

Retrofitting Flood-Prone Residential Structures

Engineering Principles and Practices, Fourth Edition

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FEMA

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Acronyms and Abbreviations

A

AC	alternating current
ACI	American Concrete Institute
AISC	American Institute of Steel Construction
APA	Engineered Wood Association
ASCE	American Society of Civil Engineers
ASD	allowable stress design
ASTM	ASTM International

B

BCA	benefit-cost analysis
BCR	benefit-cost ratio
BFE	base flood elevation

C

CFR	Code of Federal Regulations
cfs	cubic feet per second
CMU	concrete masonry unit
CSA	Case Study A
CSB	Case Study B

D

DFE	design flood elevation
DFIRM	digital Flood Insurance Rate Map

F

FEMA	Federal Emergency Management Agency
FIRM	Flood Insurance Rate Map
FIS	Flood Insurance Study
FPL	flood protection level
ft	feet
ft^2	square feet
ft^3	cubic feet
ft/sec	feet per second

G

GFCI	ground fault circuit interrupter
gpm	gallons per minute

H

hp	horsepower
HVAC	heating, ventilation, and air conditioning

I

IASM	International Association of Structural Movers
IBC	International Building Code
I-Codes	International Codes
in.	inches
$in.^2$	square inches
IRC	International Residential Code

K

kW	kilowatts

L

LAG	lowest adjacent grade
lb(s)	pound(s)
lb/ft^2	pounds per square foot
lb/ft^3	pounds per cubic foot
lf	linear feet
LRFD	load and resistance factor design

M

MAT	Mitigation Assessment Team
MRI	mean recurrence interval
MSC	FEMA Map Service Center
MW	masonry wall

N

NAVD	North American Vertical Datum
NFIP	National Flood Insurance Program
NFPA	National Fire Protection Association
NGVD	National Geodetic Vertical Datum
NOAA	National Oceanic and Atmospheric Administration

R

RI	recurrence interval

S

sec	seconds
sec^2	seconds squared

sf	square foot
SEI	Seismic Engineering Institute

U

UF	underground feeder
UL	Underwriters Laboratories
USACE	U.S. Army Corps of Engineers

Chapter 1. Introduction to Retrofitting

Retrofitting is any change to an existing structure to reduce the flood hazard, improve energy, change the home's floor plan, or other reasons to make the home more amenable to the owner. The focus of this publication is flood retrofit options intended to reduce or eliminate future damage caused by floods and related hazards. Publications that describe retrofitting residences to improve resistance to wind damage, wildfire, and earthquakes are listed in Appendix G.

Retrofitting flood-prone residential structures helps achieve an important objective of the National Flood Insurance Program (NFIP): to break the cycle of repetitive flood damage. Many buildings have been flooded, repaired, and flooded repeatedly. In some floodplains, this cycle occurs every few years. The Federal Emergency Management Agency (FEMA) estimates that buildings that meet or exceed the National Flood Insurance Program minimum floodplain management requirements incur, on average, 65% less flood damage than buildings that predate adoption of local floodplain management requirements. In general, buildings that were constructed before the adoption of local floodplain management requirements may not have been constructed with features that reduce flood damage. Owners of these buildings may be interested in the retrofitting measures and best practices described in this publication.

1.1. Goals and Intended Users

This publication has been developed by FEMA with support from other groups to assist state, local, tribal, and territorial governments, various planners, engineers, architects, contractors, property owners, and other interested stakeholders involved in planning and implementing residential flood retrofitting projects. Its objective is to provide engineering design, economic guidance, and best practices to engineers, architects, and local code officials about what constitutes technically feasible and cost-effective retrofitting measures for flood-prone residential structures.

The focus of this publication is retrofitting one- to four-family residences subject to flooding situations without wave action. Various retrofitting measures and best practices that provide active and passive flood mitigation measures efforts using dry and wet floodproofing. These include elevation of the structure in place, relocation of the structure, construction of barriers (floodwalls and berms), dry floodproofing (sealants, closures, sump pumps, and backflow valves), and wet floodproofing (flood damage-resistant materials and protection of utilities and contents).



Note

One- to four-family residence: The National Flood Insurance Program classifies insured buildings into several building types. This publication addresses retrofitting of one- to four-family residences which include single family detached houses, row houses, townhouses (brownstones), and mid-rise multi-family buildings.

Note

This publication will provide valuable assistance to the design professional, among other interested stakeholders. It should not be used as a code reference or a replacement for engineering or architectural performance standards.

Existing data and current standards have been used to inform this publication. Detailed sections on evaluation, planning, and retrofitting design measures, along with case studies of completed retrofitting projects, are included.

Architects, engineers, owners, planners, code officials, and other stakeholders should recognize that retrofitting residential structures influences how structures perform when exposed to hazards other than flooding, such as wind and seismic hazards. Failure to understand and adequately address potential damage from other hazards can result in increased vulnerabilities and unnecessary future damage. An integrated, multi-hazard approach can reduce future disaster impacts. Flood-related hazards such as water-borne ice and debris impact forces, erosion effects mudslide impacts, as well as non-flood-related hazards such as earthquakes, wind forces, and wildfires should be considered in the retrofitting process. Retrofitting structures to withstand only floodwater-generated forces may reduce a structure's ability to withstand multiple hazards, well into the future. It is important to approach the retrofitting method selection and design process with a multi-hazard perspective.

Note

In addition to FEMA, other flood-related technical resources are available through the U.S. Army Corps of Engineers, U.S. Geological Survey, the National Weather Service, the Natural Resource Conservation Service, as well as regional planning zones and state, local, territorial, and Tribal governments.

This publication does not address retrofitting structures located in Coastal High Hazard Areas (FEMA flood Zone V/VE) or Coastal A Zones. For Information on design considerations in Zone V/VE, readers should refer to the FEMA Coastal Construction Manual (FEMA P-55, 2011). Other hazard risks are described in Chapter 3 Determination of Site-Specific Hazards and Appendix E Alluvial Fan Flooding.

1.2. Organization of the Publication

This publication has seven chapters and seven appendices.

Chapter 1. Introduction to Retrofitting. This chapter gives a basic overview of the different flood retrofit options with a discussion of the pros and cons of each retrofit type. An overview of the retrofitting process is also given.

Chapter 2. Regulatory Requirements and Retrofitting Parameters. Typical community floodplain management and building code requirements are discussed. The role of local officials in a retrofitting project, the various tenets of the National Flood Insurance Program, and the International Code Council (I-Code®) series are discussed. Aspects of retrofitting that influence the choice of a retrofit method are presented. Matrix worksheet forms to support designers in narrowing the range of retrofit options are provided. Case studies are introduced, which continue by building upon each other through the remainder of the publication.

Chapter 3. Determination of Hazards. Guidance on flood load calculations, addressing other hazards, and geotechnical considerations are provided. These factors determine appropriate retrofitting solutions for a specific residential structure. Case studies continue.

Chapter 4. General Design Practices. Information on load combinations and potential primary failure points for retrofitted structures are presented. Examples are provided through the case studies.

Chapter 5. Elevation and Relocation Techniques. A step-by-step discussion of design processes for traditional structural elevation, elevation alternatives and relocation are presented, with continued case study examples.

Chapter 6. Floodproofing and Flood Barrier Techniques. This chapter provides step-by-step design processes for wet floodproofing, dry floodproofing, floodwalls, and berms. Case studies are provided.

Chapter 7. Cost-Effectiveness and Alternative Selection. Benefit-cost analysis methodology for determining the cost-effectiveness of various retrofitting methods is described. The discussion includes combining cost-effectiveness analysis results with other alternative selection factors to determine the final recommended retrofitting measure(s). Case studies are included.

Appendix A. Case Study A Calculations and Supporting Materials. This appendix includes detailed sample design calculations for Case Study A.

Appendix B. Case Study B Calculations and Supporting Materials. This appendix includes detailed sample design calculations for Case Study B.

Appendix C. Case Study C Island Case Study Calculations and Supporting Materials. This appendix includes detailed sample design calculations for Case Study C, including elevation and wet floodproofing of a residence built using typical island construction techniques in Puerto Rico that can be relevant to other islands (e.g., Hawaii) and U.S. territories.

Appendix D. Design Flood Best Practices. This appendix summarizes how to apply the best practices in ASCE 7-22 S2 and ASCE 24-24 (not yet adopted in current building codes) to determine the Design Flood Elevation and update design loads for increased flood retrofitting resilience.

Appendix E. Alluvial Fan Flooding. This appendix presents a description of alluvial fan flooding and its associated hazards, along with regulatory and design considerations in alluvial fan flooding areas.

Appendix F. Floodwall Design Details and Calculations. This appendix describes the detailed engineering approach with equations for designing a residential floodwall and floodwall closures.

Appendix G. References and Resources. This appendix includes a list of references cited throughout this publication as well as other resources that may be of interest.

Throughout this publication, the following content is highlighted in color-coded boxes by content type:



Special Note, Warning, or Definition: Significant or interesting information or special precautions.



Case Studies



Cross Reference or Additional Resources: Reference to another relevant part of the text or another source of information.



Equation: Use of a mathematical equation.

1.3. Methods of Retrofitting

Retrofitting measures for flood hazards include the following:

- **Elevation:** Raising an existing structure on fill or higher foundations, including solid perimeter walls (crawl space), columns, or pilings.
- **Relocation:** Moving an entire structure to a location either outside of the identified floodplain or to another less hazardous location.
- **Dry Floodproofing:** Strengthening existing foundations, floors, and walls to withstand flood forces, using shields, barriers, sealing penetrations, and other methods to keep water out of the structure. Potential seepage into dry floodproofed areas must also be addressed.
- **Wet Floodproofing:** Modifying a structure to allow floodwater entry and exit to minimize unequal hydrostatic loads that could cause structural damage. Incorporation of flood damage-resistant materials and equipment modification is also a wet floodproofing strategy.
- **Floodwalls/Flood Berms**: Constructing barriers around a structure.

Retrofitting measures can require human intervention (active) or be passive. Adequate warning time to enable activating the floodproofing measures (e.g., placing flood shields in doors and windows) is necessary for some measures to be effective. Passive measures are preferred as flood protection is not dependent on human intervention.



Note

Cost is an important factor to consider when evaluating whether to elevate a structure. As an example, light wood-frame structures are easier and often less expensive to elevate than masonry structures; which are not only more expensive to elevate but are also susceptible to cracks. In some cases, more practical and cost-effective alternative measures may be to abandon lowest floor or replace the structure with an elevated building designed to reduce flood risk.

1.4. Elevation and Relocation Techniques

1.4.1. TRADITIONAL STRUCTURAL ELEVATION

Elevating a structure to prevent floodwater from reaching portions of structures and their associated utility systems susceptible to flood damage is an effective retrofitting technique. The structure is raised so that the lowest floor is at or above the Base Flood Elevation for floodplain management ordinance and building code compliance in the Special Flood Hazard Area. Heavy-duty hydraulic jacks are used to lift the building. Cribbing supports the structure while a new or extended foundation is constructed below. Instead of constructing new support walls, open foundations such as piers, posts, columns, and piles are often used.

Upon completion of any mitigation work related to elevating a building, it is important to have a surveyor complete a new Elevation Certificate to document the elevation of the new lowest floor for code compliance and potential flood insurance premium adjustments. Communities may adopt minimum elevations for buildings in Special Flood Hazard Areas that are higher than the effective base flood elevation, advisory base flood elevations, or other available data if higher than the effective base flood elevation. The addition of height above the base flood elevation, expressed in feet, is called a freeboard requirement. FEMA recommends elevation requirements in accordance with ASCE 24 to account for uncertainties, future development, and floods higher than the base flood. Designers, contractors, and owners should contact a qualified insurance agent or the National Flood Insurance Program for more information about policy coverage, coverage limits, and costs.

KEY TERMINOLOGY

Base flood, or 100-year flood, is the elevation of floodwaters during a "base flood" which has a 1% annual chance of being equaled or exceeded. The **Base Flood Elevation (BFE)** is the elevation of surface water resulting from a base flood.

Design Flood Elevation (DFE) is a regulatory flood elevation requirement adopted by the community for the elevation to which a structure must be elevated or floodproofed for flood protection. It is typically the sum of the base flood elevation and a freeboard factor.

Freeboard is an additional height added to the base flood elevation to provide an extra level of protection. It is often determined by the local community or incorporated into building codes and accounts for uncertainties in flood prediction.

Flood Protection Level (FPL), as used in this publication, is the elevation of flood protection selected by the owner and used by the designer to evaluate and design retrofitting measures when compliance with National Flood Insurance Program requirements for new construction is not required (including wet floodproofing, dry floodproofing, and floodwalls and berms). Compliance with elevation requirements is required when buildings are substantially improved within Special Flood Hazard Areas.

Substantial Improvement is any reconstruction, rehabilitation, addition, or other improvement of a structure, the cost of which equals or exceeds 50% of the market value of the structure before the "start of construction" of the improvement. This term includes structures that have incurred "Substantial Damage," regardless of the actual repair work performed.

Substantial Damage is damage of any origin sustained by a structure whereby the cost of restoring the structure to its pre-damaged condition would equal or exceed 50% of the market value of the structure before the damage occurred.

While elevation may provide structures with increased protection from floodwater, other hazards should be considered before implementing this strategy. Failure to adequately address other hazards will typically increase long-term hazard vulnerability and risk of future damage and loss of function. Elevated structures may encounter additional wind forces on wall and roof systems, and additional loading to footings. Extended and open foundations (e.g., piers and posts) may also be subject to undermining, movement, and impact failures caused by seismic activity, erosion, scour, ice or debris flows, mudslides, and alluvial fan forces.

Note

FEMA strongly encourages flood retrofitting projects provide protection to the Design Flood Elevation. A best practice is to elevate even higher. The property owners and design professionals should meet with the community building official to discuss the selected retrofit measure and the elevation to which it will protect the home.

Cross Reference

See FEMA *Foundation Requirements and Recommendations for Elevated Homes Hurricane Sandy Recovery Fact Sheet No. 2* (May 2013) for detailed information on elevated foundations.

Elevation on Solid Perimeter Foundation Walls

Elevation on solid perimeter foundation walls is appropriate in areas of low to moderate water depth and velocity. After the structure is lifted above its current foundation, the support walls can be extended vertically using materials such as concrete masonry units or cast-in-place concrete. Figure 1-1 shows an elevation of solid perimeter foundation walls, and Figure 1-2 shows a home elevated on extended foundation walls. The structure is then set down onto the extended walls. While this may seem to be the easiest solution to increase flood protection, there are several important considerations. Depending on the structure and potential flood, wind, seismic, and snow loads, new larger footings may be necessary. Additional structural stability may be necessary to reinforce the footings and walls with steel reinforcing bars.

Deep floodwater can generate loads great enough to collapse the structure regardless of construction material. Building solid foundation walls with openings or vents will help alleviate flood loads by allowing equalization of the hydrostatic forces. New and substantially damaged or improved elevated buildings must have flood openings installed in accordance with National Flood Insurance Program and adopted building code requirements. Specific guidance can be found in FEMA *Technical Bulletin 1, Openings in Foundation Walls and Walls of Enclosures* (March 2020) and FEMA *Technical Bulletin 2, Flood Damage-Resistant Materials Requirements* (January 2025).

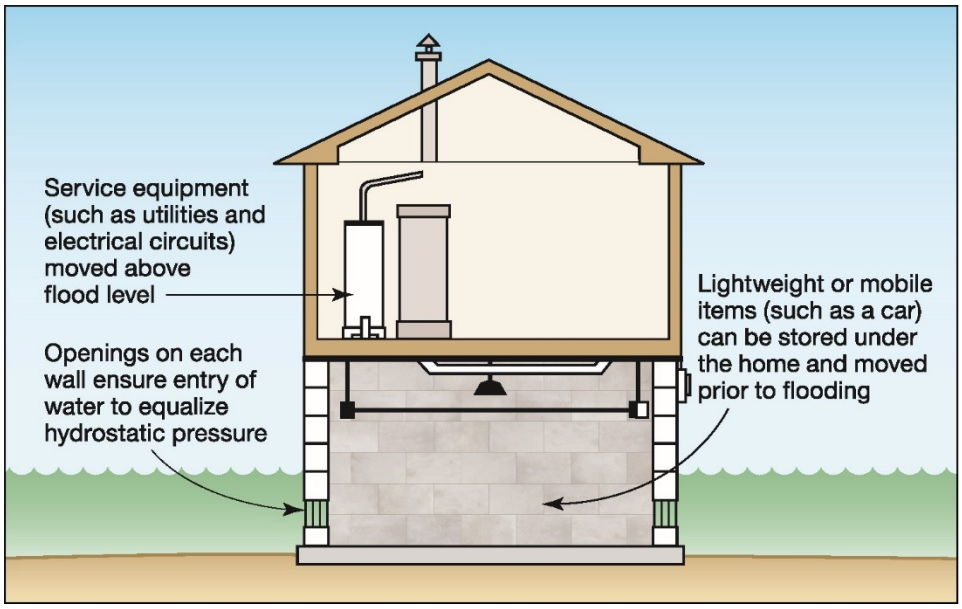


Figure 1-1 Elevation on solid perimeter foundation walls



Figure 1-2 Elevation of a residence on extended foundation walls

Elevation on Open Foundation Systems

Open foundation systems feature vertical structural members that support the structure at key points without the support of a continuous foundation wall. Open foundation systems include piers, posts, and columns, which enable floodwater to move under the structure and minimize flood and debris impact loads on the building and its foundation.

Elevation on Piers, Posts or Columns

The most common example of an open foundation is piers, which are vertical structural members supported entirely by reinforced concrete footings. Despite their popularity in construction, piers are often the elevation technique least suited for withstanding significant horizontal flood forces. In conventional use, vertical loading is prioritized in pier design. However, when exposed to flooding, piers may also experience horizontal loads due to moving floodwater or debris impact forces. Other environmental loads, such as seismic and wind loads, can also create significant horizontal forces. For this reason, piers used in retrofitting must not only be substantial enough to support the vertical load of the structure but must also be sufficient to resist a range of horizontal forces.

Piers are used in shallow depth flooding conditions with low velocity (less than 5 feet per second), ice, debris, and water flow potential. They are normally constructed of reinforced and grouted concrete masonry units or "cinder block", or cast-in-place concrete with steel reinforcement in the pier and its support footing. The steel reinforcement bars (rebar) are tied together to prevent movement during grout or concrete placement. Connections between the superstructure and piers serve to resist seismic, wind, and buoyancy (uplift) forces. Overturning can occur from the combination of vertical and horizontal forces on a shallow depth pier foundation. Figure 1-3 shows the schematic of a residential structure on piers.



Figure 1-3 Elevation on piers

Elevation on posts or columns is effective in areas characterized as vulnerable to moderate flood depths and velocity on flood hazard maps. Posts are wood and square-shaped to permit easy attachment to the house structure, while columns are built of wood, steel, or concrete and may be square or round. Set into pre-dug holes, posts or columns are anchored or embedded in concrete pads to manage substantial load requirements. Posts are mounted on concrete pads/footers. Concrete, earth, gravel, or crushed stone is usually backfilled into the hole and around the base of the post.

While piers are designed to function as individual support units, posts normally must be braced. There are a variety of bracing techniques, such as wood knee and cross bracing, steel rods, and guy wires. Cost, local flood conditions, loads, building material availability, and local construction practices determine the bracing technique. Figure 1-4 shows an example of a post and column foundation.



Figure 1-4. Elevation on posts or columns

Note

The International Residential Code uses "posts" and "columns" interchangeably. Posts are commonly wood, while columns can be wood, metal, or concrete.

Elevation on Piles

Piles differ from posts because they are driven, jetted, or set (augured) deeper into the ground than posts. Thus, they are less susceptible to high velocity floodwaters, scouring, and debris impact. Piles must either rest on a support layer, such as bedrock, or be driven deep enough to create enough friction to transfer the anticipated loads to the surrounding soil. Piles are usually wood, although steel and reinforced precast or prestressed concrete are also common in some areas. Piles may require bracing.

Note

Although more commonly associated with coastal areas, elevation on piles can be effective at retrofitting in riverine areas subject to deep, high-velocity flooding with erosion and scour.

Because driving piles requires bulky, heavy construction machinery, the effort to replace the foundation often requires moving the home off the foundation set on cribbing until the operation is complete. The structure is then set on the new foundation. Additional cost and construction site space requirements can limit the use of piles in areas where alternative elevation methods are feasible.

Several innovative methods have been developed for setting piles. These include jetting exterior piles in the ground at an angle using high-pressure water flow and trenching or auguring holes for interior pile placement. Augured piles use a concrete footing for anchoring instead of friction forces. This requires raising the home several feet above its final elevation to allow room for workers to install the piles. Jetting and auguring piles reduces the uplift capacity. Figure 1-5 shows a schematic of a residential structure on piles.

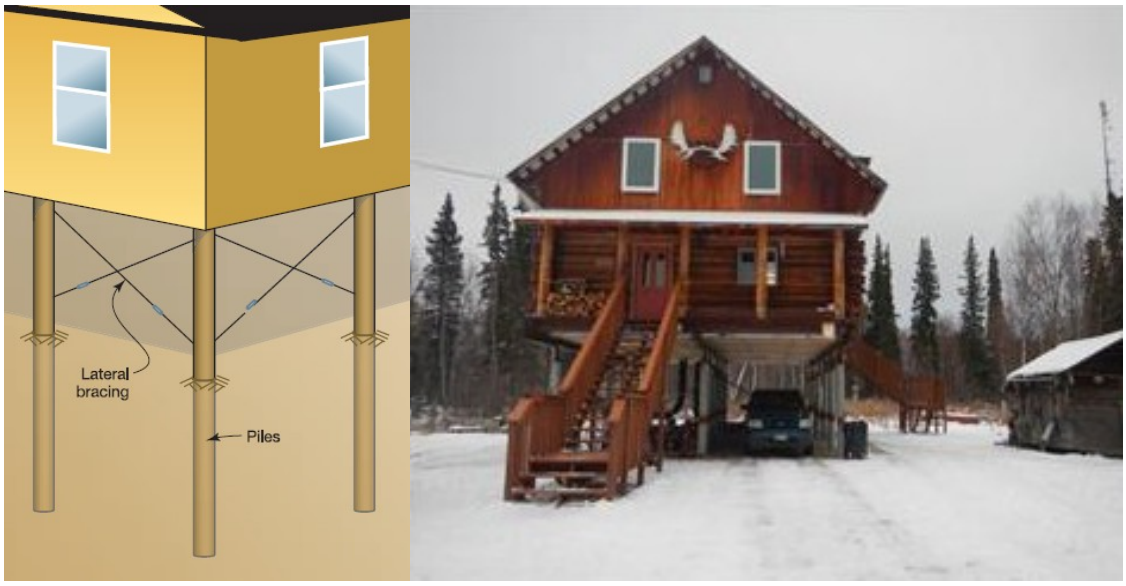


Figure 1-5. Elevation on piles

1.4.2. ALTERNATIVES TO TRADITIONAL STRUCTURAL ELEVATION

Structural elevation is a well-recognized measure for flood risk reduction that can also result in lower flood insurance premiums. In some cases, elevation may not be an option for some housing types that cannot be feasibly elevated due to structural characteristics, location, condition, or local regulations. It is usually prohibitive to elevate attached dwelling units, connected row houses, town homes, or mid-rise multi-family buildings. Elevation may also be limited to older or damaged buildings. Alternatives to traditional structural elevation are listed below.

- **Basement Infill** involves filling a basement located below the Base Flood Elevation to grade. Sections of the basement walls or the new foundation wall extending above grade must be fitted with flood openings that allow automatic entry and exit of floodwaters (refer to Section 1.5.2 Wet Floodproofing for details). Any basement utility systems and associated equipment must be elevated to protect utilities from damage or loss of function from flooding.

- **Abandon Lowest Floor** involves abandoning the lowest floor of a two- or more story slab-on-grade residential building. The lowest floor walls must be retrofitted with flood openings to allow automatic entry and exit of floodwaters. Additionally, any utility systems and associated equipment on the lowest floor should be elevated to protect utilities from damage or loss of function from flooding.

- **Converting or Elevating the Lowest Interior Floor** involves elevating the lowest interior floor within a residential building with high ceilings. The space below the lowest elevated interior floor walls must be either filled to create a stem wall or retrofitted with flood openings that allow automatic entry and/or exit of floodwaters. Any utility systems and associated equipment located below the lowest interior floor should be elevated to protect utilities from damage or loss of function.

Alternative elevation measures can reduce flood damage depending on the specific flood risk and mitigation measure used. Use of these measures may enable a building to meet current National Flood Insurance Program minimum requirements and the local floodplain ordinance if the lowest floor is elevated to or above the base flood elevation or locally adopted regulatory flood elevation. Flood insurance premiums may also be lowered.

Figure 1-6 provides advantages and disadvantages associated with elevating or retrofitting a home.

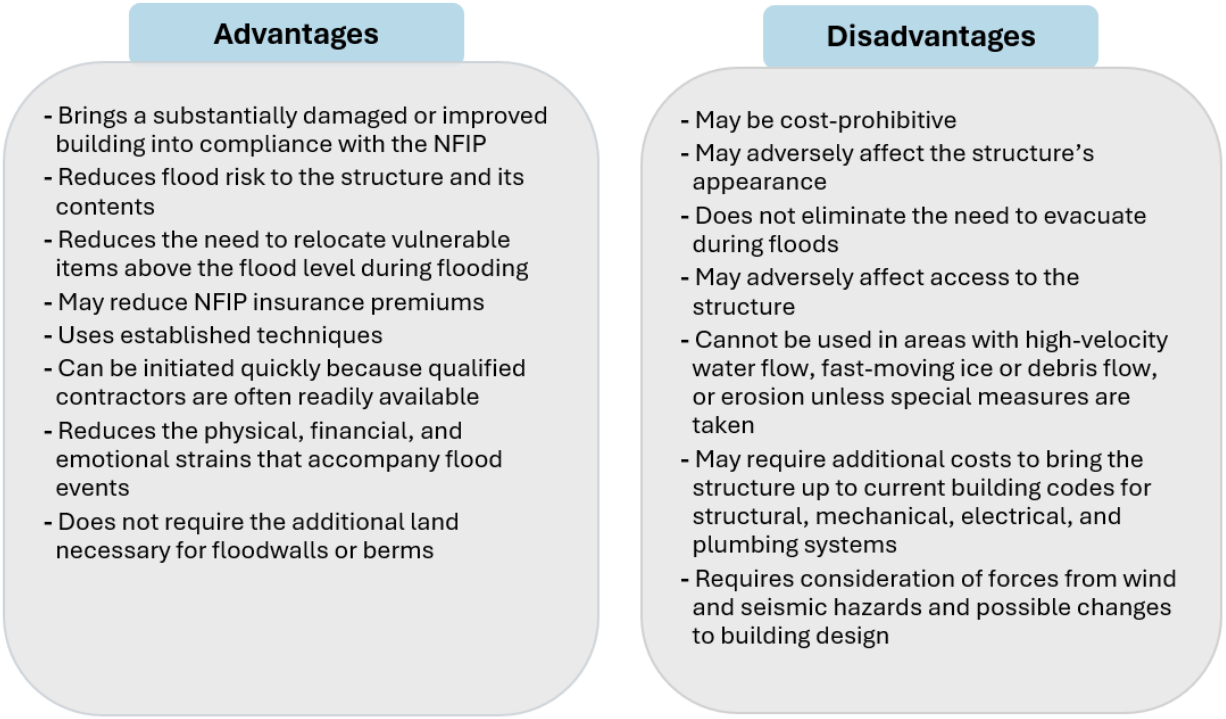


Figure 1-6. Advantages and Disadvantages of Elevation

1.4.3. RELOCATION

Relocation involves moving a structure to a location less prone to flooding or flood-related hazards, such as erosion. The structure may be moved to another portion of the current site or a different site.

The surest way to minimize the risk of flood damage is to relocate the structure out of the floodplain. Relocation involves placing the structure on a wheeled vehicle, as shown in Figure 1-7. The structure is transported to a new location and lowered onto a new foundation.



Figure 1-7. Structure placed on a wheeled vehicle for relocation to a new site

Relocation is an appropriate measure in high hazard flood areas where continued occupancy is unsafe or owners want to significantly reduce or eliminate their flood vulnerabilities. It is also viable in communities that consider using the resulting open space for more appropriate floodplain activities. Relocation may offer an alternative to elevation for substantially improved or substantially damaged structures required to meet National Flood Insurance Program requirements.

Compared to elevation, relocation requires steps that typically increase the cost. Additional costs include moving the structure to its new location, purchase and preparation of the new parcel for the home and utilities, construction of a new foundation, and restoration of the old site. Most types and sizes of structures can be moved either as a unit or in segments. One-story wood-frame houses are usually the easiest to move, particularly if they are located over a crawl space or basement that provides easy access to floor joists. Smaller, lighter wood-frame structures may also be lifted with house moving equipment and often can be moved without partitioning. Homes constructed of brick, concrete, or masonry are also moveable, often with more difficulty and increased costs. Figure 1-8 shows a sketch of a home proposed for relocation.

