date	B8. Flood Zone(s) NA	B9. Base Flood Elevation(s) (Zone AO, use base flood depth) NA

B10. Indicate the source of the Base Flood Elevation (BFE) data or base flood depth entered in Item B9.
     ☐ FIS Profile   ☐ FIRM   ☐ Community Determined   ☒ Other (Describe) NA
B11. Indicate elevation datum used for BFE in Item B9: ☐ NGVD 1929   ☐ NAVD 1988   ☐ Other (Describe) _____
B12. Is the building located in a Coastal Barrier Resources System (CBRS) area or Otherwise Protected Area (OPA)?   ☐ Yes   ☐ No
     Designation Date _____   ☐ CBRS   ☐ OPA

SECTION C - BUILDING ELEVATION INFORMATION (SURVEY REQUIRED)

C1. Building elevations are based on: ☐ Construction Drawings*   ☐ Building Under Construction*   ☒ Finished Construction
     *A new Elevation Certificate will be required when construction of the building is complete.
C2. Elevations – Zones A1-A30, AE, AH, A (with BFE), VE, V1-V30, V (with BFE), AR, AR/A, AR/AE, AR/A1-A30, AR/AH, AR/AO. Complete Items C2.a-h
     below according to the building diagram specified in Item A7. Use the same datum as the BFE.

     Benchmark Utilized _____ Vertical Datum _____
     Conversion/Comments _____

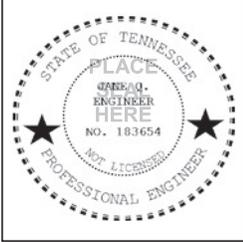   Check the measurement used.

   a) Top of bottom floor (including basement, crawlspace, or enclosure floor) 250.3   ☒ feet ☐ meters (Puerto Rico only)
   b) Top of the next higher floor   260.3   ☒ feet ☐ meters (Puerto Rico only)
   c) Bottom of the lowest horizontal structural member (V Zones only) _____._____   ☐ feet   ☐ meters (Puerto Rico only)
   d) Attached garage (top of slab) _____._____   ☐ feet   ☐ meters (Puerto Rico only)
   e) Lowest elevation of machinery or equipment servicing the building   254.2   ☒ feet ☐ meters (Puerto Rico only)
     (Describe type of equipment and location in Comments)
   f) Lowest adjacent (finished) grade next to building (LAG)   250.0   ☒ feet ☐ meters (Puerto Rico only)
   g) Highest adjacent (finished) grade next to building (HAG)   260.0   ☒ feet ☐ meters (Puerto Rico only)
   h) Lowest adjacent grade at lowest elevation of deck or stairs, including _____._____   ☐ feet   ☐ meters (Puerto Rico only)
     structural support

SECTION D - SURVEYOR, ENGINEER, OR ARCHITECT CERTIFICATION

This certification is to be signed and sealed by a land surveyor, engineer, or architect authorized by law to certify elevation
information. *I certify that the information on this Certificate represents my best efforts to interpret the data available.I
understand that any false statement may be punishable by fine or imprisonment under 18 U.S. Code, Section 1001.* ☐
     Check here if comments are provided on back of form.   Were latitude and longitude in Section A provided by a
                              licensed land surveyor? ☐ Yes ☐ No

Certifier's Name   Jane Q. Engineer   License Number   183654

Title   Project Engineer   Company Name   Engineering, Inc.

Address   72 McSwarley Street   City   Memphis   State   TN   ZIP Code   36547

Signature   Date   Telephone

(Seal: STATE OF TENNESSEE — PLACE ENGINEER HERE — NO. 183654 — NOT LICENSED — PROFESSIONAL ENGINEER)

FEMA Form 81-31, Mar 09   See reverse side for continuation.   Replaces all previous editions

Figure 6-37. Elevation certificate excerpt for the Borges house

Property Location and Owner Information		2011 Appraisal and Assessment Information	
Parcel ID:	D0134 L00000	Class:	RESIDENTIAL
Property Address:	18 Chai Avenue	Land Appraisal:	$50,900
Municipal Jurisdiction:	UNINCORP	Building Appraisal:	$150,338
Neighborhood Number:	0000000	Total Appraisal:	$201,238
Land Square Footage:	6795		
Acres:	0.1560	Total Assessment:	$50,700
Lot Dimensions:	61.55/66.43X110/85		
Subdivision Name:	BRECKENWOOD SEC F	Greenbelt Land:	$0
Subdivision Lot Number:	000	Homesite Land:	$0
Plat Book and Page:	00-00	Homesite Building:	$0
Number of Improvements:	0	Greenbelt Appraisal:	$0
Owner Name:	BORGES JORGE LUIS	Greenbelt Assessment:	$0
In Care Of:			
Owner Address:	18 Chai Avenue		
Owner City/State/Zip	Memphis, TN 36549		

Dwelling Construction Information			
		Heat:	CENTRAL A/C AND HEAT
Stories:	1.5	Fuel:	NA
Exterior Walls:	Brick Veneer	Heating System:	NA
Land Use:	Single Family		
Year Built:	1991	Fireplace Masonry:	0
Total Rooms:	6	Fireplace Pre-Fab:	0
Bedrooms:	3		
Bathrooms:	2	Ground Floor Area:	1600
Half Baths:	0	Total Living Area:	1600
Basement Type:	Slab		
		Car Parking:	Garage

Figure 6-38. Tax card for the Borges house

16 Sep 2011		Project: **Case Study 3**		Pg 1 of 9

Total Benefits: **$11,700**   Total Costs: **$9,191**   BCR: **1.27**

Project Number: Disaster #:   Program: Agency: **City of Memphis**

State: **Tennessee**   Point of Contact: Analyst:

Project Summary:

Project Number: Disaster #:

Program: Agency: City of Memphis

Analyst:

Point of Contact: Phone Number:

Address: Memphis, Tennessee

Email:

Comments:

Structure Summary For:

1-Dry Floodproofing, 18 Chai Ave, Memphis, Tennessee, 36549, Shelby

Structure Type: Building   Historic Building: No   Contact:

Benefits: $5,757   Costs: $4,971   BCR: 1.16

Mitigation	Hazard	BCR	Benefits	Costs
Dry Flood Proofing	Damage-Frequency Assessment	1.16	$5,757	$4,971

2-Wet Floodproofing, 18 Chai Ave, Memphis, Tennessee, 36549, Shelby

Structure Type: Building   Historic Building: No   Contact:

Benefits: $5,943   Costs: $4,220   BCR: 1.41

Mitigation	Hazard	BCR	Benefits	Costs
Other flood proofing measures	Damage-Frequency Assessment	1.41	$5,943	$4,220

Figure 6-39. Sample BCA report excerpt for dry and wet floodproofing of the Borges house

6.3.6   Real World Examples

Although the Borges house is fictional, wet- and dry-floodproofing are both commonly used flood mitigation measures outside of the 100-year floodplain. Figures 6-40 through 6-43 are examples of real structures that have been protected using the mitigation measures discussed in this case study.

Figures 6-40 and 6-41 show flood shields installed in dry floodproofed buildings.

**Figure 6-40.
Example of a flood shield over a door**

**Figure 6-41.
Example of a flood shield over a door**

Figures 6-42 and 6-43 show typical flood openings in exterior walls:

Figure 6-42.
Example of flood vents

Figure 6-43.
Example of flood vents