Structural relocation professionals can assist property owners with relocation considerations. Structural soundness should be evaluated, and arrangements should be made for temporary housing and storage of belongings. Many states and communities have transportation requirements for moving buildings.

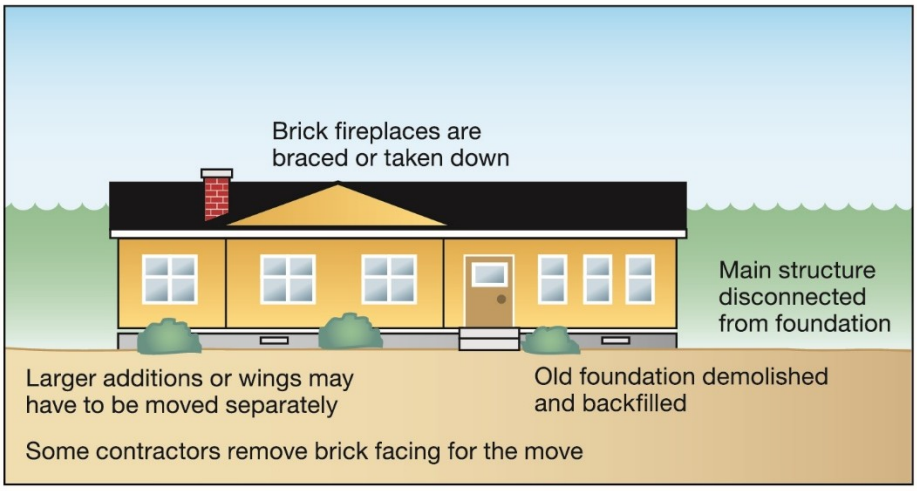


Figure 1-8. Structure to be relocated

Figure 1-9 provides advantages and disadvantages associated with residential relocation.

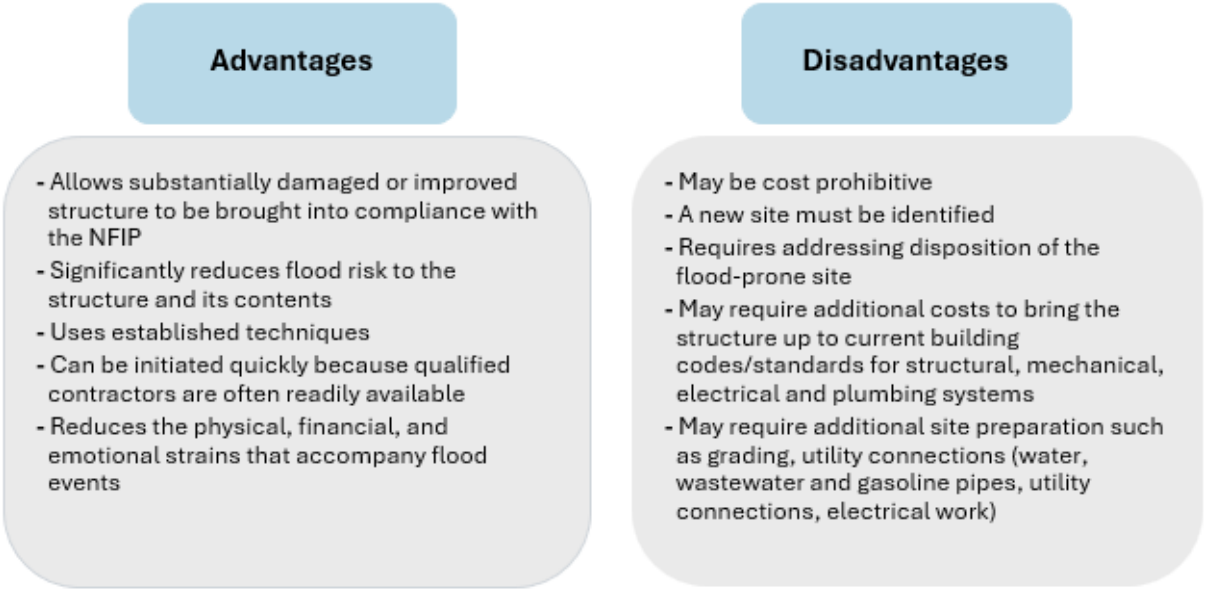


Figure 1-9. Advantages and Disadvantages of Relocation

1.5. Floodproofing and Flood Barriers

1.5.1. DRY FLOODPROOFING

In dry floodproofing, the portion of a structure that is below the Design Flood Elevation (walls and other exterior components) is sealed to make the building substantially impermeable to floodwater. Such watertight systems can include wall coatings, waterproofing compounds, impermeable sheeting, opening protection, gaskets, sealing of wall, floor penetrations, and supplemental impermeable wall systems, such as cast-in-place concrete. Doors, windows, sewer and water lines,

and vents are closed with permanent or removable shields or valves. Dry floodproofing also requires secondary drainage with pump systems to remove floodwaters that seep into the structure over time. Figure 1-10 is a schematic of a dry floodproofed home.

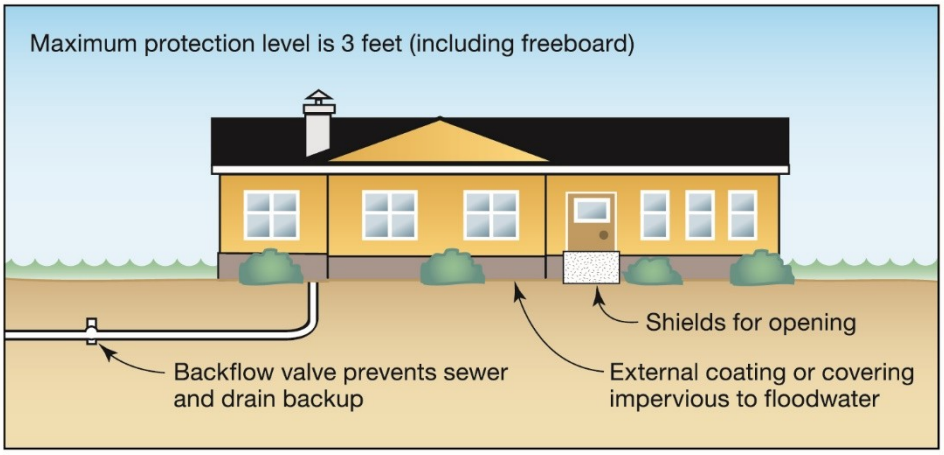


Figure 1-10. Dry floodproofed structure

Dry floodproofing is a potential flood mitigation option for residential properties outside of the Special Flood Hazard Area, as well as for building areas above the Base Flood Elevation/Design Flood Elevation. Each building should be evaluated for specific flood risks, effectiveness, and feasibility of dry floodproofing. Dry floodproofing is not recognized or permitted when compliance is required by the National Flood Insurance Program for residential structures. Implementing these measures will not contribute to floodplain management ordinance compliance, nor will they reduce annual National Flood Insurance Program flood insurance premiums. However, when properly implemented, dry floodproofing will usually reduce building and utility system flood damage risk and vulnerability.

FEMA P-2037 *Flood Mitigation Measures for Multi-Family Buildings* provides guidance for building owners, designers, investors, builders/contractors, institutional partners, housing agencies and residents, and property and facility managers on flood risk evaluation and mitigation. This guidance defines a multi-family building as a building with five or more dwelling units. Multi-family buildings typically have two stories or more above ground and may have one or more floors below ground. The term includes condominium and apartment buildings in addition to congregate residences (e.g., nursing homes, assisted living facilities, dormitories, group homes, detoxification facilities, and detention centers). Options for dry floodproofing and drainage improvement are presented for multi-family buildings located within floodplains, particularly in urban areas.

The predicted flood duration is critical when designing a floodproofing system since seepage can increase over time, potentially making floodproofing measures ineffective. Waterproofing compounds, sheeting, or sheathing may fail or deteriorate if exposed to floodwaters for extended periods. Floodproofing systems are also subject to damage or puncture in areas that experience high velocity flood flows or are subject to ice or debris impacts. The US Army Corps of Engineers National Flood Proofing Committee has researched the effect of various water depths on masonry walls and

determined that no more than three feet of floodwaters should be allowed on an unreinforced or under-reinforced concrete block wall unless it has been specifically designed and constructed to withstand flood loads exceeding three feet in depth. Application of floodproofing systems should include determination of a building's structural soundness and its ability to resist flood and flood-related loads. Once this is done, an engineering evaluation of the building should be conducted to determine the appropriate height of protection as the basis for residential dry floodproofing design.

Warning

Even brick or concrete block walls should not be floodproofed above a predicted flood height of three feet (without an extensive engineering analysis) due to the danger of structural failure from excessive hydrostatic and other flood-related forces.

Dry floodproofing is not recommended for structures with basements. These types of buildings can be susceptible to significant lateral hydrostatic and uplift (buoyancy) forces. Dry floodproofing is not appropriate for a wood-frame superstructure, even with brick or stone veneer, since these weaker construction materials will often fail or leak at lower flood depths due to hydrostatic forces. By contrast, buildings constructed of stronger and more impervious reinforced concrete or masonry block may be considered for dry floodproofing retrofits.

Note

The designer should consider incorporating freeboard into the 3-foot height constraint as a factor of safety against structural failure (limiting flood height to a maximum of two feet). Other factors of safety might include additional pumping capacity and stiffened walls.

Dry floodproofing for new and substantially damaged or improved houses located in a Special Flood Hazard Area is prohibited, when National Flood Insurance Program compliance is required. Figure 1-11 provides advantages and disadvantages associated with dry floodproofing a home.

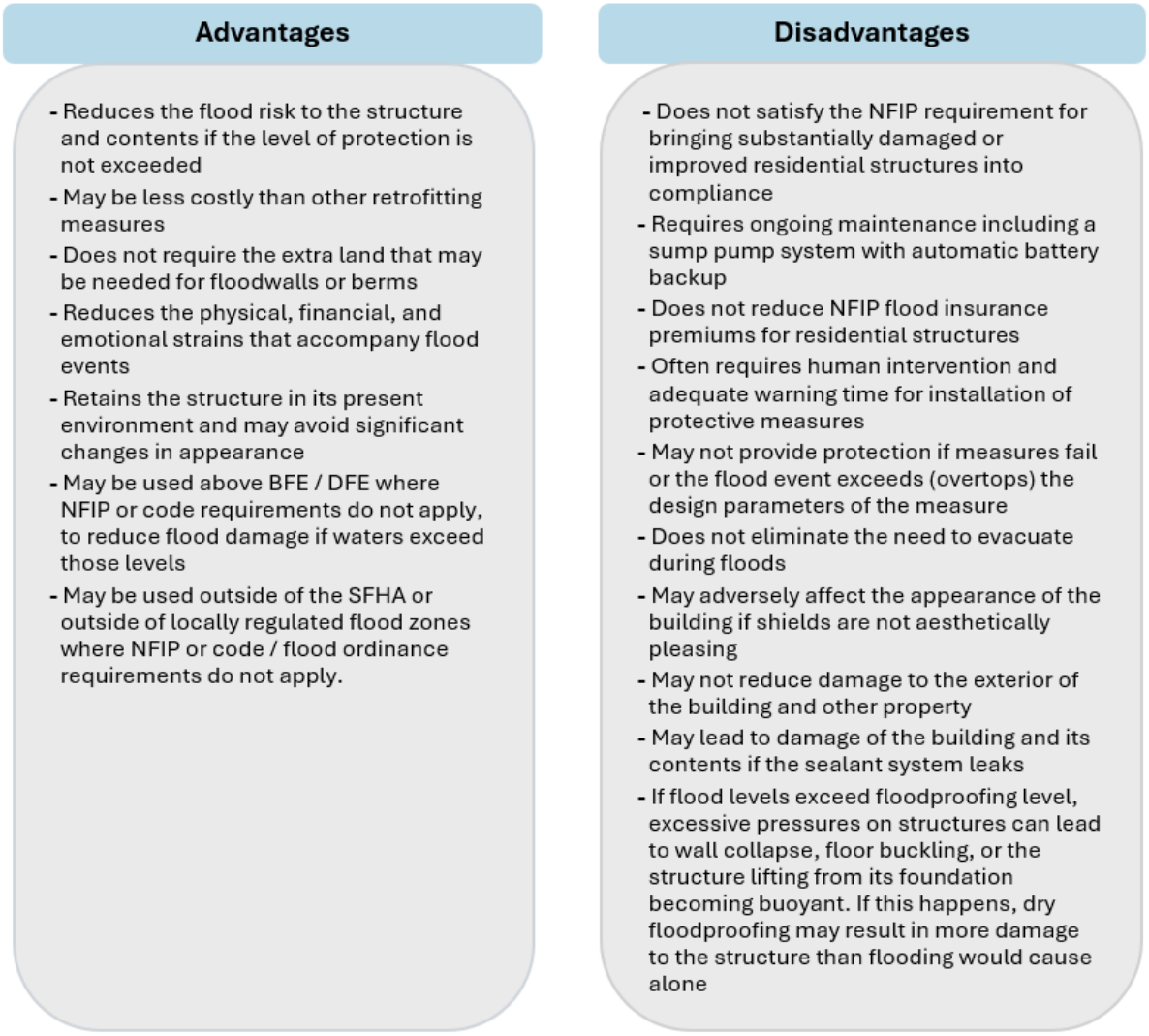


Figure 1-11. Advantages and Disadvantages of Dry Floodproofing

Additional Resources

Additional information on dry floodproofing can be obtained from FEMA Technical Bulletin 3, Requirements for the Design and Certification of Dry Floodproofed Non-Residential and Mixed-use Buildings Located in Special Flood Hazard Areas in Accordance with the National Flood Insurance Program (FEMA, May 2025). Designers should also reference Section 6.2 of AASCEANSI 24-24, Flood Resistant Design and Construction (American Society of Civil Engineers, 2025).

1.5.2. WET FLOODPROOFING

Another flood retrofitting measure is wet floodproofing. This involves modifying a building to allow floodwaters to enter, minimizing damage to the house and its contents. Figure 1-12 depicts a wet floodproofed house.

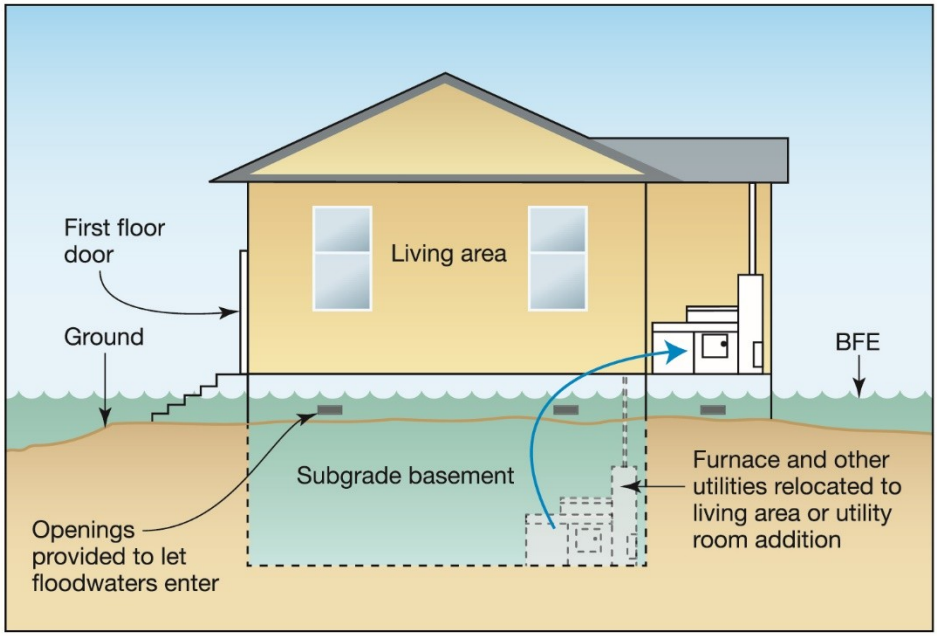


Figure 1-12. Wet floodproofed residence

Wet floodproofing can be used when all other mitigation techniques are not feasible or are too costly. Wet floodproofing can be appropriate if a structure has available space where items at risk of damage can be stored temporarily. Utilities and heating, ventilation, and air conditioning (HVAC) equipment may need to be relocated along with other non-moveable items or protected with flood-resistant building materials. Wet floodproofing may also be appropriate for houses with basements and crawlspaces that cannot be protected by other retrofitting measures.

Compared with the more extensive flood protection measures described in this publication, wet floodproofing is usually the least expensive. Major costs involve protection and/or elevation of utility systems, installation of flood damage-resistant materials, labor and equipment to move items, and cleanup/sanitation when floodwaters recede. During actual flood conditions, typical building contents or equipment may be disrupted or displaced due to flood loads, buoyancy, or flood-borne debris.

Table 2 of FEMA's National Flood Insurance Program Technical Bulletin 2*, Flood Damage-Resistant Materials Requirements for Buildings Located in* Special Flood Hazard Areas in accordance with the National Flood Insurance Program (FEMA, January 2025), provides product and material ratings for flood damage resistance for standard construction materials. It should be noted that materials are rated as either "acceptable" or "unacceptable" for use below the Base Flood Elevation in a Special Flood Hazard Area. For materials not listed in Technical Bulletin 2, designers should reference ASTM

E3075, *Standard Test Method for Water Immersion and Drying for Evaluation of Flood Damage Resistance* (ASTM, 2024), and ASTM E3369, *Standard Specification for Determining the Flood Damage Resistance Rating of Building Materials* (ASTM, 2024).

Only wet floodproofing can be used above Base Flood Elevation/Design Flood Elevation, but it is prohibited to bring a residence into compliance with National Flood Insurance Program requirements since the lowest occupied floor must be at or above Base Flood Elevation/Design Flood Elevation. Wet floodproofing is not allowed as an alternative to the lowest floor elevation requirements for new or substantially improved houses.

Figure 1-13 provides advantages and disadvantages associated with wet floodproofing a residence.

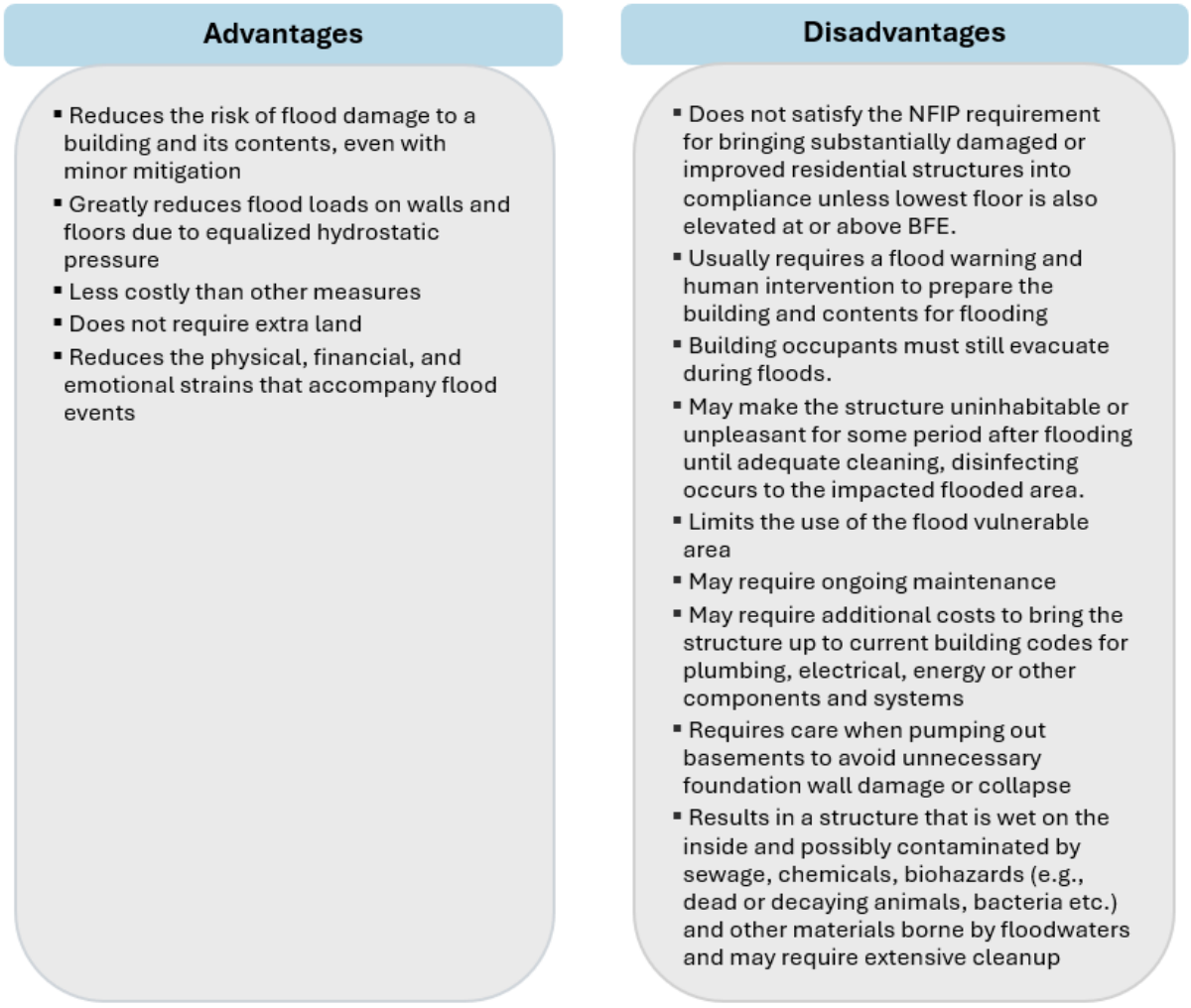


Figure 1-13. Advantages and Disadvantages of Wet Floodproofing

Additional Resources

For more information, refer to FEMA's Technical Bulletin 7, Wet Floodproofing Requirements and Limitations for Buildings and Structures Located in Special Flood Hazard Areas in Accordance with the National Flood Insurance Program (FEMA, May 2025). This updated Technical Bulletin references and uses the two ASTM standards, which enable stakeholders to determine flood damage resistance.

Also, refer to FEMA P-348, Protecting Building Utility Systems from Flood Damage: Principles and Practices for the Design and Construction of Flood Resistant Building Utility Systems (FEMA, February 2017).

1.5.3. FLOOD BARRIERS

Construction of a barrier between the structure and source of flooding can protect homes that cannot be retrofitted or economically retrofitted using the previously detailed approaches. There are two basic types of barriers: floodwalls and flood berms. They are usually limited to four feet for floodwalls and six feet for flood berms due to cost, aesthetics, access, water pressure, and space. Local zoning and building codes may also restrict use, size, and location.

Floodwalls are engineered barriers designed to keep floodwaters from the structure or the property protected behind them. Floodwalls can be constructed in a wide variety of shapes and sizes, typically built of reinforced concrete and/or masonry materials.

A floodwall can surround an entire structure or, depending on the flood levels, site topography, and design preferences, it can also protect isolated structure openings such as doors, windows, or basement entrances. Floodwalls can be designed as attractive features to the residential setting using decorative brick or block and landscaping. Figure 1-14 shows a schematic of a home protected by a floodwall and a flood berm.

Note

Residential floodwalls are typically only technically and economically feasible at providing protection for flood depths up to four feet, and residential flood berms for flood depths up to six feet.

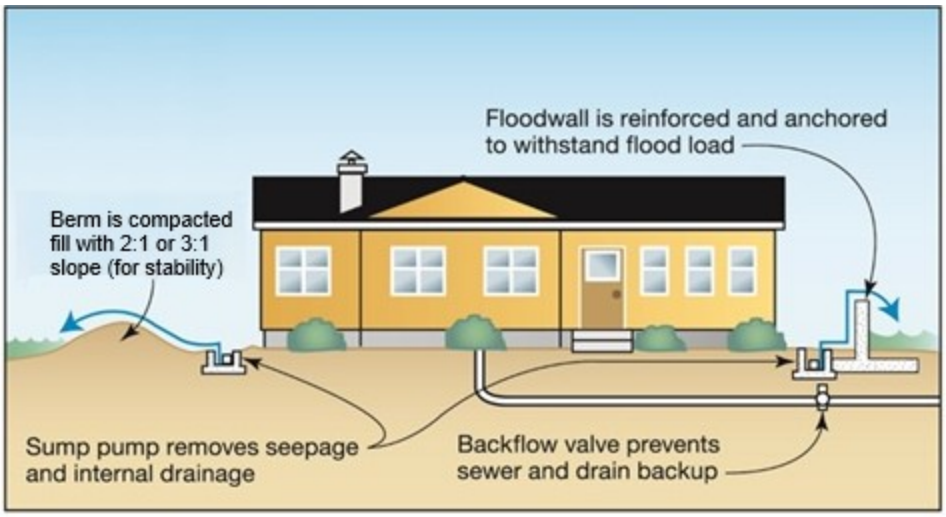


Figure 1-14. Structure protected by a floodwall and flood berm

Warning

While floodwalls are allowed under National Flood Insurance Program regulations and berms are not addressed, floodwalls cannot be used to make an existing structure compliant with National Flood Insurance Program requirements.

Since floodwalls are usually more expensive to build than a berm, floodwalls are usually only used on sites that are too small for flood berms or where flood velocities may erode earthen berms. Some owners may believe that floodwalls are more aesthetically pleasing and allow preservation of site features, such as landscaping and trees. Figure 1-15 shows a building surrounded by a flood berm.



Figure 1-15. Flood berm protecting the residence

A flood berm is typically a compacted earthen structure that blocks floodwaters from a building. To be effective, flood berms must be constructed of impervious soils with adequate side slopes for stability. Flood berms may surround a building or tie-in to high ground at each end.

Flood berms are most effective where predicted flooding is less than five feet. Otherwise, the cost and the land area required for berms usually make them impractical.

Special design considerations must be taken when floodwalls or flood berms are used to protect houses with basements, since berms are susceptible to seepage, which can increase hydrostatic and saturated soil pressure on foundations. Access openings (vehicles, pedestrian gates) must have the ability to be closed in advance of flooding to prevent water entry.

Floodwall and flood berm costs can vary greatly, depending on height, length, availability of construction materials, labor, access closures or over the top access, and the interior drainage system. Flood berm costs can be reduced if proper fill material is available nearby.

Figure 1-16 provides advantages and disadvantages associated with protecting a home with a floodwall or a flood berm.

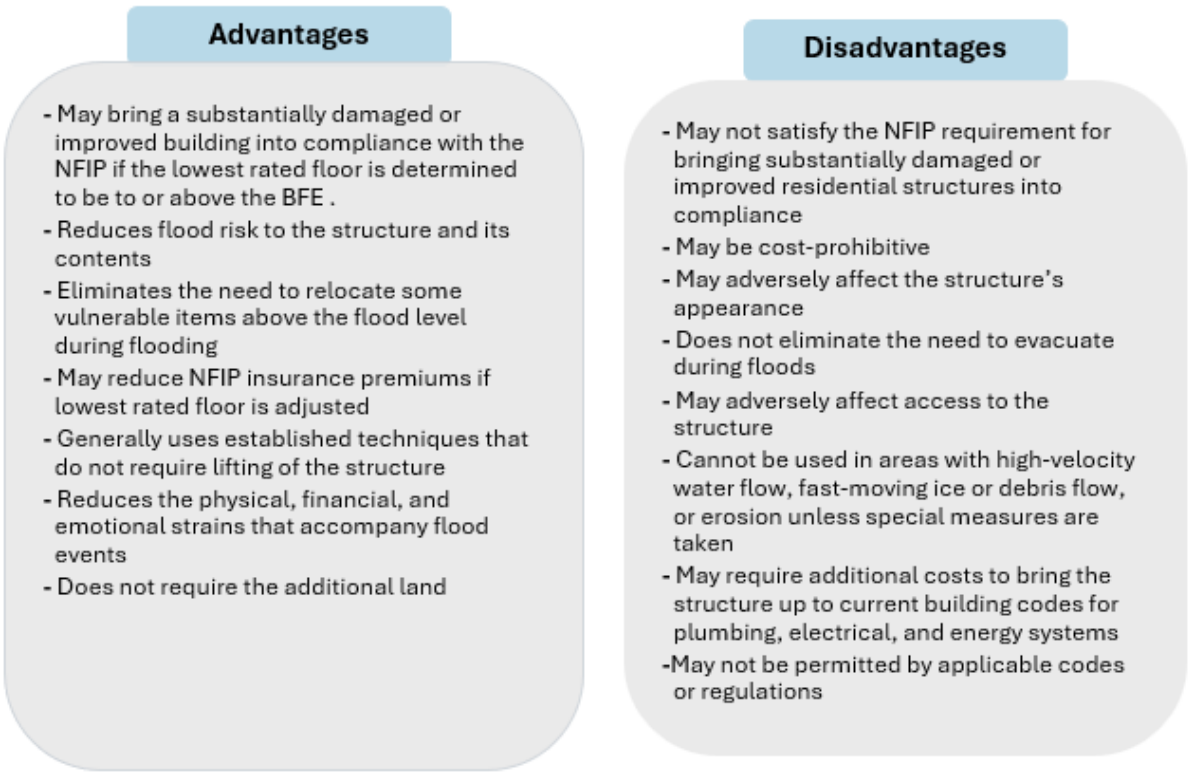


Figure 1-16. Advantages and Disadvantages of Floodwalls and Berms

1.6. Retrofitting Considerations

Appropriately applied retrofitting measures have advantages over other damage reduction methods. Property owners can retrofit without waiting for government action required for larger flood control projects. Retrofitting may provide protection in areas where large structural projects, such as dams or major waterway improvements, are not feasible, warranted, or appropriate. Some general considerations when implementing a retrofitting strategy include:

- Some retrofitting measures applied to substantial damage or improvement projects may be non-compliant with National Flood Insurance Program requirements, local building codes, and floodplain management ordinances.
- Codes, ordinances, and regulations, such as setbacks and wetland protection, must be observed when applicable.
- Retrofitted residences should be evacuated in advance of forecasted flooding. Most retrofitting measures should be designed by experienced design professionals (engineers and architects) and built by seasoned contractors to ensure proper adherence to all applicable codes and standards.
- Most retrofitting measures require routine scheduled maintenance to ensure continued protection of the building to its designed protection level.
- Floods may exceed the design flood elevation provided by retrofitting measures. Owners should maintain adequate flood insurance coverage as added protection.
- If the mitigation measure requires human intervention, a deployment plan is recommended.

1.7. Retrofitting Process

Retrofitting projects should follow a specific site and building evaluation process including risk analysis, consideration of alternatives, detailed design, and construction steps, as shown in Figure 1-17. Successful completion of a retrofitting project will require a series of homeowner coordination and design meetings. Ultimately, the homeowner will be living with the retrofitting measure, so associated residual risks should be addressed by the selected retrofit design.



Note

Within each of these steps, homeowners provide input into the evaluations, analyses, decisions, and design concepts to ensure that the final product meets their concerns and requirements. The property owner is responsible for maintenance of the flood mitigation measures.

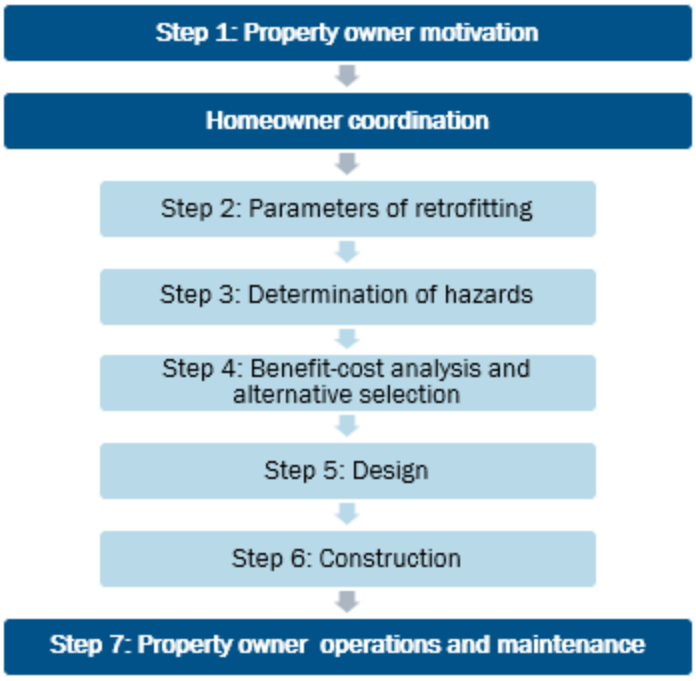


Figure 1-17. Primary steps in retrofitting process

Step 1. Property Owner Motivation: The motivation for retrofitting often follows a house flooding nearby floods. Substantial damage due to a flood or other event, or embarking on a substantial improvement or renovation, may motivate retrofitting for flood resilience to meet local floodplain regulation requirements. Community officials, contractors, or design professionals can provide retrofitting information and technical assistance.

Step 2. Parameters of Retrofitting: Conduct necessary site visits, regulatory reviews, and building evaluations to select applicable and technically feasible retrofitting approaches that merit further analysis.

Step 3. Determination of Hazards: Perform a detailed analysis of flood, flood-related, and other hazards, followed by evaluation of the specific site and building to be retrofitted.

Step 4. Benefit-Cost Analysis and Alternative Selection: Benefit-cost analyses can support ranking of technically feasible retrofitting techniques, combining an objective economic analysis of each retrofitting measure considered with subjective homeowner decision factors.

Step 5. Design: During this phase, specific retrofitting measures are designed, construction details developed, cost estimates prepared, and construction permits obtained.

Step 6. Construction: Upon final design approval, a contractor is selected, and the retrofitting measure is built or installed.

Step 7. Property Owner Operations and Maintenance: The development of a well-conceived operation and maintenance plan is critical to the success of the project.

1.8. Other Retrofitting Resources

When considering retrofitting a structure, it is important to approach the retrofitting method selection and design process with a multi-hazard perspective. Improvements to buildings that are made to increase resistance to the effects of natural hazards should focus on those items that will potentially return the largest benefit to the building owner. If the existing building is considered inadequate to resist natural hazard loads, retrofit improvements should be considered for the following building elements:

- Exterior Stairs, landings, decks, and porches
- Exterior metal (handrails, connectors, etc.)
- Windows and doors
- Foundation
- Exterior equipment
- Roof
- Siding

All relevant natural hazards should be considered to make a fully informed retrofitting plan. An engineer or design professional should be consulted to ensure that a retrofit project for one hazard type will not impede the structure's resistance to other types of natural hazards. Refer to Section 3.2 for details.



Additional Resources

FEMA has several other guidance resources that are free, publicly available, and may be of help to your retrofit project—a comprehensive list of documents and links can be found in Appendix G.

Chapter 2. Regulatory Requirements and Retrofitting Parameters

Most communities identified as floodprone by FEMA adopt and enforce floodplain management ordinances to participate in the National Flood Insurance Program. Local floodplain management ordinances require communities to regulate buildings in Special Flood Hazard Areas. Residential retrofitting projects are regulated by local floodplain and zoning regulations and state and local building codes, which set construction standards for development in flood hazard areas. This includes requirements for new construction and work on existing buildings determined to be substantial improvement or repair of substantial damage. Communities adopt and use Flood Insurance Studies and accompanying Flood Insurance Rate Maps with their floodplain management ordinance, which meet minimum requirements included in Title 44 Code of Federal Regulations (CFR) Section 60.3. In return for local management of floodplains, FEMA accepts communities into the National Flood Insurance Program and makes federal flood insurance coverage available to property owners and tenants.

2.1. Regulatory Requirements

2.1.1. THE NATIONAL FLOOD INSURANCE PROGRAM FLOODPLAIN MANAGEMENT REGULATIONS

During 1968, Congress authorized the National Flood Insurance Program through the National Flood Insurance Act, as amended (Title 42 United States Code [U.S.C.] Section 4001 et seq.), and Title 44 Code of Federal Regulations Sections 59 and 60. A fundamental requirement for participation in the National Flood Insurance Program is that communities that have designated Special Flood Hazard Areas must "[r]equire permits for all proposed construction and other developments including the placement of manufactured homes" [Title 44 Code of Federal Regulations Section 60.3(b)(1)]. National Flood Insurance Program regulations establish the minimum design and construction standards for development in Special Flood Hazard Areas, including new construction and substantial improvements and repair of buildings that incur substantial damage.

Cross Reference

Community and Development - The National Flood Insurance Program regulations are in Title 44 Code of Federal Regulations:

- **Definitions** (Title 44 Code of Federal Regulations Section 59.1): https://www.ecfr.gov/current/title-44/chapter-I/subchapter-B/part-59
- **Criteria for Land Management and Use** (Title 44 Code of Federal Regulations Section 60): https://www.ecfr.gov/current/title-44/chapter-I/subchapter-B/part-60/subpart-A
- **Community:** "[A]ny state or area or political subdivision thereof, or any Indian tribe or authorized Tribal organization, or Alaska Native village or authorized native organization, which has authority to adopt and enforce floodplain management regulations for the areas within its jurisdiction."
- **Development:** "[A]ny man-made change to improved or unimproved real estate, including but not limited to buildings or other structures, mining, dredging, filling, grading, paving, excavation or drilling operations or storage of equipment or materials."

2.1.2. TERMS AND DEFINTIONS USED IN THIS PUBLICATION

Several terms used in this publication are defined in the National Flood Insurance Program regulations, while some are defined in other guidance publications.

Base Flood Elevation: The elevation of the base flood, including wave height, relative to the National Geodetic Vertical Datum (NGVD), North American Vertical Datum (NAVD), or other datum specified on the Flood Insurance Rate Map. The base flood is the flood having a 1% chance of being equaled or exceeded in any given year (commonly called the "100-year flood").

Basement: An area of a building having its floor subgrade (below ground level) on all sides. (Title 44 Code of Federal Regulations Section 59.1)

Buildings: Buildings are identified as follows:

- **Compliant Building:** A building constructed in compliance, and remains in compliance, with a community's current floodplain management requirements for the current flood zone and Base Flood Elevation or flood depth where the building is located.
- **Conforming Building:** A building that was not required to comply with a community's current floodplain management requirements, but it happens to conform to those requirements.
- **Legal Non-conforming Construction:** A structure that complied with floodplain requirements in effect when permitted, but Base Flood Elevations or flood zones have since changed. Although a legal non-conforming structure may have been in compliance at the time it was constructed, it

must come into compliance with current National Flood Insurance regulations or codes when a triggering event occurs, such as substantial improvement or substantial damage.

- **Pre-FIRM building:** refers to buildings for which construction or substantial improvement occurred on or before December 31, 1974, or before the effective date of an initial Flood Insurance Rate Map.

- **Post-FIRM Building**: refers to buildings for which construction or substantial improvement occurred after December 31, 1974, or after the effective date of an initial Flood Insurance Rate Map or December 31, 1974, whichever is later.

- **Substantially Improved/Substantially Damaged Building:** An existing building that has been Substantially Improved or has experienced Substantial Damage.

Enclosed Area or Enclosure: An area below an elevated building that is enclosed by walls on all sides.

Floodway/Regulatory Floodway: means the channel of a river or other watercourse and the adjacent land areas that must be reserved in order to discharge the base flood without cumulatively increasing the water surface elevation more than a designated height (Title 44 Code of Federal Regulations Section 59.1).

Floodway Fringe: The portion of the floodplain situated between the floodway boundary and the natural limits of the floodplain. Development in the floodway fringe is regulated but allowed, provided that buildings are elevated above Base Flood Elevation.

Flood Insurance Study (FIS): An examination, evaluation and determination of flood hazards and, if appropriate, corresponding water surface elevations, or an examination, evaluation and determination of mudslide (i.e., mudflow) and/or flood-related erosion hazards. (Title 44 Code of Federal Regulations Section 59.1)

Flood Insurance Rate Map (FIRM): An official map of a community, on which the Federal Insurance Administrator has delineated both the special hazard areas and the risk premium zones applicable to the community. A Flood Insurance Rate Map that has been made available digitally is called a Digital Flood Insurance Rate Map (DFIRM). (Title 44 Code of Federal Regulations Section 59.1)

Flood Zones: Flood hazard areas identified on Flood Insurance Rate Maps.

Lowest Floor: The lowest floor of the lowest enclosed area (including basement). An unfinished or flood-resistant enclosure, usable solely for parking of vehicles, building access, or storage in an area other than a basement, is not considered a building's lowest floor, provided that such enclosure is not built so that the structure is in violation of the applicable non-elevation design requirements in Title 44 Code of Federal Regulations Section 60.3.

New Construction: For floodplain management purposes, new construction means structures for which the start of construction commenced on or after the effective date of a floodplain

management regulation adopted by a community and includes any subsequent improvements to such structures. (Title 44 Code of Federal Regulations Section 59.1).

Special Flood Hazard Area: The land area determined to be subject to flooding by the base flood, which is the flood that has a 1% chance of being equaled or exceeded in any given year (commonly called the 100-year flood). Special Flood Hazard Areas are identified as Zone A (A, AE, A1-30, AH, AO, A99, and AR) and Zone V (V, VE, V1-30, and VO) on Flood Insurance Rate Maps prepared by FEMA.

Substantial Damage: Damage of any origin sustained by a structure whereby the cost of restoring the structure to its pre-damaged condition would equal or exceed 50% of the market value of the structure before the damage occurred.

Substantial Improvement: Any reconstruction, rehabilitation, addition, or other improvement of a structure, the cost of which equals or exceeds 50% of the market value of the structure before the "start of construction" of the improvement. This term includes structures that have incurred "substantial damage," regardless of the actual repair work performed. The term does not, however, include either:

1. Any project for improvement of a structure to correct existing violations of state or local health, sanitary, or safety code specifications which have been identified by the local code enforcement official and are the minimum necessary to assure safe living conditions, or
2. Any alteration of a "historic structure," provided that the alteration will not preclude the structure's continued designation as a "historic structure."

Floodplain Management Regulations

The National Flood Insurance Program regulations establish criteria for land management and use that communities must adopt and enforce to be eligible to participate in the National Flood Insurance Program. The criteria specify how new construction and existing buildings that are substantially improved or sustain substantial damage by any cause must be constructed to minimize future flood damage. Table 2-1 summarizes the key requirements for residential buildings in Zone A/AE.

Table 2-1. Summary of Key National Flood Insurance Program Requirements for Residential Buildings in Zone A/AE

National Flood Insurance Program Regulation	Requirement
Design and Construction Title 44 CFR Section 60.3(a)(3)(i)	Buildings and foundations must be designed, constructed, and adequately anchored to prevent flotation, collapse, and lateral movement resulting from hydrodynamic and hydrostatic loads, including the effects of buoyancy.
Lowest Floor Elevation Title 44 CFR Section 60.3(c)(2)	Top of the lowest floor must be at or above Base Flood Elevation.
Flood Damage-Resistant Materials Title 44 CFR Section 60.3(a)(3)(ii)	Structural and nonstructural building materials below the Base Flood Elevation must be flood damage-resistant materials.
Enclosures below elevated buildings Title 44 CFR Section 60.3(c)(5)	Use of fully enclosed areas below elevated buildings is restricted to parking of vehicles, building access, and storage. Enclosure walls must have a minimum of two flood openings and adequate flood opening area to allow for the automatic inflow and outflow of floodwater.
Utility systems and equipment Title 44 CFR Section 60.3(a)(3)(iv)	Utility system components and equipment must be located (elevated) at or above the Base Flood Elevation or designed to prevent water from entering and accumulating in components during flooding.

Substantial Improvement and Substantial Damage

Local officials are responsible for determining whether proposed improvements for buildings in Special Flood Hazard Areas are substantial improvements and whether buildings in Special Flood Hazard Areas that are damaged by any cause have incurred substantial damage. When work proposed for existing buildings and legal non-conforming buildings is determined to constitute substantial improvement or repair of substantial damage, then property owners must bring the buildings into compliance with local and state regulations and building codes.

Local officials must carefully review proposals to use the retrofitting measures described in this publication that involve modifications to residential buildings:

- **Elevation:** Substantial improvement determinations are not necessary for proposals to elevate homes because the cost of elevation typically exceeds 50% of the pre-event market value of the structure, and the objective is compliance with the requirements for new construction and Substantial Improvement/Substantial Damage.

- **Relocation:** Substantial improvement determinations are not necessary for homes proposed for relocation within Special Flood Hazard Areas because cost of elevation typically exceeds 50%of the pre-event market value of the structure, and the end National Flood Insurance Program compliance to the new site is required, and floodplain management requirements do not apply to homes that are relocated to sites outside of regulated floodplains.

- **Dry Floodproof:** Substantial improvement determinations **must** be made for these projects. Retrofit using dry floodproofing measures is not permitted when National Flood Insurance Program compliance is required and work is determined to meet the definition of substantial improvement.

- **Wet Floodproof:** Substantial improvement determinations **must** be made for these projects. Retrofit using wet floodproofing measures is not permitted when National Flood Insurance Program compliance is required and work is determined to meet the definition of substantial improvement.

Local officials must consider multiple factors and may encounter many scenarios while administering Substantial Improvement/Substantial Damage requirements.



Cross Reference

FEMA P-758, The *Substantial Improvement/Substantial Damage Desk Reference* (2010), is a publication that describes types of improvements, illustrates how compliance can be achieved, and outlines suggested procedures to implement regulatory requirements.

2.2. National Flood Insurance Program Flood Hazard Mapping Information

Communities that participate in the National Flood Insurance Program adopt the minimum requirements of the National Flood Insurance Program based on the level of flood hazard information provided by FEMA or other requirements that exceed the National Flood Insurance Program minimum requirements. The National Flood Insurance Program uses the base flood to delineate Special Flood Hazard Areas on Flood Insurance Rate Maps. The base flood is the flood level that has a 1% chance of being equaled or exceeded in any given year. Base Flood Elevations are determined relative to a datum when engineering analyses are performed.

Communities adopt Flood Insurance Studies and Flood Insurance Rate Maps to administer their regulations using mapped Special Flood Hazard Areas and Base Flood Elevations, where identified, to regulate development. It is important for owners and designers to know the Base Flood Elevation or estimate the flood depth where Base Flood Elevations are not identified, when buildings are required to comply or be brought into National Flood Insurance Program compliance. When compliance is not required, the flood level or depth selected for consideration of retrofit measures is

determined by several factors, such as the owner's desired level of protection, the type of measure selected, feasibility, and other factors.

Warning

Flood Insurance Studies and Flood Insurance Rate Maps are developed using the best available information. Many studies and maps are more than 10 years old and may not reflect current conditions. Flood Insurance Rate Maps do not delineate all areas subject to flooding (e.g., urban flooding or local drainage problems), nor are areas subject to future flood risk or repetitive flooding identified. State, local, territorial, and Tribal governments or communities that believe their effective Flood Insurance Studies and Flood Insurance Rate Maps no longer adequately reflect their flood hazards should request the state agency that facilitates flood mapping to coordinate with FEMA to prioritize and initiate a Flood Insurance Study/Flood Insurance Rate Map update.

2.2.1. FLOOD INSURANCE STUDY

The Flood Insurance Study is a compilation and presentation of information prepared by FEMA that provides background on the flood mapping methodology and includes detailed information on the community's hydrology and hydraulics. The Flood Insurance Study provides a community's flood history and sources of flooding. Where engineering analyses are prepared, Flood Insurance Studies show discharges, or flow rates, and flood profiles for riverine floodplains.

Additional Resources

- Flood Insurance Studies can be viewed online at the FEMA Map Service Center, https://msc.fema.gov/portal/home.
- For instructions on using a Flood Insurance Study, view the Flood Insurance Study tutorial at https://www.fema.gov/sites/default/files/2020-07/how-to-read-flood-insurance-study-tutorial.txt.

The Flood Insurance Study for communities with riverine floodplains describes how the flood hazard information was developed for watercourses studied using detailed methods, including floodways, discharges, velocities, and flood profiles that show water surface elevations for different flood frequencies along watercourses. Figure 2-1 shows a typical riverine floodplain cross-section, including the floodway and floodway fringe. Where approximate methods were used, those methods are described in the Flood Insurance Study. Special Flood Hazard Areas delineated based on approximate methods do not have Base Flood Elevations.

FEMA develops floodway modeling using detailed methods to simulate encroachment on both sides of the studied watercourses, delineating the floodway boundary based on predetermined increases

in water surface elevations along a reach. The floodway is the channel and adjacent land areas that must be reserved to pass the base flood without cumulatively increasing the water surface more than a designated height. In practice, this means proposed encroachments in the floodway are prohibited unless applicants submit engineering analyses that demonstrate the encroachments will not cause any increase in flood levels during a base flood.

Where FEMA has provided Base Flood Elevations but has not delineated floodways, engineering analyses must demonstrate that the cumulative effect of a proposed encroachment, when combined with all other existing or proposed encroachments, will not increase the Base Flood Elevation more than one foot at any point within the community. Many states and communities limit the allowable increase to less than one foot.

Figure 2-1 shows a "floodway fringe", the area between the floodway boundary and the landward boundary of the Special Flood Hazard Area. The floodway fringe encompasses the portion of the floodplain that could be completely obstructed without the submission of engineering analyses.

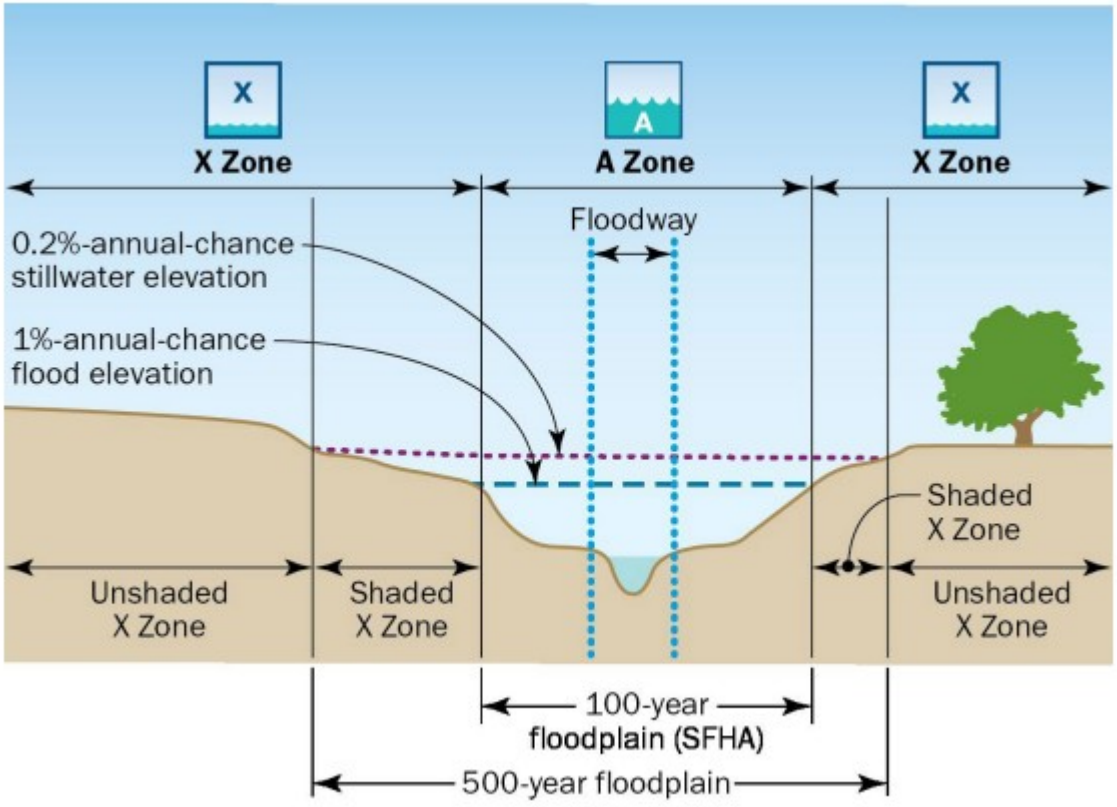


Figure 2-1. Typical riverine floodplain cross-section. (FEMA P-2345)

2.2.2. FLOOD INSURANCE RATE MAP

A Flood Insurance Rate Map is the official flood map of a community on which floodplains are delineated with the applicable zones. The flood risk data used to prepare Flood Insurance Rate Maps is summarized in Flood Insurance Studies.

Flood Insurance Rate Maps depict Special Flood Hazard Areas determined using various methods of study and analysis, including historic, meteorological, hydrologic, and hydraulic data.

Additional Resources

- Flood Insurance Rate Maps can be viewed in community offices, as part of state or local GIS mapping functions, and online at the FEMA Map Service Center, https://msc.fema.gov/portal/home, where users can make FIRMettes (full-scale portions of Flood Insurance Rate Maps).
- For instruction on reading Flood Insurance Rate Maps, see https://www.fema.gov/sites/default/files/documents/how-to-read-flood-insurance-rate-map-tutorial.pdf.

Flood zones shown on Flood Insurance Rate Maps indicate the level of data used to develop hazard information and may indicate the severity or type of flooding. Figure 2-2 illustrates how zones are illustrated and designated on digital Flood Insurance Rate Maps, and Figure 2-3 details typical zone delineation for riverine flooding.

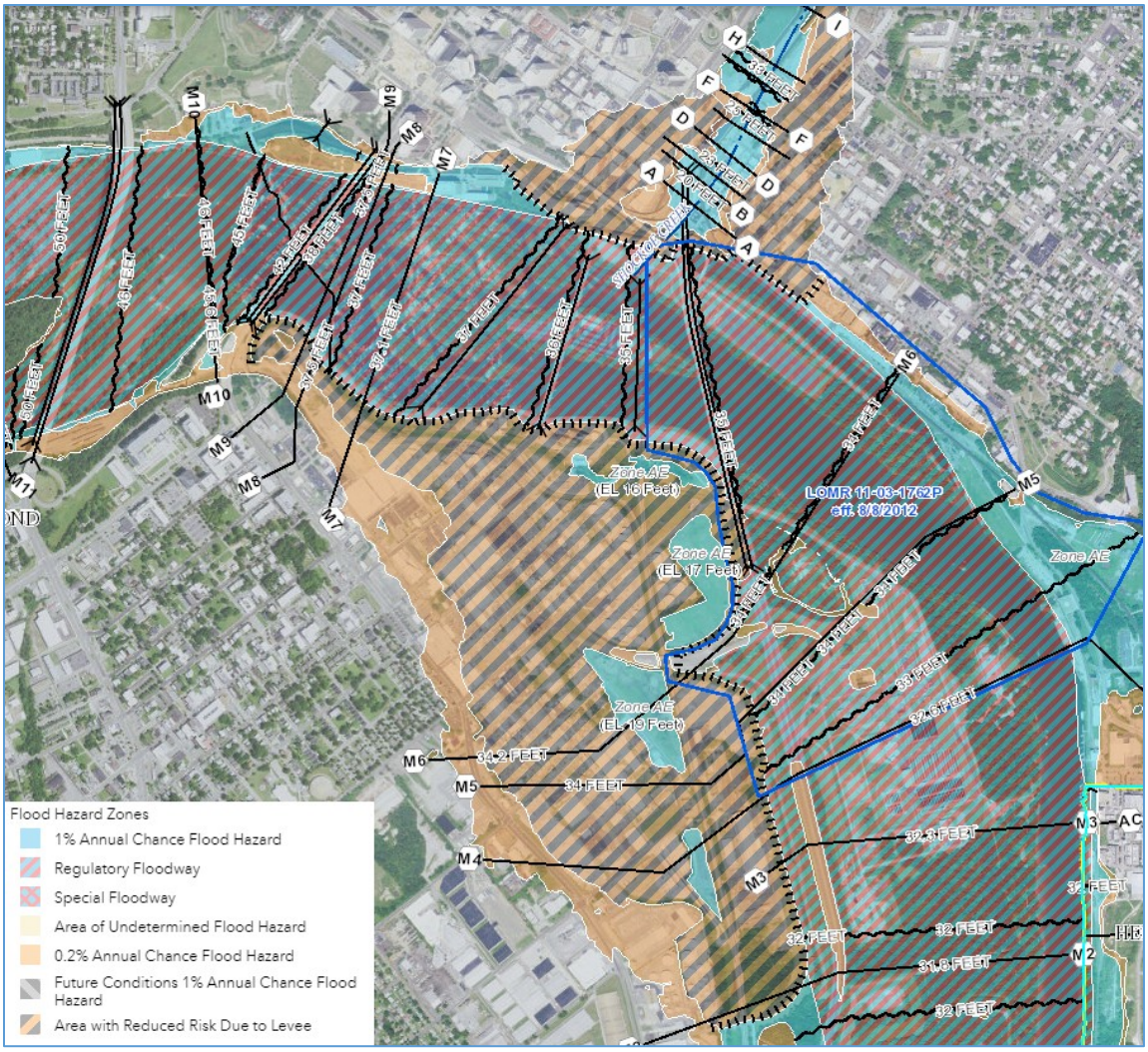


Figure 2-2. Typical Riverine Digital Flood Insurance Rate Map (DFIRM)

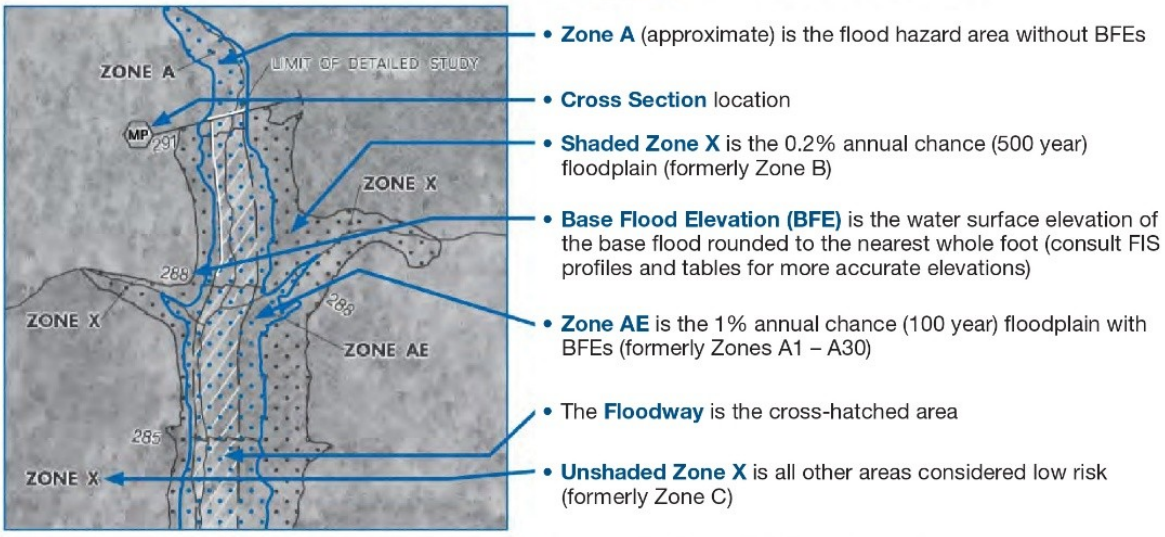


Figure 2-3. Typical zone delineation for riverine flooding

2.3. Case Study Introduction

This publication features case studies to present structural and various retrofitting scenarios. These examples illustrate many of the procedures discussed throughout the chapters as well as the actual design practices. Three case study scenarios will be evaluated: two scenarios will be interspersed throughout the main publication, with supporting calculations in Appendices A and B, and one full case study is in Appendix C. A brief overview of the retrofit methods illustrated in the case studies is provided in Table 2-2.

Table 2-2. Case Study Summary

Case Study	Retrofit Measures	Location Within This Document
A	Relocation or Elevation	Chapters 2, 3, 4, 5, 7, and Appendix A
B	Floodwall or Dry Floodproofing	Chapters 2, 3, 4, 6, 7, and Appendix B
C	Alternative Elevation or Wet Floodproofing	Appendix C

The case studies are fictionalized scenarios developed to illustrate retrofit option selection and the design process. Narratives, graphics, photos, and calculations are fabricated and not based on actual owners, designers, contractors, or structures. While fictionalized, each case study represents real circumstances commonly encountered in areas vulnerable to flood damage.



Case Study A - Introduction: Residential Retrofit in Riverine Floodplain Using Relocation or Elevation

Case Study A (CSA) introduces the retrofit of a residential building in a riverine floodplain through relocation or elevation. Details are provided in the paragraphs that follow.

Description Of Property

John and Jane Doe

55 Cedar River Road, Mount Vernon, IA 52314

The Doe family has owned a large plot of land near Mount Vernon, Iowa, since the early twentieth century. The 4-acre plot slopes up from the Cedar River to a hill with mostly grass. Their current home, a one-story, wood-frame structure, built in the 1960s, is located at 55 Cedar River Road, north of the Highway 1 bridge crossing the Cedar River. The home was constructed before a Flood Insurance Rate Map existed. It has experienced varying levels of flooding from the Cedar River since its construction. A detached saferoom (10 feet x 10 feet) was added close to the back of the structure in 2005, allowing for quick access while remaining structurally independent. The house is in the Special Flood Hazard Area (100-year floodplain), but due to the sloping nature of the site, most of the rest of the parcel – including the safe room – is located outside the Special Flood Hazard Area.

John and Jane Doe, the current owners, have decided that they would like to retrofit their home to resist flood damage. The local floodplain ordinance does not allow elevation on fill, and they do not like the idea of an open foundation. Mr. and Mrs. Doe indicated they would like to pursue retrofitting options that could allow them to obtain a reduced National Flood Insurance Program flood insurance premium, if possible.

Structure Information

The home is a one-story, wood-frame structure built over a crawlspace classified as a Flood Design Class 2 structure per ASCE 24. The structure appears to be in serviceable condition with no apparent or known major structural defects. Figure CSA-1 shows the front elevation and floor plan. The building has a wood-framed floor system supported by perimeter foundation walls and a system of interior wood beams and concrete masonry unit (CMU) piers. It has a total footprint of approximately 1,600 square feet.

The foundation consists of 8-inch-thick grouted CMU perimeter walls, which are supported by 2-foot-wide by 1-foot-thick reinforced concrete footers. Within the crawlspace, there are twelve grouted CMU piers, spaced approximately 10 feet apart and each supported by footers measuring 2 feet by 2 feet by 1 foot thick. The perimeter walls and interior piers extend 3 feet below grade to the top of their respective footers. The ground level within the crawlspace is flush with the exterior grade. While the perimeter foundation walls do not include flood openings, crawlspace ventilation is provided through standard vent openings.

The structure features a first level finished floor elevation of 694.2 feet and a ground elevation at the crawlspace of 692.2 feet, both referenced to vertical datum NAVD 88. The building envelope consists of a traditional wood-frame with wood siding. The roof system includes a gable roof without overhangs over the main portion of the house, which spans a 40-foot by 40-foot area, finished with asphalt shingles.

Internally, the home is constructed with wood stud interior walls, sheathed in gypsum board, and features hardwood flooring throughout the interior.

Site

The 4-acre plot's lowest elevation is 690 feet near the river, sloping upward to an elevation of 730 feet. The site soils are primarily a mixture of silty sand (Soil Type SM).

Refer to the Doe house tax card in Appendix A for additional information regarding the site and assessed building value.

Flood Hazard Data

The local floodplain management ordinance regulates all proposed development in the floodplain. Elevation on fill is prohibited, and a 2-foot freeboard is required for all new construction and substantial improvements. The structure is located near the low point of the property and is in the Special Flood Hazard Area, although most of the parcel is outside of the regulatory floodplain. The flood map (FIRMette) is included in Section 2.2.5. The Flood Insurance Study lists the flood elevations and discharges for the existing structure, as shown in Figure CSA-2 and summarized in Table CSA-1.

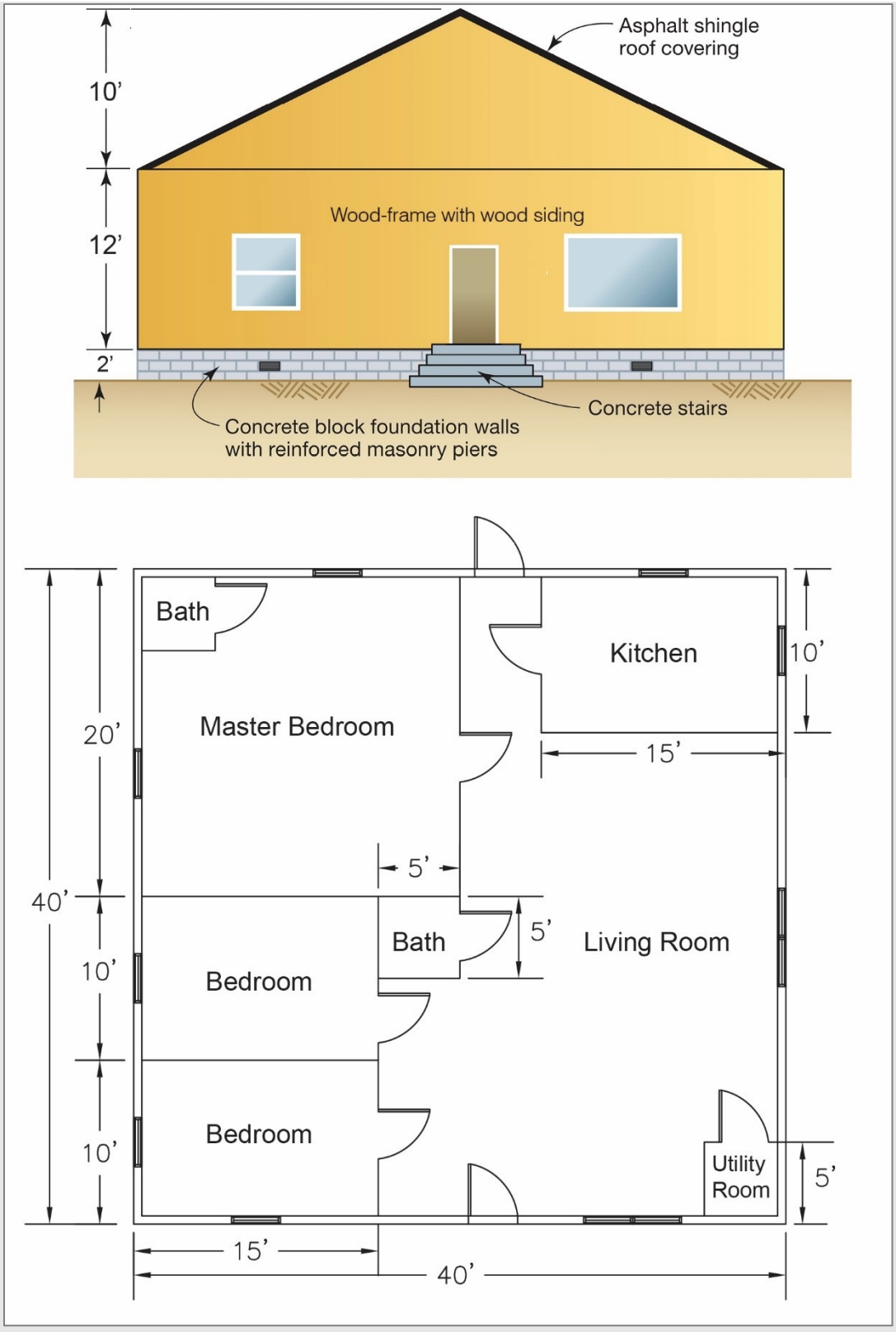


Figure CSA-1. The Doe house front elevation and floor plan

Table 9: Summary of Discharges (continued)

Flooding Source	Location	Drainage Area (Square Miles)	Peak Discharge (cfs)					
			10% Annual Chance	4% Annual Chance	2% Annual Chance	1% Annual Chance	1% Plus Annual Chance	0.2% Annual Chance
Buffalo Creek	In northeast quarter of Section 4, T86N, R6W	188.0	8,235	*	13,705	16,320	*	23,090
Buffalo Creek	Just above south section line of Section 19, T86N, R6W	171.0	7,870	*	13,145	15,680	*	22,250
Buffalo Creek	In northwest quarter of Section 11, T86N, R6W	151.0	7,415	*	12,450	14,880	*	21,195
Buffalo Creek	Just above unnamed tributary in northeast quarter of Section 4, T86N, R6W	142.0	7,200	*	12,120	14,500	*	20,690
Cedar River	At south county boundary	6,997.0	53,800	*	78,000	88,000	*	113,000
Cedar River	At State Highway 1 bridge	6,974.0	53,500	*	77,900	87,900	*	112,900
Cedar River	Just upstream of confluence with Big Creek	6,844.0	53,200	*	77,700	87,700	*	112,700
Cedar River	Just upstream of confluence with Morgan Creek	6,510.0	53,500	*	78,100	88,100	*	113,100
Cedar River	At gaging station in Cedar Rapids at 7th Avenue SW	6,458.0	53,000	*	77,000	87,000	*	112,000
Cedar River	Just upstream of confluence of Otter Creek	6,381.0	53,700	*	78,400	88,400	*	113,400
Cedar River	Just upstream of confluence of Opossum Creek	6,243.0	53,800	*	78,500	88,600	*	113,600
Dry Creek at Cedar	Confluence with Cedar River	27.0	3,090	4,550	5,510	6,450	7,888	8,940

Figure CSA-2. Flood Insurance Study Excerpt: Discharge table for the Doe house location (applicable discharges boxed in red) obtained from Table 9, Volume 1, FEMA Flood Insurance Study, Linn County, Iowa

Table CSA-1. Summary of Flood Elevations and Discharges for the Doe House

	Streambed	10-year	50-year	100-year	500-year
Elevation (ft)	671.2	695	696.3	697.8	699.8
Peak Discharge (cfs)	NA	53,500	77,900	87,900	112,900

cfs = cubic feet per second
Note: All topographic maps and flood hazard data reference NAVD88.
Sources: msc.fema.gov, County: Linn, Parcel: 19113C0465E) and FilRMette (Refer to Figure CSA-7 and Figure CSA-8)

In this example, the top of the crawlspace floor is equivalent to the lowest adjacent grade. The flow velocity under base flood conditions is 2.0 feet/second based on data extrapolated from the Flood Insurance Study. In this case, a 2.0 foot/second flow velocity is considered reasonable, but it may not be in all situations.

Special Note

The flow velocity during flood conditions may be difficult to obtain without additional assistance. An engineer can assist in gathering this information. Additionally, the following resources may also be helpful for estimating the design flood velocity:

- Appendix D of FEMA P-2345, *Building Designer's Guide to Calculating Flood Loads Using ASCE 7-22 Supplement 2*, Second Issuance, April 2024.
- Appendix C of FEMA P-85, *Protecting Manufactured Homes from Floods and Other Hazards*, Second Edition, November 2009.

Case Study B - Introduction: Residential Retrofit Outside of the Floodplain Using Floodwalls or Dry Floodproofing

Case Study B (CSB) introduces the retrofit of a multi-family residential building outside the floodplain using floodwalls or dry floodproofing. Details are provided in the paragraphs that follow.

Description Of Property

John Smith

The Valley Apartments

2908 Valley Drive

Mesa, Arizona, 85203

The Valley Apartments is a two-story masonry building that is 50 feet wide and 100 feet long, constructed in 1985 (Figure CSB-1). It has 10,000 square feet of mixed-use space. The first floor is used for meeting rooms, laundry, and offices, and the second floor is dedicated to apartments. The lot is relatively flat with grades that slope gradually away from the building. The site is located outside of a mapped flood hazard area. The soil type is a poorly draining silty clay with low permeability (Soil Type SM-SP).

A 3-foot-tall brick masonry fence encloses the lot. Access to the site is through wrought iron gates at the driveway and a walkway that leads to the front entrance.



Figure CSB-1. Front elevation of The Valley Apartments

John Smith acquired the property in 2005 for $1.5 million. The building had been well-maintained but had flooded periodically. Flood damage was limited to interior finishes and some electrical and mechanical system components, but repairs required occupants to temporarily vacate the building, which necessitated securing temporary housing. Recently, flooding has become more frequent and more severe. The causes of the more frequent and intense flooding are not known, but changing hydrology, more intense rainfall events, and saturated soils resulting from frequent, heavy rainfall are believed to be the primary causes. Floods usually dissipate within a few hours. The most extreme flooding event led to two feet of water in the building.

Mr. Smith would like to reduce flood risks, provide greater protection for the building, and reduce the disruptions to the building occupants.

Structure Information

The Valley Apartments is constructed with 8-inch-thick partially reinforced CMU walls supported by concrete footings. The building has a stucco exterior finish. The second level floors, ceilings, and the roof structure are wood-framed. The first floor is constructed with a concrete slab, which is believed to be unreinforced. The top of the footings are one foot below grade and

determined to be 2.5 feet wide and one foot thick. The interior bearing walls are expected to be supported by 2-foot-wide by 1-foot-thick footings. No structural drawings exist for the building.

Flood Hazard Data

The Valley Apartments building has no single source of flooding, and floodwater can inundate the building from any direction. The maximum expected rainfall intensity for that location is approximately one inch per hour. Since 2005, Mr. Smith has recorded the following damage as shown in Table CSB-1.

Table CSB-1. Summary of Damage for The Valley Apartments

Damage Year	Flood Depth (in.)	Damage (2025 Dollars)
2006	6	$46,000
2008	10	$83,000
2014	8	$235,000
2020	24	$370,000

2.4. Model Building Codes and Referenced Standards

2.4.1. MODEL BUILDING CODES

The International Codes (I-Codes), published by the International Code Council, are a family of model codes that includes the International Building Code® (IBC), International Residential Code® (IRC), International Existing Building Code® (IEBC), and numerous codes that govern the installation of mechanical, plumbing, fuel gas, and other aspects of building design and construction. The flood provisions in the I-Codes are specified in the referenced standard ASCE 24, *Flood Resistant Design and Construction* (ASCE 24). FEMA has supported development of the model building code and has determined that the latest published editions of the I-Codes meet or exceed National Flood Insurance Program requirements for buildings and structures.

The National Fire Protection Association's (NFPA) NFPA- 5000, *Building Construction and Safety Code,* is another model code that includes flood provisions by reference to ASCE 24. In addition, the plumbing and mechanical codes published by the International Association of Plumbing and Mechanical Officials include requirements for installations in flood hazard areas.

Many states adopt building codes based on the model I-Codes and require community code enforcement. States often amend the I-Codes, including the flood provisions. Some communities adopt building codes at the local level and may amend the model codes. National Flood Insurance Program participating communities are required to enforce National Flood Insurance Program

requirements through their floodplain management ordinances, and/or flood-related provisions within their adopted building codes and standards.

Additional Resource

Excerpts of the flood provisions of the I–Codes and *Highlights of ASCE 24* are available on the FEMA Building Science webpage at https://www.fema.gov/emergency-managers/risk-management/building-science/building-codes.

2.4.2. CONSENSUS STANDARDS

Numerous technical standards related to design and construction practices and construction materials are typically incorporated by reference into building codes and regulations. The requirements in the referenced standards are part of the code or regulation that references the standards. Referenced standards are technical specifications that are often developed through a consensus process by standards-setting organizations. The process involves committees of nationally recognized experts who follow a prescribed consensus standards process.

Consensus standards that are referenced for flood-resistant design and construction include:

American Concrete Institute (ACI)

- **ACI 318,** *Building Code Requirements for Structural Concrete and Commentary*. This standard provides requirements for the materials, design, and detailing of structural concrete buildings and non-building structures. ACI 318 is a referenced standard in the International Building Code, International Residential Code, and NFPA 5000.

- **ACI 562,** *Assessment, Repair, and Rehabilitation of Existing Concrete Structures—Code Requirements.* This standard provides uniform requirements aimed at extending the service life of existing structures, covering aspects of concrete repair. ACI 562 is a reference standard in the International Existing Building Code and NFPA 5000.

American Society of Civil Engineers/Structural Engineering Institute (ASCE/SEI)

- **ASCE/SEI 7,** *Minimum Design Loads and Associated Criteria for Buildings and Other Structures*. This standard provides requirements for dead, live, soil, flood, wind, snow, rain, ice, seismic and other loads and load combinations. ASCE 7 is a referenced standard in the International Building Code, International Residential Code, International Existing Building Code, and NFPA 5000.

- **ASCE/SEI 24**, *Flood-Resistant Design and Construction*. This standard provides minimum requirements for flood-resistant design and construction. ASCE 24 is a referenced standard in the International Building Code, International Residential Code, and NFPA 5000. ASCE 24 specifies minimum requirements for flood-resistant design and construction of structures located

in flood hazard areas. The basic design requirements that are addressed in ASCE 24 include flood loads, load combinations, elevation of lowest floors, foundation requirements, materials, wet and dry floodproofing, utility installation, building access, among others. In addition, ASCE 24 includes specifications for the design of a perimeter wall, pile, column, and shear wall foundations.

Note

ASCE building standards are typically updated on a six-year cycle. This publication uses the 2022 edition of ASCE 7 (ASCE 7-22) and the 2014 edition of ASCE 24 (ASCE 24-14); which are referenced by the 2024 editions of International Building Code and the International Residential Code.

ASCE 7-22 Supplement 2 (ASCE 7-22 S2) published in May 2023 revises Chapter 5 Flood Loads, and those revisions align with the 2024 edition of ASCE 24 (ASCE 24-24). However, neither ASCE 7-22 S2 nor ASCE 24-24 are referenced in the 2024 International Building Code of 2024 International Residential Code. A proposal to include ASCE 7-22 S2 in the 2027 I-Codes has been submitted.

Refer to Appendix D for additional guidance on the latest flood design practices reflected in ASCE 7-22 S2 and ASCE 24-24.

2.5. Community Regulations and Permits

Before committing a significant investment of time and money to identify, plan, and design retrofit measures, property owners and their design professionals should contact local permitting officials who regulate development and building construction. Examining local codes and ordinances, and consultation with local officials, will identify specific compliance requirements.

State and local floodplain management requirements that are more restrictive or stringent than the minimum requirements of the National Flood Insurance Program take precedence. This publication and other FEMA publications provide guidance on minimum National Flood Insurance Program requirements and describe best practices. Design professionals, builders, and property owners should contact local officials to determine whether more restrictive provisions apply to buildings and sites. All other applicable federal, state, or local government requirements, including building codes, areas governed by the Coastal Barrier Resources Act, environmental, historic, and other regulations, may be required.

Common higher standards pertinent to work on existing buildings and the mitigation measures described in this publication include:

- Freeboard, or additional elevation above the Base Flood Elevation, which is the minimum required by the National Flood Insurance Program. Freeboard adds an additional layer of protection above the Base Flood Elevation that can extend further than the horizontal Special

Flood Hazard Area boundary of Flood Insurance Rate Maps to provide protection from wave action, downstream restrictions like undersized culverts or bridge openings, impervious pavement in the upstream watershed, and increased flood intensity and frequency.

- Limitations on enclosures below elevated buildings, including prohibiting enclosures, limiting the size of enclosures, and requiring non-conversion agreements for enclosures. In general, communities impose enclosure limits to reduce the likelihood that owners might illegally convert the enclosed areas to uses other than permitted only for parking, storage, and building access.

- Restrictive standards prohibiting development in certain areas, such as conservation zones, setbacks from waterways, or floodways. These restrictions could limit the use of floodwalls and levees. Communities may use these restrictions to guide where relocated buildings are sited. There may also be restrictions placed on using certain building materials and practices that have previously proven ineffective during flooding.

- Some communities require that structures undergoing significant work (meeting the substantial improvement threshold) be brought into compliance with some requirements in current building codes. These might include the addition of smoke detectors, sprinklers, removal of lead paint and water pipes, or upgrades in electrical wiring.

2.6. Retrofitting Parameters

2.6.1. DETERMINATION OF HOMEOWNER PREFERENCE PARAMETERS

Proper evaluation of retrofitting parameters will require a series of homeowner coordination and design input meetings. Ultimately, the homeowner will know their property flood risk, so the flood mitigation retrofit should be developed collaboratively by the property owner and the designer. The functional and cosmetic aspects of each proposed retrofitting measure, such as access, egress, landscaping, and appearance, should be fully examined. Most retrofitting measures are permanent; construction is complex, and it is like a major home addition or renovation.

Project elements to address:

- Post-retrofit building aesthetics
- Project cost
- Flood risk
- Accessibility
- Local code requirements
- Substantial damage/substantial improvement
- Building mechanical/electrical/plumbing upgrades
- Off-site flooding impacts
- Multi-hazard retrofits like safe rooms, storm shelters, or wildfire hardening

The Preliminary Floodproofing/Retrofitting Preference Matrix (Figure 2-4) assists the designer in documenting the initial consultation with the property owner. Evaluation of local government regulations (Part A: Local Regulations) determines what is permissible, so the designer can eliminate some options from further consideration. Discussion of the considerations for the remaining measures should lead to a “no” or “yes” for each of the boxes (Figure 2-4 Instructions will assist completion of the preliminary homeowner evaluation.) Analysis of the responses will help the homeowner and designer select viable, homeowner-preferred retrofitting measures for further examination. If a “no” or “yes” cannot be determined, then more research may be required. Conservative assumptions should be made when appropriate and later revisited to keep the process moving forward.

Preliminary Homeowner Retrofitting Preference Matrix											
Owner Name:								**Preparer:**			
Address:								**Date:**			
Property Details:											
Considerations	**Retrofitting Measures**										
	Structural Elevation			**Elevation Alternatives**			**Relocation**	**Floodproofing**		**Flood Barriers**	
	Stem Wall (Fill)	**Perimeter Wall/ Piers**	**Piles**	**Basement Infill**	**Abandon/ Repurpose Lowest Floor**	**Elevate Lowest Interior Floor**		**Dry**	**Wet**	**Floodwall**	**Berm**
PART A: Local Regulations											
Measure Not Feasible (NF) or Not Allowed											
PART B: Homeowner Concerns											
Aesthetics											
High Cost											
Risk - Flood Insurance Rates											
Accessibility											
Increase Flooding on Neighboring Sites											
Other:											
Total X's ***(Lowest is Preferred)***											
Purpose:	The purpose of the Preliminary Homeowner Retrofitting Preference Matrix is to determine whether or not the retrofitting measure is allowed under local regulations or homeowner requirements.										
Instructions:	Step 1: Complete Part A of the matrix by placing an "X" in the box for each measure which is not feasible or is not allowed based on the configuration of the existing structure and/or property. For these measures, skip Steps 2 through 5 and put an "NF" for Not Feasible under the Total X's at the end of Part B. Step 2: Complete Part B of the matrix for only those measures that are allowable (no "X" in Part A). Step 3: For those measures allowed under Part A, evaluate the considerations in Part B to determine if the homeowner has concerns that would affect its implementation. A concern is defined as a homeowner issue that, if unresolved, could make the retrofitting measure infeasible. Step 4: If the homeowner has a concern, place an "X" in the box under the appropriate measure/consideration. Step 5: Add up the total number of X's for each allowable measure, and input the result under the Total X's at the end of Part B.										
Evaluation of Results:	The retrofitting measure(s) with the least number of X's (and no NF's) is the most preferred.										

Figure 2-4. Preliminary Homeowner Retrofitting Preference Matrix

2.6.2. INITIAL HOMEOWNER MEETING

The first step in the homeowner coordination effort is an educational process for both the designer and the property owner.

The homeowner learns:

- Flood risk for the site and building

- Potential flood impacts
- Potential retrofit benefits to lower annual flood insurance premiums
- Project risk and cost considerations
- What to expect during each retrofitting process step

The designer learns:

- Date of building construction and date of any additions or renovations
- Flood history of the structure
- Homeowner preferences
- Homeowner budget constraints, building accessibility requirements
- Information about the property, such as:
  - Soil type
  - Topography
  - Drainage
  - Accessory buildings and fencing
  - Trees, vegetation, landscaping
  - Utilities
  - Construction access
  - Building and lot dimensions/setbacks

During the first meeting, the homeowner and designer should walk through the building and lot to determine the condition of the building and its flood vulnerability. The lowest floor and the elevation of openings throughout the building where floodwater can enter should be determined during the site visit.



Note

Review of information obtained during the first homeowner-designer meeting will help determine the flood hazard to the building and property and vulnerability to floodwater intrusion.

2.6.3. INITIAL SITE VISIT

A low point of entry determination, illustrated in Figure 2-5, identifies the elevation of the lowest floor and each of the structure's openings and should include:

- Lowest floor or basement slab
- Windows, doors, and vents
- Mechanical/electrical equipment, including venting
- Drains and floor penetrations
- Water faucets, sump pump discharges, and other wall penetrations

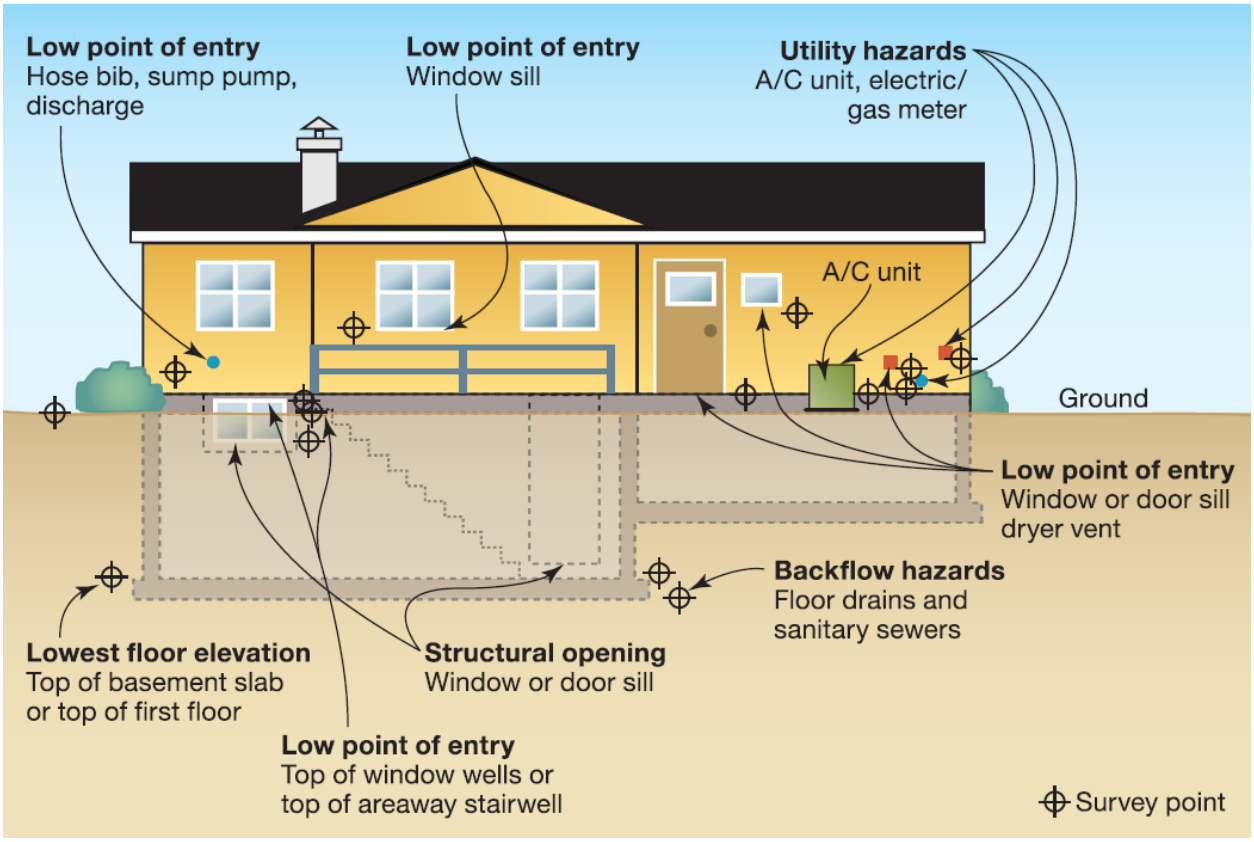


Figure 2-5. Typical residential building floodwater low point of entry locations

In addition to the lowest floor and structure openings, the following data points should also be identified during the first site visit:

- Finished floor/lowest floor elevation of the structure
- Property buildings or other features that require flood protection, like storage sheds, wellheads, and fuel storage tanks
- An elevation reference mark on or near the house

Once the low point of entry is determined, the homeowner and designer can determine the Design Flood Elevation and/or identify openings that need to be protected.

Note

An Elevation Certificate completed by a professional engineer or land surveyor is necessary within a Special Flood Hazard Area or local flood hazard area to inform the development of the project design and is required by most local governments as part of the proposed project review and building permit process. However, frequently the homeowner and designer may be able to estimate potential elevation of flooding, the elevation of the lowest floor, and the low points of entry to the structure, sufficient for an initial evaluation to further explore flood mitigation options.

The approximate height of the retrofitting measure can be used to evaluate each of this chapter's retrofitting parameters. The building condition should be evaluated as the designer notes the low point of entry.

2.6.4. AESTHETIC CONCERNS

Although physical and budgetary factors inform feasible retrofitting options for a home, the property owner may prioritize other factors, such as aesthetics.

Owners sometimes reject mitigation measures that score high for structural feasibility if they perceive the finished retrofit is unattractive, diminishes the structure's appearance (curb appeal) or future resale value. Often, what may be aesthetically pleasing may not be technically appropriate to reduce flood intrusion. In this situation, the designer and owner need to facilitate a solution that structurally protects the building, maintains building access and function, and is attractive.

Technically sound retrofitting options that are visually acceptable can be developed through a thorough understanding of the building condition, the flood threat, the benefits of the proposed retrofitting options, and conceptual design. The retrofit concept should include the proposed building modification as well as landscaping and access. Historic architectural features of the retrofitted building, as well as the neighborhood, along with the view of and from the residence, should be included in the evaluation of retrofit options.

2.6.5. BUDGET CONCERNS

During the initial consultation, the designer should not conduct a detailed cost analysis. Rough estimates of the cost of various retrofitting measures should be provided to the property owner. As stated in Chapter 1, the cost of retrofitting is dependent on multiple factors, including building condition, selected retrofitting measure, Design Flood Elevation, material selection and availability, labor costs, and other site-specific issues (i.e., soil conditions, flood risk, and other hazard vulnerabilities).

The costs in Tables 2-5 through 2-8 may assist with preliminary project planning and budgeting. Table 2-9 provides a comparison of relative costs and risks of all floodproofing methods.

Additional costs that may be incurred:

- Temporary living quarters (displacement costs) that may be necessary during construction (estimate: relocation: 3 to 4 weeks; elevation: 2 to 3 weeks)
- Professional or architectural design (10% of the costs of selected retrofitting measures)
- Contractors' profit (10% of the estimated costs)
- Contingency to account for unknown or unusual conditions

Note

Building relocation contractor costs typically include new site preparation and stabilization of the old site.

Table 2-3. Relative Costs of Elevating a Home

Construction Type	Existing Foundation	Retrofit	Relative Cost
Frame	Basement, crawlspace, or open foundation slab-on-grade	Elevate on continuous foundation walls or open foundation	Lowest
Frame with masonry veneer	Basement, crawlspace, or open foundation	Elevate on continuous foundation walls or open foundation	Lower range
Load-bearing masonry	Basement, crawlspace, or open foundation	Extend existing walls and create new elevated living area	Mid-range
Frame	Slab-on-grade	Elevate on continuous foundation walls or	Mid-range
Frame with masonry veneer	Slab-on-grade	Elevate on continuous foundation walls or open foundation	Higher range
Load-bearing masonry	Slab-on-grade	Elevate on continuous foundation walls or	Highest

Table 2-4. Relative Costs of Relocation*

Construction Type	Existing Foundation	Relative Cost
Frame	Crawlspace, open foundation, or slab-on-grade	Lowest
Frame with masonry veneer	Crawlspace or open foundation	Lower range
Load-bearing masonry	Crawlspace or open foundation	Lower range
Frame	Basement	Mid-range
Frame with masonry veneer	Basement	Mid-range
Load-bearing masonry	Basement	Mid-range
Frame	Slab-on-grade	Higher range

Construction Type	Existing Foundation	Relative Cost
Frame with masonry veneer	Slab-on-grade	Higher range
Load-bearing masonry	Slab-on-grade	Highest

*Note: Relocation includes relocating existing home and installing the home on a new foundation at the new site, hooking up utilities, and restoring the old site.

Table 2-5. Relative Costs of Floodwalls and Berms

Type	Relative Cost
Berms, two feet above ground level	Lowest
Berms, four feet above ground level	Lower range
Floodwalls, two feet above ground level	Mid-range
Berms, six feet above ground level	Higher range
Floodwalls, four feet above ground level	Highest

Table 2-6. Relative Costs of Wet Floodproofing

Construction Type	Existing Foundation	Retrofit	Relative Cost
Frame, frame with masonry veneer or load-bearing masonry	Crawlspace	Wet floodproof crawlspace to a height of 2 feet to 4 feet above lowest adjacent grade	Lowest
	Basement	Wet floodproof unfinished basement to a height of 2 feet to 4 feet above the basement floor	Mid-range
	Basement	Wet floodproof unfinished basement to a height of 8 feet above the basement floor	Highest

Table 2-7. Relative Costs and Risks of Floodproofing Methods

Floodproofing Retrofit Method	Cost	Remaining Risk to Flooding
Elevation	High	Low
Relocation	Highest	Lowest
Dry Floodproofing	Low	Highest
Wet Floodproofing	Medium	Medium-High
Floodwalls and Berms	Medium-High	Medium

Figure 2-6 can serve as a guide for developing the initial planning level estimate for each retrofitting alternative being considered.

Preliminary Cost Estimating Worksheet

Owner Name:_____ Prepared By:_____

Address: _____ Date: _____

Property Location: _____

Cost Component	Unit	Unit Cost	Quantity	Total
Subtotal Retrofitting Measures				
Contractor's Profit (10%)				
Design Fee (10%)				
Loss of Income (optional)				
Displacement Expenses (optional)				
Contingency				
Subtotal Other Costs				
Total Costs				

Figure 2-6. Preliminary Cost Estimating Worksheet

2.6.6. RISK CONCERNS

Another factor to include during the proposed flood retrofitting option evaluation is the risk of not renovating the residence. The remaining, or "residual" flood risk of each proposed retrofitting option can be estimated using its flood exceedance probability and its design flood elevation. For example, relocating outside of the floodplain significantly reduces or eliminates the risk of flood damage. A berm designed to protect against a 10% chance annual exceedance probability (10-year) flood would have an 88% chance of being overtopped during a 20-year period. This information can help the property owner and designer evaluate each retrofit option. Table 2-8 provides flood risk probabilities associated with flood occurrence and magnitude recurring at five interval scenarios.

Table 2-8. Flood Risk over the Life of the Structure

Length of Period (years)	10-Year Recurrence Interval	25-Year Recurrence Interval	50-Year Recurrence Interval	100-Year Recurrence Interval	500-Year Recurrence Interval
1	10%	4%	2%	1%	0.2%
10	65%	34%	18%	10%	2%
20	88%	56%	33%	18%	2%
25	93%	64%	40%	22%	5%
30	96%	71%	45%	26%	6%
50	99+%	87%	64%	39%	10%
100	99.99+%	98%	87%	63%	18%

The table values represent the probabilities, expressed in percentages, of flood occurrence of specific magnitude or larger over time. Probability (P) may be calculated for any given Length of Period (n) and Recurrence Interval (RI) using the following equation:

$P = \left[1 - \left(1 - \frac{1}{RI}\right)^{n}\right]$ where RI and n are in years.

Flood probabilities can be used to evaluate flood retrofitting reduction of nuisance damage requiring cleanup and sanitation. Reducing flood damage cleanup and repair, lost time from work, or average non-use of a building from once in two years to once in 10 years, could provide enough incentive to retrofit.

2.6.7. ACCESSIBILITY FOR INDIVIDUALS WITH SPECIAL NEEDS

Accessibility for individuals aging in the home, with physical limitations or with other special needs, should be addressed to accommodate the specific needs of the residence's occupants. Retrofitting measures can create access challenges for a home that was previously fully accessible. The Americans with Disabilities Act of 1990 and the Fair Housing Amendment Act of 1988, and other accessibility codes and regulations, do not specifically address private single-family residences. However, these regulations include concepts that the designer can reference to meet the property owner's needs.

It is important for the designer to remember that access challenges for daily ingress and egress, as well as emergency evacuation, are varied:

- Limited mobility requiring the use of a cane, walker, or wheelchair
- A person's limited strength to open doors, climb stairs, install flood shields, or operate other devices
- Partial or total loss of hearing or sight

Special accommodation such as small elevators may be needed. Discussion of the household's needs should be discussed with the owner while using the Preliminary Homeowner Retrofitting Preference Matrix (Figure 2-7) so the preferred retrofit options can be ranked.



Note

A designer should become familiar with current hazard risks, flood history, codes, legal restrictions, and property owner needs relevant to the property location and building condition.

Preliminary Homeowner Retrofitting Preference Matrix											
Owner Name:								**Preparer:**			
Address:								**Date:**			
Property Details:											
Considerations	**Retrofitting Measures**										
	Structural Elevation			**Elevation Alternatives**			**Relocation**	**Floodproofing**		**Flood Barriers**	
	Stem Wall (Fill)	**Perimeter Wall/ Piers**	**Piles**	**Basement Infill**	**Abandon/ Repurpose Lowest Floor**	**Elevate Lowest Interior Floor**		**Dry**	**Wet**	**Floodwall**	**Berm**
PART A: Local Regulations											
Measure Not Feasible (NF) or Not Allowed											
PART B: Homeowner Concerns											
Aesthetics											
High Cost											
Risk - Flood Insurance Rates											
Accessibility											
Increase Flooding on Neighboring Sites											
Other:											
Total X's ***(Lowest is Preferred)***											
Purpose:	The purpose of the Preliminary Homeowner Retrofitting Preference Matrix is to determine whether or not the retrofitting measure is allowed under local regulations or homeowner requirements.										
Instructions:	Step 1: Complete Part A of the matrix by placing an "X" in the box for each measure which is not feasible or is not allowed based on the configuration of the existing structure and/or property. For these measures, skip Steps 2 through 5 and put an "NF" for Not Feasible under the Total X's at the end of Part B. Step 2: Complete Part B of the matrix for only those measures that are allowable (no "X" in Part A). Step 3: For those measures allowed under Part A, evaluate the considerations in Part B to determine if the homeowner has concerns that would affect its implementation. A concern is defined as a homeowner issue that, if unresolved, could make the retrofitting measure infeasible. Step 4: If the homeowner has a concern, place an "X" in the box under the appropriate measure/consideration. Step 5: Add up the total number of X's for each allowable measure, and input the result under the Total X's at the end of Part										
Evaluation of Results:	The retrofitting measure(s) with the least number of X's (and no NF's) is the most preferred.										

Figure 2-7. Preliminary Retrofitting Preference Matrix

2.7. Community Regulations and Permitting Parameters

2.7.1. STATE AND LOCAL CODES

Most state and local governments regulate building activities through adopted building codes, and floodplain and zoning ordinances. With the intent of protecting health and safety, most state and

local codes are fashioned around the model building codes discussed in the Model Building Codes and Referenced Standards section above.

The designer should be aware that modifications may be undertaken to make the model codes more responsive to the local conditions and concerns in the area, such as hurricanes, wildfires, seismic activity, extreme heat/cold, or humidity.



Note

Some states with statewide building codes do not allow for local building code requirements to differ from state requirements.

Determination of which retrofitting measures are allowed under local regulations is an important step in compiling the Preliminary Homeowner Retrofitting Preference Matrix (Figure 2-7). Retrofitting measures prohibited by local codes, ordinances, and regulations will be eliminated from further consideration.

2.7.2. ZONING ORDINANCE AND BUILDING CODE REVISIONS

Residential building improvements, including flood retrofitting, must comply with local ordinance and building code requirements. Most building codes require local government approval for elevation projects, especially if foundation or structural modification and utility alteration are elements of the project.

Structures built prior to adoption of the current zoning ordinance are considered “legally non-conforming.” While lawful when constructed, if these buildings do not meet current local requirements, they are “grandfathered”, which allows the building to continue its present use (if not abandoned) even if they would no longer be permitted under the current zoning ordinance.

Legal non-conformance protects property owners from hardship due to regulatory changes that could disrupt their occupancy of their home. If more stringent zoning requirements have been adopted since a building was constructed, such as property line setback or limited building height or number of levels, retrofitting options may be limited.

It is important for the design team to verify the legal non-conforming status of an older building with local planning or zoning officials. Real estate professionals or legal experts can provide guidance on non-conforming uses. This information will inform the owner and designer of any limitations for the structure, such as restrictions on expansion or modification of the building.

These buildings are also likely not compliant with current building code requirements. Local code restrictions can influence the selection of a retrofitting method because construction may trigger compliance to currently adopted building codes. This is likely for more costly retrofits, which may exceed substantial improvement thresholds.

Warning

Some communities require that structures undergoing significant rehabilitation, either because of previous damage or significant improvements/additions, be brought into compliance with current building codes. In addition to floodplain management requirements, these requirements could include items such as the addition of fire alarms, removal of lead water pipes, upgrades in electrical wiring, etc.

2.7.3. OFF-SITE FLOODING IMPACTS

If a preferred retrofitting measure requires modification of the building site, the designer should include potential impacts to adjacent properties, especially those downstream:

- Will construction of berms and floodwalls create diversions to drainage?
- Will new runoff be created that could harm nearby properties?
- If floodproofing disturbs the existing landscape, will re-grading and re-landscaping undermine adjacent streets and structures?
- Will grading or foundation alteration increase the risk of severe erosion, sliding, or subsidence?
- Will the retrofitted building be unsightly?
- If a building is relocated to another location on the property, or if elevated, will it encroach on established easements or rights-of-way?
- Will the relocated building infringe on wetland areas or regulated floodplains?

These and other questions must be addressed by the homeowner and designer during evaluation of proposed retrofitting options, with consideration of potential liabilities of altering drainage patterns or site features. The designer should ensure that any modified drainage will not negatively impact surrounding properties. On site drainage modifications due to the proposed retrofitting project should be understood with full resolution of any potential drainage impacts.

Note

Addressing off-site impacts and issues is a requirement of zoning and floodplain management ordinances.

Warning

National Flood Insurance Program, state, and local regulations do not typically permit construction in a floodway. In some cases, construction may potentially be allowable in a floodplain if strict requirements are met in order to avoid increasing downstream flood levels.

2.8. Technical Parameters

Once the designer has resolved preliminary retrofitting preference issues with the owner, a more detailed evaluation of the project's technical requirements is necessary, including flood hazard, site, and building characteristics. The remainder of this chapter provides background information on these issues, along with worksheets and instructions, which will be useful to the designer during worksheet completion.

2.8.1. FLOODING CHARACTERISTICS

Riverine flooding is usually the result of heavy or prolonged rainfall or snowmelt occurring in upstream inland watersheds. In some cases, especially in and around urban areas, flooding can also be caused by inadequate or improper drainage. In coastal areas subject to tidal effects, flooding can result from wind-driven and prolonged high tides, poor drainage, storm surge with waves, backwater effects and tsunamis.

There are several important flood characteristics that must be examined to determine which retrofitting measure will be best suited for a specific location: depth and elevation, flow velocity, frequency, rates of rise and fall, duration, and debris impact. These characteristics not only indicate the precise nature of flooding but can also be used to anticipate the performance of different retrofitting measures based on the localized flood hazard.

Flood Depth and Elevation

Depth and elevation of flooding are related. Flood depth is measured from the floodwater surface to the adjacent ground level, while flood elevation is measured against an established standard topographic datum or fixed reference point. Determining the potential depth of flooding for certain flood frequencies is critical because it is often the primary factor in evaluating flood damage potential. Buildings are susceptible to floods of various depths.

Floods of greater depth statistically occur over time, less frequently than shallower floods. Potential flood elevations from significant flooding sources are depicted in Flood Insurance Studies for most participating National Flood Insurance Program communities. Flood insurance studies provide predicted flood levels (typically at the 10%, 2%, 1%, and 0.2% annual chance events), along with historic flood levels and other information that can help inform understanding of the building's flood risk and potential damage from flooding. Potential flood depths can be calculated by determining the

height of the flood above the ground elevation of the structure. Figure 2-8 illustrates historic flood depths documented by a building's mud lines or high water marks.



Figure 2-8. High water mark document flood depth.

For sites lacking the specificity of a Flood Insurance Study or state, community, or privately prepared local floodplain study, determination of flood depth may require a detailed engineering evaluation of local flood characteristics and drainage conditions to develop the necessary relationship between flow (discharge), water surface elevation, and flood frequency. The designer should contact the local government engineer, building official, or floodplain administrator for guidance on computing flood depth for sites outside of existing study areas.

Floodwater can impose hydrostatic forces on buildings. These forces result from the static mass of water acting on any point where floodwater contacts a structure. They are equal in all directions and always act perpendicularly (or normal) to the surfaces on which they are applied. Hydrostatic loads can act vertically on structural members such as floors and decks (buoyancy forces) and laterally (hydrostatic forces) on upright structural members such as walls, piers, and foundations. Hydrostatic forces increase linearly as the depth of water increases. Figure 2-9 illustrates the hydrostatic and buoyancy forces generated by water depth.

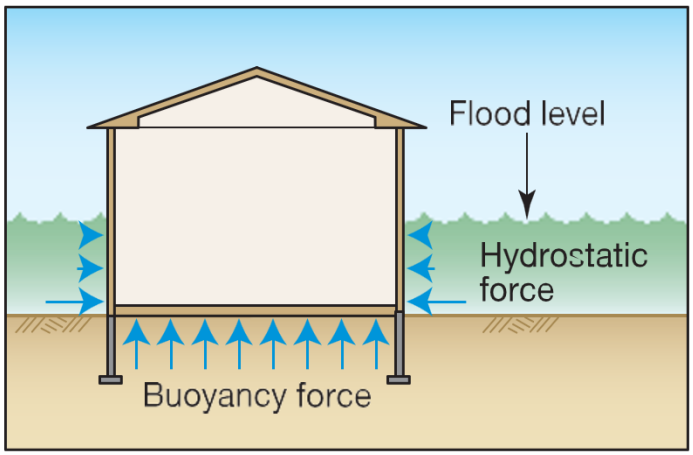


Figure 2-9. Hydrostatic and Buoyancy Forces

If a well-constructed building is subject to flooding depths of less than three feet, unequalized hydrostatic forces may not cause significant damage. Barriers, sealants, and closures may be appropriate retrofitting measures. If shallow flooding (less than three feet) causes a basement to fill with water, then wet floodproofing methods can be used to reduce basement flood damage.

If a residential building is subject to flooding greater than six feet, either elevation or relocation is often the preferred retrofitting method. Water depths greater than three feet often create hydrostatic force loads, which can cause structural damage or structural collapse when floodproofing the building. Floodwalls or berms designed to withstand flooding depths greater than three feet, but less than six feet, should be evaluated as flood mitigation options.

Note

Existing and historical data can be used to analyze the flood hazard. Residents and local officials can provide flood history as well as anecdotal depths of flooding, types of velocity (moving or standing water), duration of flooding, and photos. Once flood history has been established, the designer can check other sources, such as newspapers and the National Weather Service, for additional information.

Flood Flow Velocity

The speed at which floodwater moves (flood flow velocity) is normally expressed in terms of feet per second (ft/sec). Riverine floodwater velocity depends primarily on the slope and roughness of the ground surface. Beyond the potential structural damage from hydrodynamic and potential debris impact forces described below, flowing water often causes erosion and scour. Both erosion and scour can weaken structures by undermining the building's foundation. Erosion and scour are discussed further in Chapter 3.

As floodwater velocity increases beyond 5 feet per second, hydrodynamic forces imposed by moving water are added to the hydrostatic forces from the depth of still water, significantly increasing the

possibility of structural failure. Hydrodynamic forces are caused by water moving against and around an object and consist of positive frontal pressure against the structure, drag forces along the sides, and negative pressures on the building's downstream face. Greater velocities can also quickly erode, or scour, the soil supporting and/or surrounding a building. Thus, the frontal pressure, drag, and suction from these fast-moving waters may move a building from its foundation or otherwise cause structural damage or failure.



Note

ASCE 24 has additional requirements and hydrodynamic force calculations change when flood velocities exceed 10 feet per second. Refer to the hydrodynamic force discussion in Chapter 3 for details.

Unfortunately, there is usually no definitive source of information to determine potential flood velocities in the vicinity of specific buildings. Flood flow velocities can cause significant damage in rural, mountainous communities that are unable to convey the flow or that have few drainage improvements, older or inadequate protection for transportation, drainage, and utility infrastructure. Furthermore, flood flow velocities are often not shown or easily determined from Flood Insurance Rate Maps or Flood Insurance Studies, challenging the awareness of high-risk or vulnerable areas. Hydraulic computer models or hand computations based on existing floodplain studies may provide estimated flood velocities in the channel and overbank areas. Where current analysis data is not available, historical information from past flood events may be useful.

Flood Frequency

Flood frequency analysis defines the probability that a flood of a specific size will be equaled or exceeded in a given timeframe in a specific location. A flood elevation with a 1% annual chance of being equaled or exceeded in a year is referred to as the "1% chance flood." Table 2-7 illustrates the relationship between flood return intervals and the probability of that event occurring during a specific time. While the 1% chance flood informs National Flood Insurance Program insurance rates and regulatory floodplain management requirements, the relative frequency of a flood (10-year vs. 50-year) can also inform retrofitting option selection.

Rates of Rise and Fall

In areas of steep topography, in small drainage areas, or in arid terrain that discharges water very quickly, floodwater can rise quickly with little or no warning. This is known as flash flooding. Many areas in the western United States are especially prone to seasonal flash flooding, where floodwater levels rise rapidly. Additionally, urban impervious areas, especially those with inadequate or blocked drainage systems, are vulnerable to flash floods. The vulnerability to high velocity floods may eliminate some types of retrofitting, especially measures like flood shields, which require human intervention. As defined by the National Weather Service, during flash floods, flooding begins within 6 hours, and often within 3 hours, of the heavy rainfall. If a building is susceptible to flash floods,

insufficient warning time prevents installation of door and window shields and deployment of temporary floodwalls or activation of pumps and backup energy sources. Temporarily relocating moveable contents to a higher level is also a challenge, given the limited warning. These mitigation measures can be effective in areas with effective emergency warning systems that are not vulnerable to flash flooding.

High rates of floodwater rise and fall may also lead to increased hydrostatic pressures. This can be due to water levels inside the structure rising and falling more slowly than outside flood levels.

Warning

Active retrofitting measures that require human intervention are not recommended in areas vulnerable to flash flooding.

Flood Duration

In many floodplains, duration is related to rates of rise and fall. With long duration flooding, dry floodproofing may be inappropriate due to the increased chance of seepage and foundation failure caused by prolonged exposure to floodwaters. Long periods of inundation are more likely to cause damage to structural members, interior finishes, and mechanical equipment than short inundation periods.

Note

A detailed hydrograph can provide information on flood duration. However, this information is usually unavailable, and new studies can be cost-prohibitive. A potential source of information is to compare historical data from similarly sized drainage basins in neighboring areas to the project watershed.

Debris Impact

While not intrinsic to flooding itself, flood borne debris impacts are related to flood characteristics—depth, velocity, rate of rise and fall—and upstream site characteristics. Rising floodwater can dislodge objects of all types and sizes, such as cars, sheds, boulders, rocks, and trees. Once unrestrained, high velocity floodwaters will transport debris downstream, endangering buildings and infrastructure. In colder climates, floodwaters during spring thaws may carry chunks of ice that batter buildings and infrastructure.

Debris can severely damage or destroy retrofitted buildings, small floodwalls, and berms. Retrofitting measures suitable for debris impact include relocation, levees, and floodwalls. ASCE 7-22 *Minimum Design Loads and Associated Criteria for Buildings and Other Structures, Supplement 2* (ASCE 7-22 S2) expands the Flood Hazard Area from the 100-year to 500-year floodplain, increases the mean

recurrence interval designs for Risk Category II, II, and IV structures, and significantly increases the debris impact loads for various scenarios to improve building resilience and performance.

Figure 2-10 provides a Retrofitting Screening Matrix based on flood characteristics discussed in this section; Figure 2-11 provides instructions for completing the matrix.



Note

Another flood-related hazard besides debris impact is alluvial fans. These areas have increased potential for high flood velocities, significant debris flow, and varying channel locations. The hazards associated with alluvial fan flooding are discussed in Appendix E.

Retrofitting Screening Matrix - Part A: Flood Characteristics											
Owner Name:								**Preparer**			
Address:								**Date:**			
Property Details:											
Flood Characteristic	**Retrofitting Measures**										
	Structural Elevation			**Elevation Alternatives**			**Relocation**	**Floodproofing**		**Flood Barriers**	
	Stem Wall (Fill)	**Perimeter Wall/ Piers**	**Piles**	**Basement Infill**	**Abandon/ Repurpose Lowest Floor**	**Elevate Lowest Interior Floor**		**Dry**	**Wet**	**Floodwall**	**Berm**
Pre-Screening from Preliminary Homeowner Preference Matrix											
Measure Not Feasible (NF)											
Flood Depth											
Shallow (< 3 ft)											
Moderate (3 to 6 ft)								**NR**			
Deep (> 6 ft)								**NR**	**NR**	**NR**	**NR**
Flood Velocity											
Slow/Moderate (≤ 5 ft/sec)											
Fast (> 5 ft/sec)	**ER**	**ER**						**NR**		**ER**	**ER**
Flash Flood Risk											
High	**ER**	**ER**						**NR**	**NR**	**NR**	**NR**
Low to Moderate											
Debris/Ice Jam Flood Risk											
High	**DI**	**DI**						**NR**		**DI**	**DI**
Low to Moderate											
Scoring											
Subtotal Y's											
Subtotal NR's											
Subtotal ER's, DI's											
PART A Score = [Ys - (NRs) - 0.5 (ERs + DIs)]											
Purpose:	The purpose of the Retrofitting Screening Matrix Part A is to provide an initial technical assessment of existing flood characteristics for retrofit project to determine what retrofit measures are the most feasible.										
Matrix Notes:	NF	Not Feasible: indicates the retrofit measure was pre-screened to be not allowed or not feasible based on the configuration of the existing structure and/or property. Refer to the Preliminary Homeowner Preference Matrix for details.									
	NR	Not Recommended: indicates the retrofit measure is not recommended for this flood condition.									
	ER	Erosion Risk: indicates that fast flow velocity/flash flooding is conducive to erosion and the retrofit measure may need to be modified to address this hazard.									
	DI	Debris Impact: indicates that debris flow or ice jam flooding is conducive to flood-borne debris impact and the retrofit measure may need to be modified to address this hazard.									
	Page 1 of 2. See next page for Instructions and Evaluation of Results										

Figure 2-10. Retrofitting Screening Matrix for Flood Characteristics

Retrofitting Screening Matrix - Part A: Flood Characteristics (continued)	
Instructions:	Step 1: Complete pre-screening by placing an "NF" in the box for each measure which is not allowed or is not feasible based on the configuration of the existing structure and/or property using the Preliminary Homeowner Preference Matrix. For these measures, skip Steps 2 through 9 and put an "NF" for Not Feasible under the PART A Score. Step 2: Review the Flood Depth section and circle the Flood Depth row that matches existing flood conditions. Place a "Y" (Yes) for each measure along the Flood Depth row you circled unless there is an NF in the top row or an NR already in that measure's box. Step 3: Review the Flood Velocity section and circle the Flood Velocity row that matches existing flood conditions. Place a "Y" (Yes) for each measure along the Flood Velocity row you circled unless there is an NF in the top row or an ER or NR already in that measure's box. Step 4: Review the Flash Flood Risk section and circle the Flash Flood Risk row that matches existing flood conditions. Place a "Y" (Yes) for each measure along the Flash Flood Risk row you circled unless there is an NF in the top row or an ER or NR already in that measure's box. Step 5: Review the Debris/Ice Jam Flood Risk section and circle the Debris/Ice Jam Flood Risk row that matches existing flood conditions. Place a "Y" (Yes) for each measure along the Debris/Ice Jam Flood Risk row you circled unless there is an NF in the top row of a DI or NR already in that measure's box. Step 6: In the Subtotal Y's row, add up the total number of "Y's" for each measure and input the subtotal in each column. Step 7: In the Subtotal NR's row, add up the number of "NR's" for each measure and input the subtotal in each column. Step 8: In the 0.5 x Subtotal ER's, DI's row, add up the total number of "ER's" and "DI's" for each measure and input the subtotal in each column. Step 9: In the PART A Score row, take Subtotal Ys value (Step 6) and subtract both the Subtotal NRs value (Step 7) and the 0.5 x Subtotal ERs, DIs value (Step 8) for each measure and input the total score in each column. Note the PART A Score can be a positive number, a negative number, or zero.
Evaluation of Results:	**Retrofit measures with the highest PART A Score are considered the most preferred** for addressing the existing flood conditions. Retrofit measures with the lowest PART A Score or NF are considered the least preferred for addressing the existing flood conditions.

Figure 2-11. Instructions for Completing the Retrofitting Screening Matrix for Flood Characteristics (Figure 2-10)

2.8.2. SITE CHARACTERISTICS

Site characteristics such as site location, erosion vulnerability, and underlying soil conditions are critical in the determination of applicable retrofitting methods.

Site Location

The floodplain is usually defined as an area inundated by a flood having a 1% annual chance of being equaled or exceeded (commonly called the "100-year flood"). The riverine floodplain is often further divided into a floodway and a floodway fringe.

As defined earlier, the floodway is the portion of the floodplain that contains the channel and enough surrounding area to enable floodwater flow without increasing a predetermined flood depth. If there are high flood depths and/or velocities, this area is the most dangerous portion of the riverine floodplain. Also, since the floodway carries most of the flood flow, any obstruction may cause floodwater to back up, causing a damming effect and increased flood levels. Thus, the National Flood Insurance Program and local communities prohibit new construction or substantial improvements in identified floodways that increase flood levels. This is called the "no-rise" requirement. Relocation is the recommended retrofitting option for a structure located in a floodway. Community and state regulations may prohibit the elevation of structures in this area. However, elevation on an open foundation may be acceptable to meet no rise requirements by conveying more flood flow than a structure elevated on a solid or closed foundation.

The portion of the floodplain adjacent to the floodway is called the floodway fringe. This area normally experiences shallower flood depths and lower velocities. With proper precautions, it is often possible to retrofit structures in the floodway fringe with adequate mitigation provisions.

Vulnerability to Erosion

Erosion refers to the wearing away of soil and rock, which occurs in riverine environments (Figure 2-12). Erosion may be caused by natural or human actions including floods, construction, and activities such as drainage alteration, fill, channel dredging, damming rivers, and altering surface vegetation.

Riverine erosion impacts the stability of stream banks and adjacent structures through the interaction of multiple geophysical and geotechnical factors listed in Section 3.3. Siting and erodibility should be considered if retrofitting in the floodplain, since fast-moving floodwater can undermine buildings and cause building, floodwall, and levee failure.

Shallow foundation systems do not provide sufficient protection against soil erosion without protection or armoring below grade foundation elements. Natural Resource Conservation Service local representatives have information on site-specific soil erodibility. In 1999, FEMA conducted an erosion mapping feasibility study that concluded that mapping of erosion-prone areas was feasible.



Figure 2-12. Example of flood-induced erosion and scour around a residential building foundation

Soil Type

Permeable soils, such as sand and gravel, allow groundwater flow. During flooding, these soils may allow water to pass under floodwalls and levees unless extensive seepage control measures are included in retrofitting measures. Saturated soil pressure against basement walls and floors may

increase. These conditions cause seepage, disintegration of certain building materials, and structural damage. Floodwalls, levees, sealants, shields, and closures may not be effective in areas with highly permeable soil types.

Note

Contact the local Natural Resource Conservation Service office or a local geotechnical engineering firm to obtain guidance on soil permeability and consolidation features. Since sites may have been backfilled with non-native materials during original construction, Natural Resource Conservation Service data should be carefully used.

Saturated soils under horizontal surfaces, such as floors, are vulnerable to uplift forces, called buoyancy. Like lateral hydrostatic forces, buoyancy forces increase in proportion to the depth of water and saturated soil above the horizontal surface. Figure 2-13 illustrates the combined lateral and buoyancy forces resulting from saturated soil.

For example, a typical wood-frame home without a basement or proper anchoring to the foundation may float if flood water levels reach as little as three feet above the first floor. Even a dry basement can potentially fail if the ground is saturated up to four feet above the basement floor. Uplift forces occur in the presence of saturated soil. Therefore, well designed, high-capacity subsurface drainage systems with sump pumps may be an effective solution and may enable the use of dry floodproofing measures.

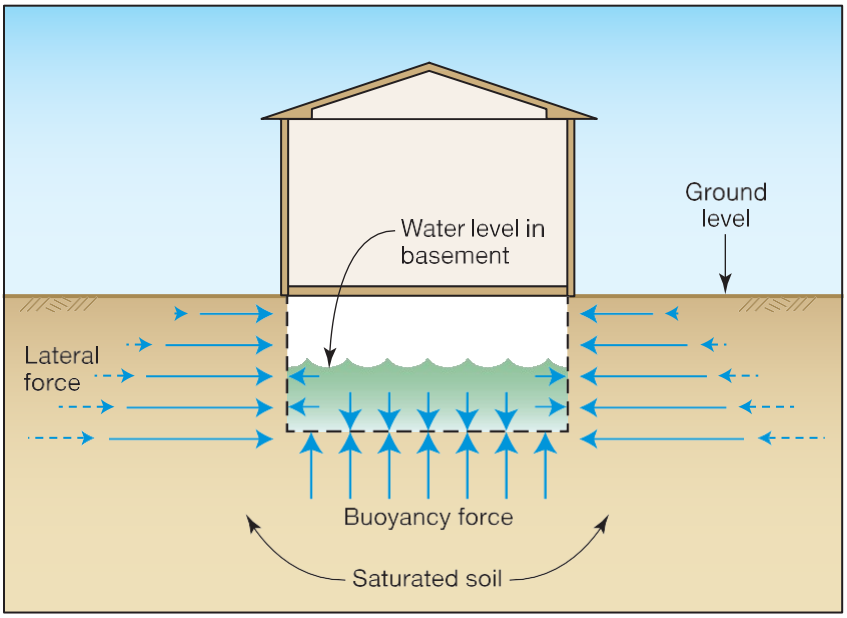


Figure 2-13. Lateral and buoyancy forces resulting from flooding

Other potential challenges with soil saturated by flooding need evaluation. If a building is located on unconsolidated soil, soil wetting may cause uneven (differential) settlement. The building can then be damaged by inadequate support and become vulnerable to rotational, pulling, or bending forces.

Soils such as clay or silt may expand when exposed to floodwater, causing massive forces against basement walls and floors. As a result, buildings may sustain serious damage even though floodwater does not enter or contact the structure itself.

Figure 2-14 provides a Retrofitting Screening Matrix based on site characteristics discussed in this section; Figure 2-15 provides instructions for completing this matrix.

Retrofitting Screening Matrix - Part B: Site Characteristics											
Owner Name:								**Preparer**			
Address:								**Date:**			
Property Details:											
Site Characteristic	**Retrofitting Measures**										
	Structural Elevation			**Elevation Alternatives**			**Relocation**	**Floodproofing**		**Flood Barriers**	
	Stem Wall (Fill)	**Perimeter Wall/ Piers**	**Piles**	**Basement Infill**	**Abandon/ Repurpose Lowest Floor**	**Elevate Lowest Interior Floor**		**Dry**	**Wet**	**Floodwall**	**Berm**
Pre-Screening from Preliminary Homeowner Preference Matrix											
Measure Not Feasible (NF)											
Site Flood Risk											
Low (Zone X)											
Moderate (Zone A)			NR								
High (Floodway)	NR	ER						NR	DR	NR	NR
High (Coastal A/Zone V)	NR	NR						NR	DR	NR	NR
Property Location											
Rural (large lots, widely spaced)											
Suburban (medium lots, moderately spaced)											NR
Urban (small lots, densely spaced)	NR	NR	NR				NR	NR		NR	NR
Soil Type											
Permeable (granular)								NR		NR	NR
Impermeable (cohesive)											
Scoring											
Subtotal Y's											
Subtotal NR's											
Subtotal ER's, DR's											
PART B Score = [Ys - (NRs) - 0.5 (ERs + DRs)]											
Purpose:	The purpose of the Retrofitting Screening Matrix Part B is to provide an initial technical assessment of existing site characteristics for retrofit project to determine what retrofit measures are the most feasible.										
Matrix Notes:	NF Not Feasible: indicates the retrofit measure was pre-screened to be not allowed or not feasible based on the configuration of the existing structure and/or property. Refer to the Preliminary Homeowner Preference Matrix for details. NR Not Recommended: indicates the retrofit measure is not recommended for this site condition. ER Erosion Risk: indicates that Floodways are generally conducive to erosion and the retrofit measure may need to be modified to address this hazard. DR Damage Risk: indicates that wet floodproofing measures can be damaged by high-velocity flooding from Floodways, Coastal A or V Zones.										
	Page 1 of 2. See next page for Instructions and Evaluation of Results										

Figure 2-14. Retrofitting Screening Matrix for Site Characteristics

Retrofitting Screening Matrix - Part B: Site Characteristics (continued)	
Instructions:	Step 1: Complete pre-screening by placing an "NF" in the box for each measure which is not allowed or is not feasible based on the configuration of the existing structure and/or property using the Preliminary Homeowner Preference Matrix. For these measures, skip Steps 2 through 8 and put an "NF" for Not Feasible under the PART B Score. Step 2: Review the Site Flood Risk section and circle the Site Flood Risk row that matches existing floodplain location. Place a "Y" (Yes) for each measure along the Site Flood Risk row you circled unless there is an NF in the top row, or an NR, ER or DR already in that measure's box. Step 3: Review the Property Location section and circle the Property Location row that matches existing property and surrounding site conditions. Place a "Y" (Yes) for each measure along the Property Location row you circled unless there is an NF in the top row, or an NR already in that measure's box. Step 4: Review the Soil Type section and circle the Soil Type row that matches existing site soil conditions. Place a "Y" (Yes) for each measure along the Soil Type row you circled unless there is an NF in the top row or an NR already in that measure's box. Step 5: In the Subtotal Y's row, add up the total number of "Y's" for each measure and input the subtotal in each column. Step 6: In the Subtotal NR's row, add up the number of "NR's" for each measure and input the subtotal in each column. Step 7: In the 0.5 x Subtotal ER's, DR's row, add up the total number of "ER's" and "DR's" for each measure and input the subtotal in each column. Step 8: In the PART B Score row, take Subtotal Ys value (Step 5) and subtract both the Subtotal NRs value (Step 6) and the 0.5 x Subtotal ERs, DRs value (Step 7) for each measure and input the total score in each column. Note the PART B Score can be a positive number, a negative number, or zero.
Evaluation of Results:	**Retrofit measures with the highest PART B Score are considered the most preferred** for addressing the existing site conditions. Retrofit measures with the lowest PART B Score or NF are considered the least preferred for addressing the existing site conditions.

Figure 2-15. Instructions for Completing the Retrofitting Screening Matrix for Site Characteristics

2.8.3. BUILDING CHARACTERISTICS

Ideally, a building consists of three different components: substructure, superstructure, and utility systems. The substructure consists of the foundation system. The superstructure consists of the structural elements and the building envelope (cladding, roofing, windows, doors, etc.) above the foundation system. The utility systems include elements such as HVAC, power, communications, plumbing, or other systems that make the building habitable.

These components are integrally linked to helping a building maintain habitability and structural integrity. Any action that affects one component may have a minimal or significant effect on the others. An understanding of building characteristics and construction methodology is an important consideration in retrofitting measure selection.

Substructure

The substructure of a building supports the above grade elements and envelope, including foundation components below the surface. This system consists of vertical foundation elements such as walls, posts, piers, and piles, which support the building loads and transmit them to the ground, and footings that bear directly on the soil.

At any time, numerous loads act on a building. The foundation system transfers these loads safely into the ground. In addition to dead and live loads, retrofitting decisions must account for the buoyant uplift thrust on the foundation, the horizontal pressure of floodwater against the building, and any loads imposed by other hazards such as wind or earthquakes.

For a foundation system to withstand these and other loads or forces, directly or indirectly, is dependent on its structural integrity. The designer should determine the type and condition of a building's foundation system early in the retrofitting evaluation.

All foundations are classified as either shallow or deep. Shallow foundation systems consist of columns or piers and wall footings, slab-on-grade, crawlspace, and basement substructures. Deep foundation systems primarily include piles. Even though each of these foundation types may be utilized either individually or in combination with others, most residential buildings are supported on shallow foundations, unless designed otherwise. Each foundation type has advantages and limitations to consider when evaluating retrofitting measures. Foundation system structural soundness must be considered.

Basement walls may be subject to increased hydrostatic and buoyancy forces; thus, retrofitting a building with a basement can be complex and costly.



Note

A cracked foundation is one indication of a weak or settling foundation. Floodwalls and berms may be the most feasible retrofitting measure to protect buildings with poor foundations. Another mitigation option is to elevate the building onto a new foundation.

Superstructure

The superstructure is the portion of the building that includes the load-bearing members and the exterior envelope systems above the foundation system (e.g., walls, floors, roofs, ceilings, doors, and other openings). The designer should carefully and thoroughly analyze the existing conditions and component parts of the superstructure to determine the best retrofitting options available. Flood and non-flood-related hazard effects should also be considered; the uplift, suction, shear, and other pressures exerted on building and roof surfaces by wind and other environmental hazards may eliminate the elevation retrofitting measure.

Utility Systems

These systems enable building habitation by moderating temperature, providing power, water, waste disposal, and communication. For a typical residential building, the combination of the mechanical, electrical, telecommunications, water supply, waste disposal, and drainage systems supports building occupants. Understanding building mechanical and utility systems enables the designer to retrofit the building to include flood mitigation measures to protect building support systems.

Introduction of new materials or the alteration of a building's existing features may require resizing existing services to accommodate the retrofit. Retrofitting may also require ductwork and electrical wiring relocation, along with modification of water supply and waste disposal systems to protect against flood damage. Septic tanks and groundwater wells require detailed evaluation and may

require protective measures or relocation of the septic tank and drain field. If relocation is considered, the designer must consider all building support systems and compare repair costs with total replacement costs.

Building Construction

Modern buildings are constructed with a variety of materials integrated into various structural systems. A building may be built with a combination of materials, making retrofitting options difficult to evaluate.

Concrete and masonry construction may be appropriate for all retrofitting measures, whereas other materials may not be structurally sound or flood damage-resistant. If a building is classified as concrete and masonry construction, all walls and foundations must be built of this material to prevent damage or failure when floods exert hydrostatic or hydrodynamic forces on the structure.

It is important to identify masonry-veneer-over-wood-frame construction since wood-frame construction is less resistant to lateral loading than a brick-and-block wall section.



Note

For evaluation of retrofitting options, all construction should be default classified as wood material, unless all walls and foundations are confirmed to be concrete or masonry.

Building Condition

Evaluation of building conditions may be difficult since many structural defects are not obvious. Careful inspection of the structure should provide for a classification of “excellent to good” or “fair to poor.” This classification is only for the reconnaissance phase of preferred retrofitting measure selection. More detailed planning and design may alter the initial judgment regarding building condition, thereby eliminating some retrofitting measures from consideration. Analysis of a building’s substructure, superstructure, and support services may be done in an initial analysis, usually based on visual inspection, and a detailed analysis (discussed in Section 4.2) that is often more informative, involves greater scrutiny, and usually requires detailed engineering calculations. It is also helpful to consider site conditions, such as the surrounding land and lot properties, for clues to the drainage patterns that will affect the building itself.



Note

Typically, a designer will begin a retrofitting project with an initial analysis of the present conditions. Decisions based on early findings may be revised after a more detailed analysis.

During an analysis, the designer should visually inspect the walls, floors, roof, ceiling, doors, windows, and other superstructure and substructure components. Walls should be examined for types of material, structural stability, cracks, and signs of distress. A crack on a wall or dampness on concrete, plaster, wood siding, or other wall finishes may be a sign of concealed problems. Doors, windows, skylights, and other openings should be checked for cracks, rigidity, structural strength, and weather resistance.

Metal-clad wood doors or panel doors with moisture-resistant paint, plastic, or plywood exterior finishes may appear fine even though the interior cores may be damaged. Aluminum windows should be checked for deterioration due to galvanic action or oxidation from contact with floodwater. Steel windows may be damage-free if they are well protected against corrosion. Wood windows require inspection for shrinkage and warping, and for damage from moisture, mold, fungi, and insects.

Flooring in a building can include a range of materials including painted concrete, carpet, elegant custom-designed wood parquet floors, and luxury plank vinyl. The designer should investigate the underlying subfloor and floor finishes. Vinyl or rubberized plastic finishes may appear untouched due to their indentation and water resistance; however, the concrete or wood subfloor may have suffered some damage. Likewise, a damage-free subfloor may be covered with a scarred finish.

An initial analysis of the conditions of the roof and ceiling of a building can be done by observation during the early decision-making stage. An understanding of the materials and construction methods will be necessary later to fully evaluate the extent of damage and retrofitting requirements. The roofs over most residential buildings consist of simple to complex wood framing that carries the ceilings below and plywood roof decks above, over which the roof finishes are placed. Finish materials include asphalt, wood, metal, clay and concrete tile, asbestos, and plastic, and are available in various compositions, shapes, and sizes. In some cases, observation may be enough to determine the suitability, structural rigidity, and continuing durability of a roof system. However, it may be necessary to remove a ceiling tile; examine shingles, slate, or roof tiles, or even bore into a roof to achieve a thorough inspection.

The inspection also determines if building materials and component parts are sound enough for the building to undergo elevation, relocation, or dry or wet floodproofing. If not, floodwalls or berms around the structure may be the best alternative if allowed by local ordinances.

Figure 2-16 presents a two-page worksheet that a designer can use to document findings during the initial building condition survey. Figure 2-17 provides a Retrofitting Screening Matrix based on many of the building characteristics discussed in this section; Figure 2-18 provides instructions for completing this matrix.

Preliminary Building Condition Worksheet – Superstructure

Owner Name: _____ Prepared By: _____

Address: _____ Date: _____

Property Location: _____

Exterior Finish: ☐ Siding ☐ Brick ☐ Stucco ☐ Other _____

Structure Level Floor/Wall	Composition Material/Spacing	Covering/Subfloor	Condition	Cracks/Water Damage Description/Location
First: Floor				
First: Walls				
Exterior				
Interior				
Second: Floors				
Second: Walls				
Exterior				
Interior				
Attic: Floors				
Attic: Walls				
Exterior				
Interior				
Roof				
Decks/Porches				

Structure Level Component	Total #	Composition	Condition	Cracks/Water Damage Description/Location
First: Windows				
First: Exterior Doors				
Second: Windows				
Second: Exterior Doors				
Attic Windows				
Skylights				

Figure 2-16. Preliminary Building Condition Worksheet (page 1 of 2)

Preliminary Building Condition Worksheet – Substructure and Service

Owner Name: _____ Prepared By: _____

Address: _____ Date: _____

Property Location: _____

Exterior Finish: ☐ Siding ☐ Brick ☐ Stucco ☐ Other _____

Foundation

Foundation Type	Wall Composition	Wall Thickness or Pile Size	Condition	Cracks/Water Damage Description/Location
☐ Monolithic slab ☐ Stem wall slab ☐ Basement ☐ Crawlspace ☐ Timber piles ☐ Other _____	☐ Masonry; CMU only ☐ Masonry; CMU and brick ☐ ICF* ☐ Poured concrete ☐ Precast ☐ Other _____			

Support Services

Service	Type	Location	Condition	Comment
Water Supply	☐ Municipal ☐ Well			
Wastewater Removal	☐ Municipal ☐ Septic			
Electrical	☐ Above ground supply ☐ Below ground supply ☐ Other			
Gas	☐ Municipal ☐ Other _____			
Heat	☐ Gas furnace ☐ Other _____			
Air Conditioning	☐ Central ☐ Other _____			
Ventilation				
Cable/Fiber Optic				
Telephone				

Figure 2-16. Preliminary Building Condition Worksheet (page 2 of 2)

Retrofitting Screening Matrix - Part C: Building Characteristics											
Owner Name:								**Preparer**			
Address:								**Date:**			
Property Details:											
Building Characteristic	**Retrofitting Measures**										
	Structural Elevation			**Elevation Alternatives**			**Relocation**	**Floodproofing**		**Flood Barriers**	
	Stem Wall (Fill)	**Perimeter Wall/ Piers**	**Piles**	**Basement Infill**	**Abandon/ Repurpose Lowest Floor**	**Elevate Lowest Interior Floor**		**Dry**	**Wet**	**Floodwall**	**Berm**
Pre-Screening from Preliminary Homeowner Preference Matrix											
Measure Not Feasible (NF)											
Building Foundation											
Slab-on-Grade			NR				NR		NR		
Basement	NR		NR					NR		NR	NR
Crawlspace/Piers	NR							NR			
Piles	NR	NR						NR			
Building Construction (Framing)											
Concrete/Masonry											
Wood Framing								NR			
Building Condition											
Excellent to Fair											
Poor	NR	NR	NR				NR	NR			
Scoring											
Subtotal Y's											
Subtotal NR's											
PART C Score = [Ys - (NRs)]											
PART A Score (see Part A)											
PART B Score (see Part B)											
FINAL SCORE = PART A Score + PART B Score + PART C Score											

Purpose: The purpose of the Retrofitting Screening Matrix Part C is to provide an initial technical assessment of existing building characteristics for retrofit project to determine what retrofit measures are the most feasible, and provide an initial combined assessment of flood, site, and building characteristics.

Matrix Notes:

NF Not Feasible: indicates the retrofit measure was pre-screened to be not allowed or not feasible based on the configuration of the existing structure and/or property. Refer to the Preliminary Homeowner Preference Matrix for details.

NR Not Recommended: indicates the retrofit measure is not recommended for this building condition.

ER Erosion Risk: indicates that fast flow velocity is conducive to erosion and the retrofit measure may need to be modified to address this hazard.

DI Debris Impact: indicates that debris flow or ice jam flooding is conducive to flood-borne debris impact and the retrofit measure may need to be modified to address this hazard.

Page 1 of 2. See next page for Instructions and Evaluation of Results

Figure 2-17. Retrofitting Screening Matrix for Building Characteristics

Retrofitting Screening Matrix - Part C: Building Characteristics (continued)	
Instructions:	Step 1: Complete pre-screening by placing an "NF" in the box for each measure which is not allowed or is not feasible based on the configuration of the existing structure and/or property using the Preliminary Homeowner Preference Matrix. For these measures, skip Steps 2 through 9 and put an "NF" for Not Feasible under the PART C Score and the FINAL SCORE. Step 2: Review the Building Foundation section and circle the Building Foundation row that matches the existing building foundation. Place a "Y" (Yes) for each measure along the Building Foundation row you circled unless there is an NF in the top row an NR already in that measure's box. Step 3: Review the Building Construction (Framing) section and circle the Building Construction row that matches the building framing. Place a "Y" (Yes) for each measure along the Building Construction (Framing) row you circled unless there is and NF in the top row of an NR already in that measure's box. Step 4: Review the Building Condition section and circle the Building Condition row that matches existing structural condition of the building. Place a "Y" (Yes) for each measure along the Building Condition row you circled unless there is an NF in the top row or an NR already in that measure's box. Step 5: In the Subtotal Y's row, add up the total number of "Y's" for each measure and input the subtotal in each column. Step 6: In the Subtotal NR's row, add up the number of "NR's" for each measure and input the subtotal in each column. Step 7: In the PART C Score row, take Subtotal Ys value (Step 5) and subtract both the Subtotal NRs value (Step 6) for each measure and input the total score in each column. Note the PART C Score can be a positive number, a negative number, or zero. Step 8: In the PART A and PART B Score rows, transfer the PART A Score from the Part A (Flood Characteristics) form and the PART B Score from the Part B (Site Characteristics) form in each column. Step 9: In the FINAL SCORE row, add the PART A Score, PART B Score and PART C Score rows and input the final total score in each column.
Evaluation of Results:	**Retrofit measures with the highest PART C Score are considered the most preferred** for addressing the existing building conditions. Retrofit measures with the lowest PART C Score or NF are considered the least preferred for addressing the existing building conditions. **Retrofit measures with the highest FINAL SCORE are considered the most preferred** for addressing the overall existing flood, site and building conditions. Retrofit measures with the lowest FINAL SCORE or NF are considered the least preferred for addressing the existing overall existing flood, site and building conditions.

Figure 2-18. Instructions for Completing the Retrofitting Screening Matrix for Building Characteristics (as shown in Figure 2-17)

2.9. Case Study Exercise 1

Use the information provided in the Case Study Introduction (Section 2.3) and the paragraphs that follow to complete the Preliminary Homeowner Retrofitting Preferences Matrix (Figure 2-7) and the three Retrofitting Screen Matrices (Figures 2-10, 2-14 and 2-17) by following the instructions (Figures 2-11, 2-15, and 2-18) for Case Studies A and B. Note supporting data and calculations can be found in Appendix A for Case Study A and Appendix B for Case Study B, with all Case Study C data found Appendix C.

Case Study A Exercise 1: Residential Retrofit in Riverine Floodplain Using Relocation or Elevation

Retrofit Options Selection

During an initial interview with Mr. and Mrs. Doe, potential retrofit options were discussed. Immediately, elevation on fill was ruled out because it is prohibited by the local floodplain ordinance. Similarly, dry floodproofing, wet floodproofing, floodwalls and small berms were all ruled out because these measures will not bring an existing home located in an Special Flood Hazard Area into compliance with the local floodplain management ordinance. As such, relocation and elevation were the only viable options for the structure that will comply with the local floodplain management regulations while also reducing National Flood Insurance Program flood insurance rates. Mr. and Mrs. Doe appreciated that the additional freeboard required by the floodplain ordinance may further reduce his National Flood Insurance Program flood insurance rates more than compliance with meeting the Base Flood Elevation. Cost was a factor for all viable retrofit options. Mr. and Mrs. Doe were particularly concerned about how their home might look with an open foundation. Based on Preliminary Homeowner Retrofitting Preferences Matrix (Figure CSA-3), the two most suitable options were 1) relocation and 2) elevating in place on taller foundation walls.

Additional evaluations by the Doe's engineer of the flood, site, and building characteristics confirmed that structural elevation on perimeter walls and piers, or relocation, were the most suitable options. The following retrofit screening matrices present the outcomes of these evaluations, as shown in Figures CSA-4 through CSA-6.

Preliminary Homeowner Retrofitting Preference Matrix											
Owner Name:	**John and Jane Doe**							**Preparer:**		**JJS-MH**	
Address:	**55 Cedar River Road**							**Date:**		**7/6/2026**	
Property Details:	**Case Study A**										
Considerations	**Retrofitting Measures**										
	Structural Elevation			**Elevation Alternatives**			**Relocation**	**Floodproofing**		**Flood Barriers**	
	Stem Wall (Fill)	**Perimeter Wall/ Piers**	**Piles**	**Basement Infill**	**Abandon/ Repurpose Lowest Floor**	**Elevate Lowest Interior Floor**		**Dry**	**Wet**	**Floodwall**	**Berm**
PART A: Local Regulations											
Measure Not Feasible (NF) or Not Allowed				X	X	X					
PART B: Homeowner Concerns											
Aesthetics	X	X	X					X			
High Cost	X	X	X				X				
Risk - Flood Insurance Rates								X	X	X	X
Accessibility							X				
Increase Flooding on Neighboring Sites	X						X			X	X
Other: Post-Flood Cleanup									X		
Total X's *(Lowest is Preferred)*	3	2	2	NF	NF	NF	3	2	2	2	2
Purpose:	The purpose of the Preliminary Homeowner Retrofitting Preference Matrix is to determine whether or not the retrofitting measure is allowed under local regulations or homeowner requirements.										
Instructions:	Step 1: Complete Part A of the matrix by placing an "X" in the box for each measure which is not feasible or is not allowed based on the configuration of the existing structure and/or property. For these measures, skip Steps 2 through 5 and put an "NF" for Not Feasible under the Total X's at the end of Part B. Step 2: Complete Part B of the matrix for only those measures that are allowable (no "X" in Part A). Step 3: For those measures allowed under Part A, evaluate the considerations in Part B to determine if the homeowner has concerns that would affect its implementation. A concern is defined as a homeowner issue that, if unresolved, could make the retrofitting measure infeasible. Step 4: If the homeowner has a concern, place an "X" in the box under the appropriate measure/consideration. Step 5: Add up the total number of X's for each allowable measure, and input the result under the Total X's at the end of Part B.										
Evaluation of Results:	The retrofitting measure(s) with the least number of X's (and no NF's) is the most preferred.										

Figure CSA-3. Preliminary Retrofitting Preference Matrix for the Doe house

Retrofitting Screening Matrix - Part A: Flood Characteristics											
Owner Name:	John and Jane Doe							Preparer		JJS-MH	
Address:	55 Cedar River Road							Date:		7/6/2026	
Property Details:	Case Study A										
Flood Characteristic	Retrofitting Measures										
	Structural Elevation			Elevation Alternatives			Relocation	Floodproofing		Flood Barriers	
	Stem Wall (Fill)	Perimeter Wall/ Piers	Piles	Basement Infill	Abandon/ Repurpose Lowest Floor	Elevate Lowest Interior Floor		Dry	Wet	Floodwall	Berm
Pre-Screening from Preliminary Homeowner Preference Matrix											
Measure Not Feasible (NF)				NF	NF	NF					
Flood Depth											
~~Shallow (< 3 ft)~~											
~~Moderate (3 to 6 ft)~~								~~NR~~			
Deep (> 6 ft)	Y	Y	Y				Y	NR	NR	NR	NR
Flood Velocity											
Slow/Moderate (≤ 5 ft/sec)	Y	Y	Y				Y	Y	Y	Y	Y
~~Fast (> 5 ft/sec)~~	~~ER~~	~~ER~~						~~NR~~		~~ER~~	~~ER~~
Flash Flood Risk											
~~High~~	~~ER~~	~~ER~~						~~NR~~	~~NR~~	~~NR~~	~~NR~~
Low to Moderate	Y	Y	Y				Y	Y	Y	Y	Y
Debris/Ice Jam Flood Risk											
~~High~~	~~DI~~	~~DI~~						~~NR~~		~~DI~~	~~DI~~
Low to Moderate	Y	Y	Y				Y	Y	Y	Y	Y
Scoring											
Subtotal Y's	4	4	4				4	3	3	3	3
Subtotal NR's	0	0	0				0	1	1	1	1
Subtotal ER's, DI's	0	0	0				0	0	0	0	0
PART A Score = [Ys - (NRs) - 0.5 (ERs + DIs)]	4	4	4	NF	NF	NF	4	2	2	2	2
Purpose:	The purpose of the Retrofitting Screening Matrix Part A is to provide an initial technical assessment of existing flood characteristics for retrofit project to determine what retrofit measures are the most feasible.										
Matrix Notes:	NF	Not Feasible: indicates the retrofit measure was pre-screened to be not allowed or not feasible based on the configuration of the existing structure and/or property. Refer to the Preliminary Homeowner Preference Matrix for details.									
	NR	Not Recommended: indicates the retrofit measure is not recommended for this flood condition.									
	ER	Erosion Risk: indicates that fast flow velocity/flash flooding is conducive to erosion and the retrofit measure may need to be modified to address this hazard.									
	DI	Debris Impact: indicates that debris flow or ice jam flooding is conducive to flood-borne debris impact and the retrofit measure may need to be modified to address this hazard.									
	Page 1 of 2. See next page for Instructions and Evaluation of Results										

Figure CSA-4. Retrofitting Screening Matrix: Flood Characteristics for the Doe house with applicable characteristics boxed in red for each row

Retrofitting Screening Matrix - Part B: Site Characteristics											
Owner Name:	John and Jane Doe							Preparer		JJS-MH	
Address:	55 Cedar River Road							Date:		7/6/2026	
Property Details:	Case Study A										
Site Characteristic	Retrofitting Measures										
	Structural Elevation			Elevation Alternatives			Relocation	Floodproofing		Flood Barriers	
	Stem Wall (Fill)	Perimeter Wall/ Piers	Piles	Basement Infill	Abandon/ Repurpose Lowest Floor	Elevate Lowest Interior Floor		Dry	Wet	Floodwall	Berm
Pre-Screening from Preliminary Homeowner Preference Matrix											
Measure Not Feasible (NF)				NF	NF	NF					
Site Flood Risk											
~~Low (Zone X)~~											
Moderate (Zone A)	Y	Y	NR				Y	Y	Y	Y	Y
~~High (Floodway)~~	~~NR~~	~~ER~~						~~NR~~	~~DR~~	~~NR~~	~~NR~~
~~High (Coastal A/Zone V)~~	~~NR~~	~~NR~~						~~NR~~	~~DR~~	~~NR~~	~~NR~~
Property Location											
~~Rural (large lots, widely spaced)~~											
Suburban (medium lots, moderately spaced)	Y	Y	Y				Y	Y	Y	Y	NR
~~Urban (small lots, densely spaced)~~	~~NR~~	~~NR~~	~~NR~~				~~NR~~	~~NR~~		~~NR~~	~~NR~~
Soil Type											
~~Permeable (granular)~~								~~NR~~		~~NR~~	~~NR~~
Impermeable (cohesive)	Y	Y	Y				Y	Y	Y	Y	Y
Scoring											
Subtotal Y's	3	3	2				3	3	3	3	2
Subtotal NR's	0	0	1				0	0	0	0	1
Subtotal ER's, DR's	0	0	0				0	0	0	0	0
PART B Score = [Ys - (NRs) - 0.5 (ERs + DRs)]	3	3	1	NF	NF	NF	3	3	3	3	1

Purpose: The purpose of the Retrofitting Screening Matrix Part B is to provide an initial technical assessment of existing site characteristics for retrofit project to determine what retrofit measures are the most feasible.

Matrix Notes:

NF Not Feasible: indicates the retrofit measure was pre-screened to be not allowed or not feasible based on the configuration of the existing structure and/or property. Refer to the Preliminary Homeowner Preference Matrix for details.

NR Not Recommended: indicates the retrofit measure is not recommended for this site condition.

ER Erosion Risk: indicates that Floodways are generally conducive to erosion and the retrofit measure may need to be modified to address this hazard.

DR Damage Risk: indicates that wet floodproofing measures can be damaged by high-velocity flooding from Floodways, Coastal A or V Zones.

Page 1 of 2. See next page for Instructions and Evaluation of Results

Figure CSA-5. Retrofitting Screening Matrix: Site Characteristics for the Doe house with applicable characteristics boxed in red for each row

Retrofitting Screening Matrix - Part C: Building Characteristics											
Owner Name:	John and Jane Doe							Preparer		JJS-MH	
Address:	55 Cedar River Road							Date:		7/6/2026	
Property Details:	Case Study A										
Building Characteristic	Retrofitting Measures										
	Structural Elevation			Elevation Alternatives			Relocation	Floodproofing		Flood Barriers	
	Stem Wall (Fill)	Perimeter Wall/ Piers	Piles	Basement Infill	Abandon/ Repurpose Lowest Floor	Elevate Lowest Interior Floor		Dry	Wet	Floodwall	Berm
Pre-Screening from Preliminary Homeowner Preference Matrix											
Measure Not Feasible (NF)				NF	NF	NF					
Building Foundation											
~~Slab-on-Grade~~			~~NR~~				~~NR~~		~~NR~~		
~~Basement~~	~~NR~~		~~NR~~					~~NR~~		~~NR~~	~~NR~~
Crawlspace/Piers	NR	Y	Y				Y	NR	Y	Y	Y
~~Piles~~	~~NR~~	~~NR~~						~~NR~~			
Building Construction (Framing)											
~~Concrete/Masonry~~											
Wood Framing	Y	Y	Y				Y	NR	Y	Y	Y
Building Condition											
Excellent to Fair	Y	Y	Y				Y	Y	Y	Y	Y
~~Poor~~	~~NR~~	~~NR~~	~~NR~~				~~NR~~	~~NR~~			
Scoring											
Subtotal Y's	2	3	3				3	1	3	3	3
Subtotal NR's	1	0	0				0	2	0	0	0
PART C Score = [Ys - (NRs)]	1	3	3	NF	NF	NF	3	-1	3	3	3
PART A Score (see Part A)	4	4	4	NF	NF	NF	4	2	2	2	2
PART B Score (see Part B)	3	3	1	NF	NF	NF	3	3	3	3	1
FINAL SCORE = PART A Score + PART B Score +	8	10	8	NF	NF	NF	10	4	8	8	6

Purpose: The purpose of the Retrofitting Screening Matrix Part C is to provide an initial technical assessment of existing building characteristics for retrofit project to determine what retrofit measures are the most feasible, and provide an initial combined assessment of flood, site, and building characteristics.

Matrix Notes:

- NF — Not Feasible: indicates the retrofit measure was pre-screened to be not allowed or not feasible based on the configuration of the existing structure and/or property. Refer to the Preliminary Homeowner Preference Matrix for details.
- NR — Not Recommended: indicates the retrofit measure is not recommended for this building condition.
- ER — Erosion Risk: indicates that fast flow velocity is conducive to erosion and the retrofit measure may need to be modified to address this hazard.
- DI — Debris Impact: indicates that debris flow or ice jam flooding is conducive to flood-borne debris impact and the retrofit measure may need to be modified to address this hazard.

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Figure CSA-6. Retrofitting Screening Matrix: Building Characteristics for the Doe house with applicable characteristics boxed in red for each row

If Mr. and Mrs. Doe's house remains in the floodplain, it must be elevated in accordance with the local floodplain management regulations. Since the local building code references ASCE 24

and the home is classified as a Design Flood Class 2, the Design Flood Elevation is the higher of the Base Flood Elevation plus 1 foot of freeboard or the Base Flood Elevation + local freeboard requirements. The local jurisdiction requires a freeboard of 2 feet, so the Design Flood Elevation will be the Base Flood Elevation + 2 feet; 697.8 + 2 feet = 699.8 feet. The FIRMette and flood profile provide the documentation of how this information was obtained, as shown in Figure CSA-7 and Figure CSA-8. The Design Flood Elevation is 699.8 feet, which offers protection up to the 500-year flood, and the 100-year flood plus 2 feet of freeboard.

Case Study A Note

Although the Doe house was not constructed with brittle exterior materials—such as brick veneer, stone, or stucco— special care needs to be taken with materials that are more susceptible to cracking or failure during elevation or relocation.

Note

A FIRMette is a full-scale section of a Flood Insurance Rate Map that a user creates themselves and is formatted to print on most home/office printers. A person can create a FIRMette from almost any effective Flood Insurance Rate Map on FEMA's online inventory using the *FIRMette Web* tool. To create a FIRMette, first visit the FEMA Flood Map Service Center at https://msc.fema.gov/portal/home, then type in the address and click the Search button. Next click the Dynamic Map button to preview the FIRMette for download or print. For additional information on *FIRMette Web* and the more advanced *FIRMette Desktop* application, visit the FEMA Flood Map Service Center Products and Tools Overview page.

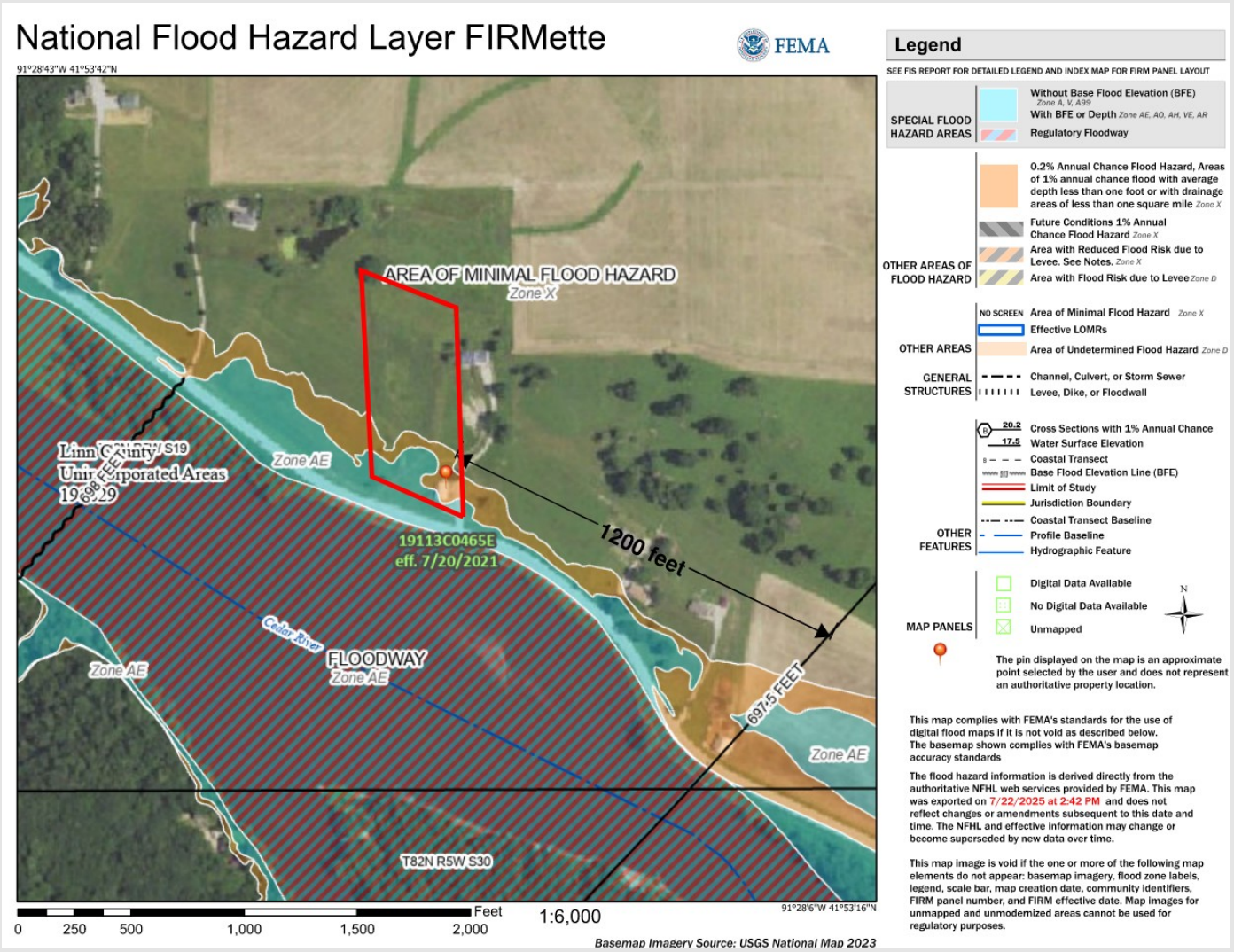


Figure CSA-7. FIRMette showing (a) Location of the Doe plot (boxed in red) Flood Insurance Rate Map Panels: 19113C0465E (b) Distance of Doe house (1,200 feet) from the Cedar River profile section H, measured from the FEMA National Flood Hazard Layer viewer

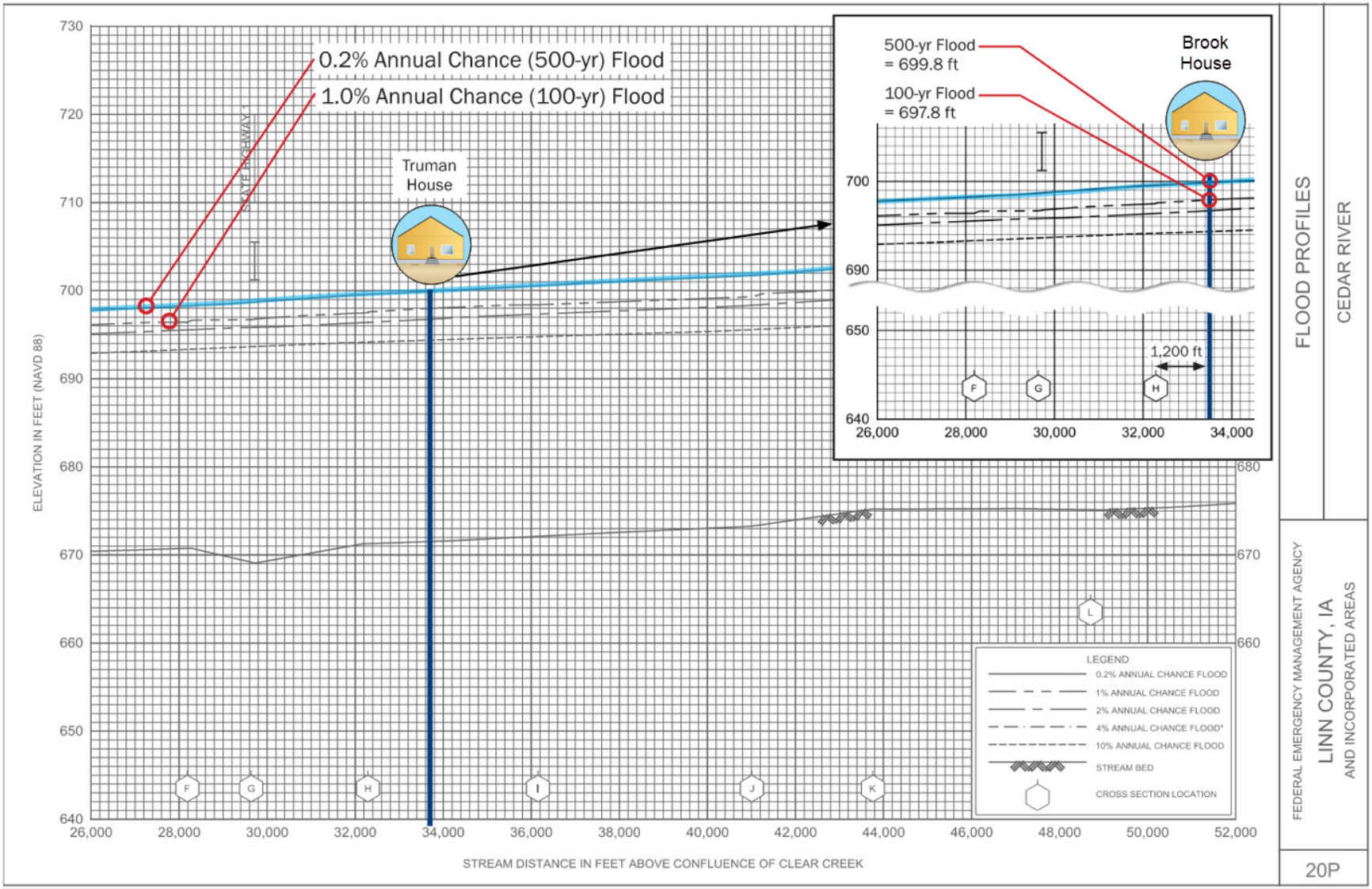


Figure CSA-8. Flood elevations at the Doe house 1,200 feet from section H on the flood profile for the Cedar River

As shown in Figure CSA-9, the first floor elevation (i.e., the top of the lowest floor) is 694.2 feet, and the elevation of the lowest adjacent grade (LAG) is 692.2 feet. The floodproofing depth (H) is the Design Flood Elevation minus the lowest adjacent grade and equals 7.6 feet (699.8 feet – 692.2 feet).

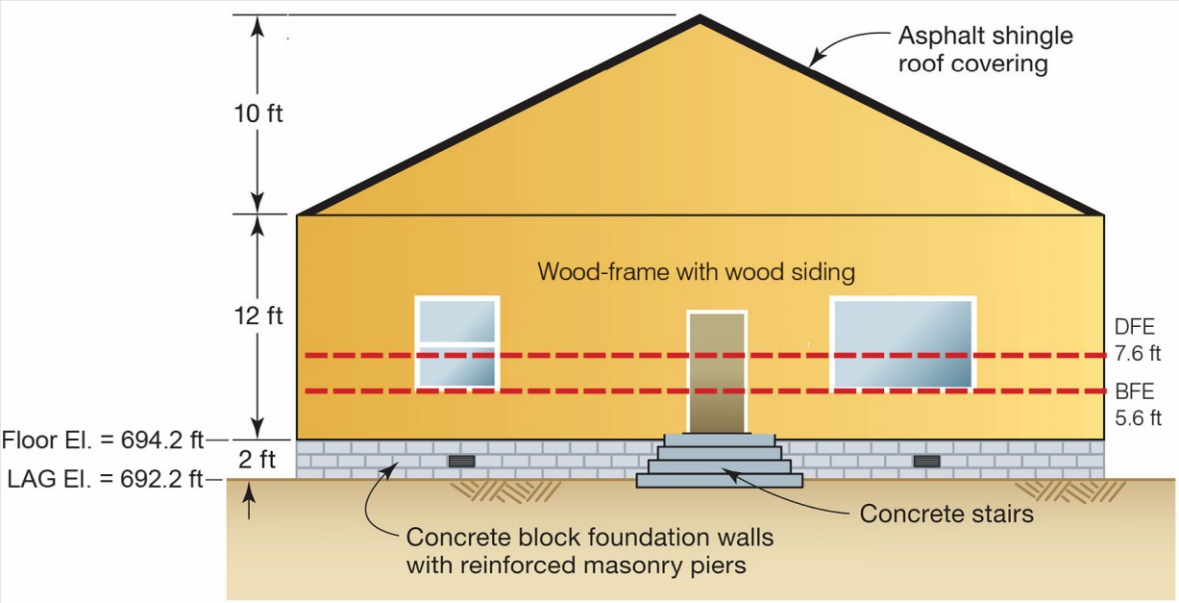


Figure CSA-9. Front elevation with key elevations and floodproofing depth

The crawlspace is an enclosed area in the Special Flood Hazard Area and is below the Base Flood Elevation. As such, it must have flood openings that equalize hydrostatic pressures by allowing for the automatic entry and exit of floodwaters. Because the crawlspace is already 2 feet high, the perimeter foundation walls need to be an additional 5.6 feet taller to place the first floor (retrofitted lowest floor) elevation at the Design Flood Elevation (i.e., 7.6 feet above the lowest adjacent grade).

Figure CSA-10 shows the proposed elevated structure. Note that the concrete staircase has been replaced with wooden stairs that allow water to flow through the base.

Note

To ensure that the foundation is properly designed, the flood forces should be calculated and checked with applicable design loads. See Section 3.1.6 for example calculations.

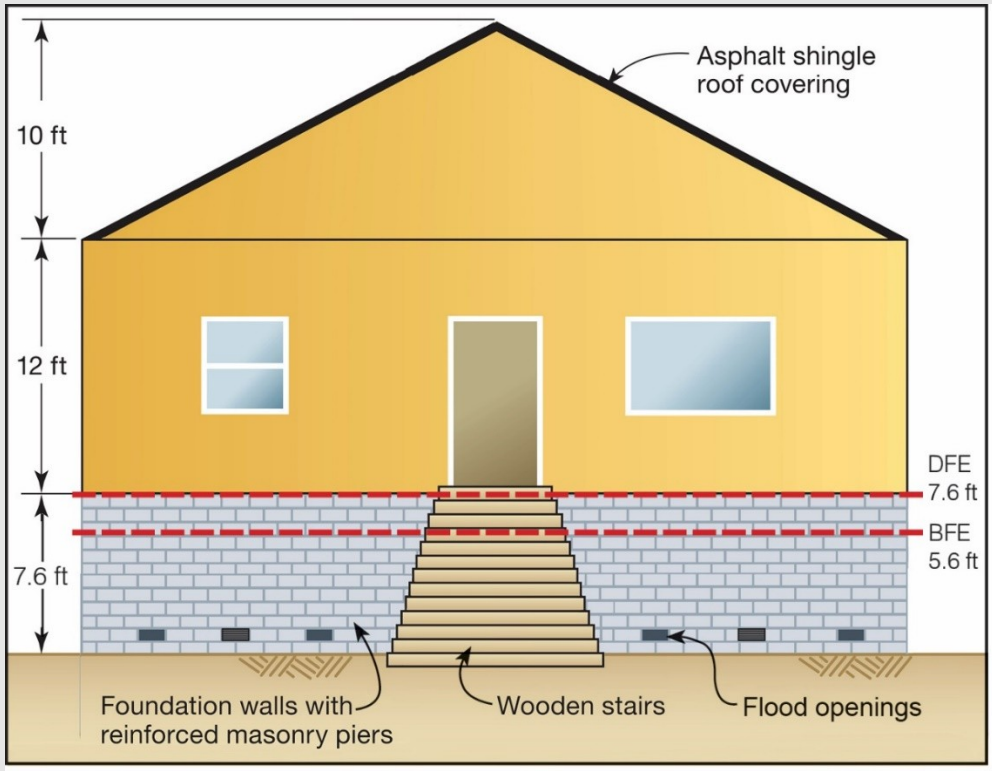


Figure CSA-10 The Doe house after elevation, including extended foundation walls and flood openings

Case Study B Exercise 1

Case Study B Exercise 1: Residential Retrofit Outside of the Floodplain Using Floodwalls or Dry Floodproofing

Retrofit Options Selection

Because The Valley Apartments is a large masonry building outside the floodplain, Mr. Smith has ruled out the expensive option of elevating. He does not have any desire to move the building; therefore, relocation is also not viable. Wet floodproofing was considered, but in discussions with the tenants, Mr. Smith was repeatedly told that the tenants did not like the idea of floodwaters coming into the building. Therefore, 1) floodwalls and 2) dry floodproofing are considered the only viable options. The following preliminary homeowner preferences and retrofitting screening matrices show the most preferable options (Figure CSB-2):

- Mr. Smith would like to protect The Valley Apartments from 2 feet of flooding plus a 1-foot of freeboard.
- Upon review with his engineer, Mr. Smith decided that 3 feet of protection would offer protection beyond any historical floods experienced in the area.

After working through the screening matrices, Mr. Smith confirmed that the most suitable options would be the construction of a floodwall or dry floodproofing. Both of these options had the best overall score. See Figure CSB-3 through Figure CSB-5 for documentation of these screening worksheets.

Preliminary Homeowner Retrofitting Preference Matrix											
Owner Name:	**John Smith**							**Preparer:**	**JJS-MH**		
Address:	**2908 Valley Drive**							**Date:**	**7/6/2026**		
Property Details:	**Case Study B**										
Considerations	**Retrofitting Measures**										
	Structural Elevation			**Elevation Alternatives**			**Relocation**	**Floodproofing**		**Flood Barriers**	
	Stem Wall (Fill)	**Perimeter Wall/ Piers**	**Piles**	**Basement Infill**	**Abandon/ Repurpose Lowest Floor**	**Elevate Lowest Interior Floor**		**Dry**	**Wet**	**Floodwall**	**Berm**
PART A: Local Regulations											
Measure Not Feasible (NF) or Not Allowed	**X**	**X**	**X**	**X**	**X**	**X**	**X**				
PART B: Homeowner Concerns											
Aesthetics											**X**
High Cost											
Risk - Flood Insurance Rates											
Accessibility											
Increase Flooding on Neighboring Sites											
Other: Post-Flood Cleanup									**X**		
Total X's ***(Lowest is Preferred)***	**NF**	**NF**	**NF**	**NF**	**NF**	**NF**	**NF**		**1**		**1**
Purpose:	The purpose of the Preliminary Homeowner Retrofitting Preference Matrix is to determine whether or not the retrofitting measure is allowed under local regulations or homeowner requirements.										
Instructions:	Step 1: Complete Part A of the matrix by placing an "X" in the box for each measure which is not feasible or is not allowed based on the configuration of the existing structure and/or property. For these measures, skip Steps 2 through 5 and put an "NF" for Not Feasible under the Total X's at the end of Part B. Step 2: Complete Part B of the matrix for only those measures that are allowable (no "X" in Part A). Step 3: For those measures allowed under Part A, evaluate the considerations in Part B to determine if the homeowner has concerns that would affect its implementation. A concern is defined as a homeowner issue that, if unresolved, could make the retrofitting measure infeasible. Step 4: If the homeowner has a concern, place an "X" in the box under the appropriate measure/consideration. Step 5: Add up the total number of X's for each allowable measure, and input the result under the Total X's at the end of Part B.										
Evaluation of Results:	The retrofitting measure(s) with the least number of X's (and no NF's) is the most preferred.										

Figure CSB-2. Preliminary Retrofitting Preference Matrix for The Valley Apartments

Retrofitting Screening Matrix - Part A: Flood Characteristics											
Owner Name:	John Smith							Preparer		JJS-MH	
Address:	2908 Valley Drive							Date:		7/6/2026	
Property Details:	Case Study B										
Flood Characteristic	Retrofitting Measures										
	Structural Elevation			Elevation Alternatives			Relocation	Floodproofing		Flood Barriers	
	Stem Wall (Fill)	Perimeter Wall/ Piers	Piles	Basement Infill	Abandon/ Repurpose Lowest Floor	Elevate Lowest Interior Floor		Dry	Wet	Floodwall	Berm
Pre-Screening from Preliminary Homeowner Preference Matrix											
Measure Not Feasible (NF)	NF	NF	NF	NF	NF	NF	NF				
Flood Depth											
Shallow (≤ 3 ft)								Y	Y	Y	Y
~~Moderate (>3 to 6 ft)~~								~~NR~~			
~~Deep (> 6 ft)~~								~~NR~~	~~NR~~	~~NR~~	~~NR~~
Flood Velocity											
Slow/Moderate (≤ 5 ft/sec)								Y	Y	Y	Y
~~Fast (> 5 ft/sec)~~	~~ER~~	~~ER~~						~~NR~~		~~ER~~	~~ER~~
Flash Flood Risk											
~~High~~	~~ER~~	~~ER~~						~~NR~~	~~NR~~	~~NR~~	~~NR~~
Low to Moderate								Y	Y	Y	Y
Debris/Ice Jam Flood Risk											
~~High~~	~~DI~~	~~DI~~						~~NR~~		~~DI~~	~~DI~~
Low to Moderate								Y	Y	Y	Y
Scoring											
Subtotal Y's								4	4	4	4
Subtotal NR's	0	0	0				0	0	0	0	0
Subtotal ER's, DI's	0	0	0				0	0	0	0	0
PART A Score = [Ys - (NRs) - 0.5 (ERs + DIs)]	NF	NF	NF	NF	NF	NF	NF	4	4	4	4

Purpose: The purpose of the Retrofitting Screening Matrix Part A is to provide an initial technical assessment of existing flood characteristics for retrofit project to determine what retrofit measures are the most feasible.

Matrix Notes:

- NF — Not Feasible: indicates the retrofit measure was pre-screened to be not allowed or not feasible based on the configuration of the existing structure and/or property. Refer to the Preliminary Homeowner Preference Matrix for details.
- NR — Not Recommended: indicates the retrofit measure is not recommended for this flood condition.
- ER — Erosion Risk: indicates that fast flow velocity/flash flooding is conducive to erosion and the retrofit measure may need to be modified to address this hazard.
- DI — Debris Impact: indicates that debris flow or ice jam flooding is conducive to flood-borne debris impact and the retrofit measure may need to be modified to address this hazard.

Page 1 of 2. See next page for Instructions and Evaluation of Results

Figure CSB-3. Retrofitting Screening Matrix: Flood Characteristics for The Valley Apartments, with applicable characteristics boxed in red for each row

Retrofitting Screening Matrix - Part B: Site Characteristics											
Owner Name:	John Smith							Preparer		JJS-MH	
Address:	2908 Valley Drive							Date:		7/6/2026	
Property Details:	Case Study B										
	Retrofitting Measures										
	Structural Elevation			Elevation Alternatives			Relocation	Floodproofing		Flood Barriers	
Site Characteristic	Stem Wall (Fill)	Perimeter Wall/ Piers	Piles	Basement Infill	Abandon/ Repurpose Lowest Floor	Elevate Lowest Interior Floor		Dry	Wet	Floodwall	Berm
Pre-Screening from Preliminary Homeowner Preference Matrix											
Measure Not Feasible (NF)	NF	NF	NF	NF	NF	NF	NF				
Site Flood Risk											
Low (Zone X)			NR					Y	Y	Y	Y
~~Moderate (Zone A)~~			~~NR~~								
~~High (Floodway)~~	~~NR~~	~~ER~~						~~NR~~	~~DR~~	~~NR~~	~~NR~~
~~High (Coastal A/Zone V)~~	~~NR~~	~~NR~~						~~NR~~	~~DR~~	~~NR~~	~~NR~~
Property Location											
~~Rural (large lots, widely spaced)~~											
Suburban (medium lots, moderately spaced)								Y	Y	Y	NR
~~Urban (small lots, densely spaced)~~	~~NR~~	~~NR~~	~~NR~~				~~NR~~	~~NR~~		~~NR~~	~~NR~~
Soil Type											
~~Permeable (granular)~~								~~NR~~		~~NR~~	~~NR~~
Impermeable (cohesive)								Y	Y	Y	Y
Scoring											
Subtotal Y's								3	3	3	2
Subtotal NR's								0	0	0	1
Subtotal ER's, DR's								0	0	0	0
PART B Score = [Ys - (NRs) - 0.5 (ERs + DRs)]	NF	NF	NF	NF	NF	NF	NF	3	3	3	1
Purpose:	The purpose of the Retrofitting Screening Matrix Part B is to provide an initial technical assessment of existing site characteristics for retrofit project to determine what retrofit measures are the most feasible.										
Matrix Notes:	NF Not Feasible: indicates the retrofit measure was pre-screened to be not allowed or not feasible based on the configuration of the existing structure and/or property. Refer to the Preliminary Homeowner Preference Matrix for details. NR Not Recommended: indicates the retrofit measure is not recommended for this site condition. ER Erosion Risk: indicates that Floodways are generally conducive to erosion and the retrofit measure may need to be modified to address this hazard. DR Damage Risk: indicates that wet floodproofing measures can be damaged by high-velocity flooding from Floodways, Coastal A or V Zones.										
	Page 1 of 2. See next page for Instructions and Evaluation of Results										

Figure CSB-4. Retrofitting Screening Matrix: Site Characteristics for The Valley Apartments, with applicable characteristics boxed in red for each row

Retrofitting Screening Matrix - Part C: Building Characteristics											
Owner Name:	John Smith							Preparer		JJS-MH	
Address:	2908 Valley Drive							Date:		7/6/2026	
Property Details:	Case Study B										
Building Characteristic	Retrofitting Measures										
	Structural Elevation			Elevation Alternatives			Relocation	Floodproofing		Flood Barriers	
	Stem Wall (Fill)	Perimeter Wall/ Piers	Piles	Basement Infill	Abandon/ Repurpose Lowest Floor	Elevate Lowest Interior Floor		Dry	Wet	Floodwall	Berm
Pre-Screening from Preliminary Homeowner Preference Matrix											
Measure Not Feasible (NF)	NF	NF	NF	NF	NF	NF	NF				
Building Foundation											
Slab-on-Grade			NR				NR	Y	NR	Y	Y
~~Basement~~	~~NR~~		~~NR~~					~~NR~~		~~NR~~	~~NR~~
~~Crawlspace/Piers~~	~~NR~~							~~NR~~			
~~Piles~~	~~NR~~	~~NR~~						~~NR~~			
Building Construction (Framing)											
Concrete/Masonry								Y	Y	Y	Y
~~Wood Framing~~								~~NR~~			
Building Condition											
Excellent to Fair								Y	Y	Y	Y
~~Poor~~	~~NR~~	~~NR~~	~~NR~~				~~NR~~	~~NR~~			
Scoring											
Subtotal Y's								3	2	3	3
Subtotal NR's								0	1	0	0
PART C Score = [Ys - (NRs)]	NF	NF	NF	NF	NF	NF	NF	3	1	3	3
PART A Score (see Part A)	NF	NF	NF	NF	NF	NF	NF	4	4	4	4
PART B Score (see Part B)	NF	NF	NF	NF	NF	NF	NF	3	3	3	1
FINAL SCORE = PART A Score + PART B Score + PART C Score	NF	NF	NF	NF	NF	NF	NF	10	8	10	8
Purpose:	The purpose of the Retrofitting Screening Matrix Part C is to provide an initial technical assessment of existing building characteristics for retrofit project to determine what retrofit measures are the most feasible, and provide an initial combined assessment of flood, site, and building characteristics.										
Matrix Notes:	NF Not Feasible: indicates the retrofit measure was pre-screened to be not allowed or not feasible based on the configuration of the existing structure and/or property. Refer to the Preliminary Homeowner Preference Matrix for details. NR Not Recommended: indicates the retrofit measure is not recommended for this building condition. ER Erosion Risk: indicates that fast flow velocity is conducive to erosion and the retrofit measure may need to be modified to address this hazard. DI Debris Impact: indicates that debris flow or ice jam flooding is conducive to flood-borne debris impact and the retrofit measure may need to be modified to address this hazard. Page 1 of 2. See next page for Instructions and Evaluation of Results										

Figure CSB-5. Retrofitting Screening Matrix: Building Characteristics for The Valley Apartments, with applicable characteristics boxed in red for each row

2.10. Balancing Historic Preservation With Flood Protection

Many historic buildings were built deliberately or intuitively to accommodate natural and environmental hazards, topography, and climate as they were known at the time. Recognizing how and why these buildings are constructed can inform a flood mitigation strategy that is appropriate for the building architecture and neighborhood characteristics, which minimizes incongruous modifications to historic residential properties.

There are retrofitting steps that will not have a negative or even significant impact upon the historic character of a site or the building features. Flood damage preventive measures can be implemented without damaging or detracting from the historic character of the property if the design and installation are carefully supervised by a historic preservation professional. State and local historic preservation offices may require plan review and approval for flood retrofit projects on historic buildings.

There may be instances when a retrofitting measure that protects the site or residence may result in loss of historic character. In these instances, the owner and designer will have to consider the cost of compromising character or historic authenticity against the benefit of flood damage prevention. Initially, consultation with the State Historic Preservation Officer will determine if the property is subject to State or National Historic Register modification rules.

Options may include elevation of a historic structure located in a flood hazard area, relocation out of the flood hazard area, dry or wet floodproofing protection with a floodwall or berm, or no action, recognizing that leaving the building vulnerable to flooding risks damage or loss. It is difficult to prescribe a specific evaluation protocol for historic structures due to the uniqueness of each building's location, structural condition, site features, the variety of preventive alternatives available, cost, and degree of potential loss of historic character. Factors for historic structure evaluation include:

- What is the risk that the historic feature or the entire site could be destroyed or substantially damaged if flood retrofitting is not employed? Will mitigation adequately reduce flood risk?
- Are there preventive alternatives that provide less protection from flood damage, but also detract less from historic character? What are they, and what is the trade-off between protection and loss of character?
- Are there design elements that can enhance the retrofit measure to lessen the detraction of historic character?

Additional Resources

Information detailing maintenance of features of historic properties in flood hazard areas can be found in:

- FEMA P-467-2, Floodplain Management Bulletin: Historic Structures, May 2008.
- The U.S. Secretary of the Interior's Standards for Rehabilitation and Guidelines of Flood Adaptation for Rehabilitating Historic Buildings, 2021.

2.11. Multiple Hazards

The selection of a retrofitting method may expose the structure to additional non-flood environmental hazards that could jeopardize the safety of the structure. Multiple hazards can be mitigated through the design of the retrofitting measure or may necessitate the selection of a different retrofitting method. Detailed information concerning the analysis and design for multiple hazards is contained in Chapters 3 and 4.

Significant flood-related hazards to consider include ice and debris flow, impact forces, and erosion forces. These hazards are discussed in Sections 3.1 and 3.2. Mudslides or alluvial fan impacts are addressed in Appendix E. Non-flood-related hazards to consider include earthquake and wind forces. Less significant hazards addressed in Chapter 3 include land subsidence, wildfires, snow loads, moveable bed streams, and closed basin lakes. Multiple hazards may affect a structure independently, such as floods and earthquakes, or concurrently, as with flood and wind in a coastal area.

Older buildings and structures were typically constructed to resist gravity loads only. Gravity loads consisted of vertical downward loads (their own weight or dead load) plus loads that considered building contents and people (live loads) on the floors. The roofs of structures were built to resist rain and snow. However, the builder may not have considered lateral and uplift loads from earthquakes, wind and buoyant loads from flooding, debris impact, saturated soil loads, among others.

2.11.1. WIND FORCES

High winds impose forces on a home and the structural elements of its foundation. Damage potential is increased when the wind forces occur in combination with flood forces. In addition, when a structure or home is elevated to minimize the effects of flood forces, the wind loads on the elevated structure may be increased. Occasionally, structural elements are laid on top of each other with minimal fastening. However, wind forces can be upwards or from any direction, exerting considerable pressure on structural components such as walls, roofs, connections, and anchorage. Therefore, wind loads should be considered in the design process at the same time as hydrostatic, hydrodynamic, and impact dead and live loads as prescribed under the applicable codes.

Additional Resources

FEMA P-804, *Wind Retrofit Guide for Residential Buildings* (FEMA, Second Edition, Second Issuance April 2023) provides guidance to improve the performance of homes in hurricane-prone regions throughout the U.S. Wind damage is mitigated through the implementation of groups of mitigation actions or packages that strengthen the building structure and its components.

2.11.2. EARTHQUAKE FORCES

Earthquakes generate dynamic seismic ground motion acceleration forces that may be simplified into static lateral forces using methods like the Equivalent Lateral Force Procedure in ASCE 7-22. Subsequently, the designer divides and distributes the resultant lateral force vertically across the different levels of the modeled structure. The structural configuration of the overall building, height above base, and the vertical combination of individual structural systems affect the load distribution and, therefore, demand critical consideration in the retrofitting process. Shear walls, lateral connections between each level, foundation reinforcement, and anchorage must be analyzed and, where appropriate, retrofitted to withstand earthquake forces as part of the complete retrofit project.

Additional Resources

FEMA 530, *Earthquake Safety Guide for Homeowners* (March 2020) introduces the basics of strengthening homes against earthquake damage and illustrates the relative cost of prevention versus repair or replacement.

For guidance on seismic retrofits of existing homes, see FEMA 232, *Homebuilders' Guide to Earthquake-Resistant Design and Construction (2024).*

Chapter 3. Determination of Site-Specific Hazards

Chapters 1 and 2 introduce retrofitting measures, highlight some general considerations when evaluating measures, and provide an overview of the retrofitting process. Chapter 2 summarizes regulatory requirements and retrofitting parameters, including the process of determining owner preferences and the hazards that need to be considered.

Retrofitting buildings requires design and construction that ensures the structure is connected and anchored to resist flotation, collapse, and lateral movement due to all combinations of loads and geotechnical conditions appropriate to potential site hazards. Consideration of floodwalls and berms also requires determining site-specific conditions.

- Section 3.1 explains flood elevation and level of protection options. Analyses necessary to determine flood- and non-flood-related forces and other site-specific considerations that control the retrofitting design are covered. This information may be useful as the designer and owner determine which retrofitting measures are technically feasible.
- Section 3.2 describes flooding characteristics and flood loads, including hydrostatic and hydrodynamic forces, flood frequency and duration, debris impact forces, and alluvial fan hazards.
- Section 3.3 describes other hazards, such as earthquakes and wind forces, as well as wildland-urban interface fire.
- Section 3.4 describes site-specific soil or geotechnical considerations, such as soil pressure, bearing capacity, land subsidence, erosion, scour, and shrink-swell potential.

3.1. Flood Elevations, Compliance, and Level of Protection

Section 2.1 describes the regulatory requirements of the National Flood Insurance Program and refers to a summary of the requirements of the International Codes and a referenced standard cited in those codes. That section also cautions property owners and design professionals to determine whether states and communities have adopted more restrictive requirements that would apply to their projects.

3.1.1. WHEN COMPLIANCE IS REQUIRED: STATE AND LOCAL REQUIREMENTS FOR DESIGN FLOOD ELEVATION

Guidance on the minimum requirements of the National Flood Insurance Program when compliance is required is provided. Compliance is required for retrofit projects that address substantial improvement or substantial damage within Special Flood Hazard Areas by elevating homes on new foundations or relocating homes. For these project types, state and local floodplain management requirements that are more restrictive or stringent than the minimum requirements of the National Flood Insurance Program take precedence. Design professionals, builders, and property owners should contact local officials to determine if more restrictive provisions apply to the proposed flood

retrofitting project. All other applicable requirements of the state or local building codes must also be met.

Base Flood Elevation is the water surface elevation of the base flood (1% annual chance flood) and the minimum elevation requirement for the lowest floor. The most common higher standard adopted by communities and some states is called "freeboard." Freeboard is an additional height or elevation above the minimum flood level (Base Flood Elevation). It is generally phrased as one, two, three, or more feet above the Base Flood Elevation.

The standards referenced in the 2024 International Codes – the 2022 edition of ASCE 7 *Minimum Design Loads and Associated Criteria for Buildings and Other Structures* and the 2014 edition of ASCE 24, *Flood Resistant Design and Construction* – define the terms Design Flood and Design Flood Elevations as follows:

- ***Design Flood:*** *The greater of the following two flood events: (1) the base flood, affecting those areas identified as special flood hazard areas on the community's FIRM; or (2) the flood corresponding to the area designated as a flood hazard area on a community's flood hazard map or otherwise legally designated.*

- ***Design Flood Elevation (DFE):*** *The elevation of the design flood, including wave height, relative to the datum specified on a community's flood hazard map.*

The Design Flood Elevation is used to refer to the flood elevation required for regulatory compliance of retrofitting design. Traditionally, the Design Flood Elevation was determined based on the Base Flood Elevation plus freeboard or by the elevation of the design flood specified by the community's flood hazard map. For residential buildings, the 2014 edition of ASCE 24 specifies a minimum freeboard of one foot above the Base Flood Elevation, but communities can specify a freeboard of two, three, or more feet.



Note

The 2027 International Codes may reference the 2024 edition of ASCE 24 (ASCE 24-24), which reflects ASCE 7-22 Supplement 2. The area regulated is the Special Flood Hazard Area plus the 500-year floodplain, where mapped on Flood Insurance Rate Maps. The 500-year floodplain only applies to Flood Design Classes 2-4. In ASCE 24-24 for residential (Flood Design Class 2) structures, the Design Flood Elevation is redefined as the higher of the 500-year flood elevation (0.2% annual chance flood) for residential buildings or the flood elevation established by the community. Additional guidance on this proposed design practice can be found in Appendix D.

3.1.2. WHEN COMPLIANCE IS NOT REQUIRED: FLOOD PROTECTION LEVEL

Compliance is not required for retrofit projects to wet floodproof or dry floodproof houses if the work is not determined to be a substantial improvement or the result of substantial damage repairs to the building. In addition, a specific flood elevation is not required for projects that reduce flood risk through construction of floodwalls or berms. Flood protection level is used to refer to the elevation of flood protection selected by the owner and used by the designer to evaluate the design of retrofitting measures when compliance is not required.



Note

Designers are encouraged to use a flood protection level that meets or exceeds the Design Flood Elevation whenever it is technically and economically feasible for the owner.

3.2. Analysis of Flood-Related Hazards

The success of retrofitting measures depends on a site-specific assessment of the flood-related forces on a structure during different frequency floods. The Flooding Characteristics Section 2.2.3.3 describes floodwater surrounding a building exerting numerous forces on the structure, including lateral and vertical hydrostatic forces, hydrodynamic forces, and debris impact forces. In addition, flood-related conditions such as surface water accumulation, lake flooding, erosion, scour and debris flows may pose a danger and require evaluation (see Figure 3-1).

Standing or slow-moving water can create horizontal hydrostatic forces (pressures) against a structure when floodwater levels on different sides of the structure are unequal. Saturated soils beneath the ground surface also impose hydrostatic loads on foundation components.

Hydrodynamic forces result from the flow of moving water against or around a structure. These high-velocity water flows can destroy solid walls and dislodge buildings with inadequate foundations. Impact loads are imposed on the structure by water-borne objects, and their effects become greater as the flow velocity and the weight of the objects increase. The basic equations for analyzing and considering flood-related forces are provided in this chapter.

Minimum requirements for flood-resistant design may be found in both consensus standards *Minimum Design Loads and Associated Criteria for Buildings and Other Structures* (ASCE 7) and *Flood Resistant Design and Construction* (ASCE 24). Equations for calculating the forces for riverine flood-related hazards can be found later in this chapter. The focus of FEMA P-259 is on new and substantially improved construction, principally detached single-family homes, attached single-family homes (townhouses), and low-rise (three-story or less) multi-family buildings.

Additional Resources

Additional information concerning the determination of flood-related forces is available in Chapter 5 of ASCE 7, *Minimum Design Loads and Associated Criteria for Buildings and Other Structures*.

Building codes are referenced in ASCE 24, *Flood Resistant Design and Construction,* which includes requirements for buildings and structures in flood hazard areas.



Figure 3-1. Flood-related hazards (top left: aerial view of alluvial fan; top right: moveable bed stream; bottom left: aerial view of closed basin lake; bottom right: urban flooding and interior drainage)

3.2.1. FLOOD DEPTH AND DESIGN FLOOD DEPTH

Determining the expected flood depth at a site is critical for the overall determination of flood-related hazards. The method for making this determination can vary depending on whether the site is located in the riverine floodplain.

Riverine Flooding

One method of determining the 100-year water surface elevations involves using a Flood Insurance Rate Map panel (see Note below). The Flood Insurance Rate Map panel identifies the specific flood zone(s) and Base Flood Elevations of the project area in question. For simplicity purposes, this publication determines flood depths using DFIRMs. On most DFIRMs, floodplain limits are delineated for the 1% and 0.2% annual chance flood.

Note

This section focuses on the 100-year (1% annual chance) flood elevations that are displayed on the current Digital Flood Insurance Rate Maps (DFIRMs) or Flood Insurance Rate Maps. As stated previously in Chapter 2, DFIRMs/Flood Insurance Rate Maps can be viewed in community offices, as part of state or local GIS mapping functions, or online at FEMA's Map Service Center, https://msc.fema.gov/portal/home, where users can make FIRMettes (full-scale portions of Flood Insurance Rate Maps).

Flood Depth and Floodproofing Design Depth

After gathering flood data from the riverine DFIRM and Flood Insurance Study, it is possible to compute the depth of flooding at a structure for any of the recurrence intervals defined along the flooding source. Flood depth can be computed by subtracting the lowest ground surface elevation (grade) adjacent to the structure from the flood elevation for a specific flood frequency, as shown in Equation 3-1.

EQUATION 3-1: FLOOD DEPTH

$$d = FE - GS$$

Where:

d = depth of flooding (ft)

FE = flood elevation for a specific flood frequency (ft)

GS = lowest ground surface elevation (grade) adjacent to a structure (ft)

Note

When computing flood depth, be sure to use the lowest eroded ground surface adjacent to the structure in question, as shown in Figure 3-2.

The Floodproofing Design Depth (H) is related to the Design Flood Elevation (DFE) is illustrated in Equation 3-2. As discussed in Section 3.1.1, the Design Flood Elevation is used to refer to the flood elevation required for regulatory compliance of retrofitting design. This Design Flood Elevation can be determined based on the Base Flood Elevation plus freeboard or by the elevation of the design flood specified by the community's flood hazard map. For residential buildings, the 2014 edition of ASCE 24 specifies a minimum freeboard of one foot above the Base Flood Elevation, but communities can specify a freeboard of two, three, or more feet.

As discussed in Section 3.3.2, retrofits that are not required to achieve the community's National Flood Insurance Program regulatory compliance requirements may use the flood protection level, which refers to the floodproofing design elevation established by the owner. The flood protection level can match or even exceed the Design Flood Elevation, but in other cases, the owner may choose a lower level of protection if the existing residence will not trigger any higher regulatory elevation or building code requirements through substantial improvements or is located outside the mapped floodplain. However, this may impact current flood insurance rates (see Caution). Additionally, if the residential structure is Substantially Improved or Substantially Damaged and is located in the floodplain, then it will need to be elevated to the Design Flood Elevation or relocated outside the floodplain.

Caution

If an owner chooses to protect an existing residential structure in the floodplain to a flood protection level that is below the Design Flood Elevation, then flood insurance rates previously subsidized by the National Flood Insurance Program are expected to increase until they reach current actual rates.

Determining the floodproofing design depth at the structure (H) is important for the flood load calculation process. Nearly every other flood load parameter or calculation (e.g., hydrostatic load, hydrodynamic load, vertical hydrostatic load, debris impact load, and local scour depth) depends directly or indirectly on the floodproofing design depth. The floodproofing design depth *(H)* is the difference between the Design Flood Elevation and the lowest grade adjacent to the structure (Figure 3-2). This computation is shown in Equation 3-2.

EQUATION 3-2: FLOODPROOFING DESIGN DEPTH

$$H = DFE - GS$$

Where:

H = floodproofing design depth over which flood forces are considered (ft)

DFE = Design Flood Elevation (ft)

GS = lowest ground surface elevation (grade) adjacent to the structure (or other reference feature such as a slab or footing) (ft)

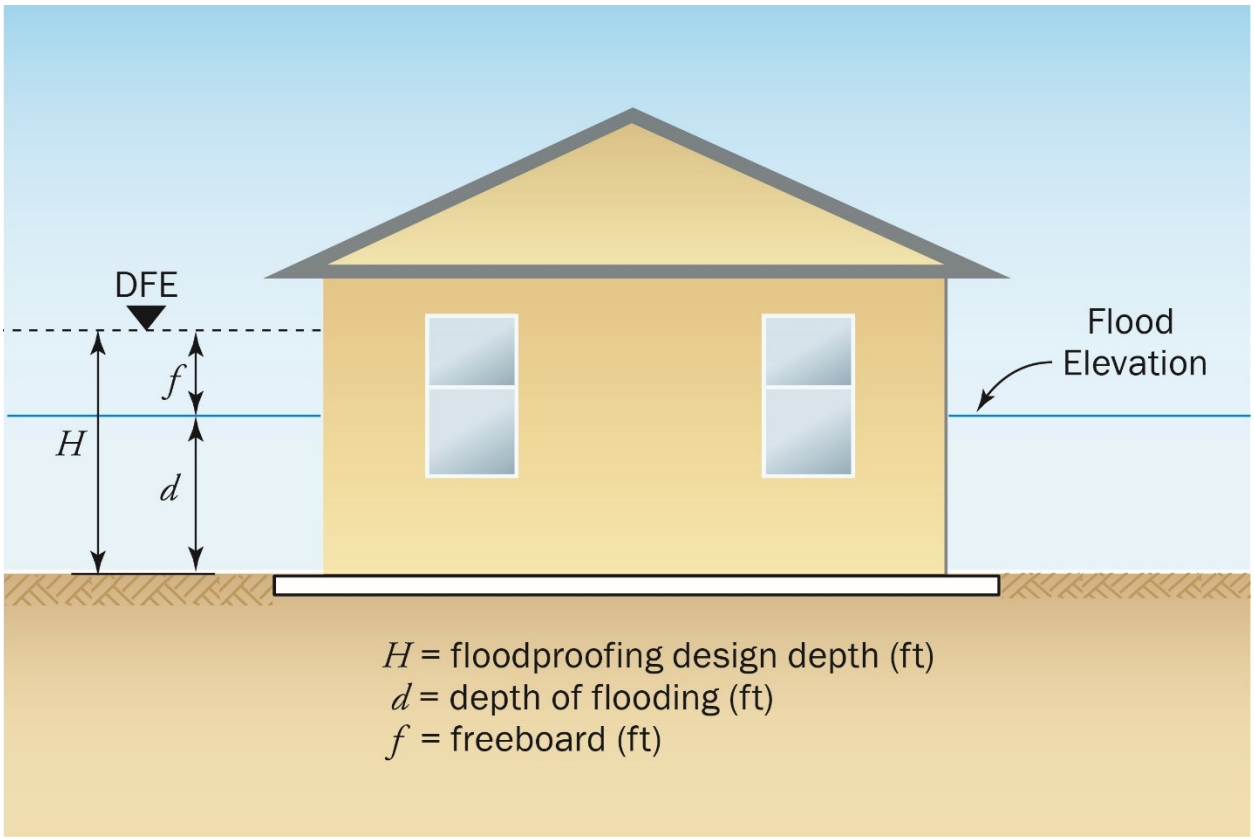


Figure 3-2. Flood depth and design depth

3.2.2. HYDROSTATIC FORCES

The force or load exerted by standing water is called “hydrostatic load” or “hydrostatic pressure.” At any point that floodwater contacts a structure, hydrostatic pressures are equal in all directions and act perpendicular to the surface on which they are applied. These loads increase linearly with depth or “head” of water. Unbalanced horizontal hydrostatic loads and vertical buoyancy forces are created when the level of standing or slow-moving floodwater on opposite sides of a wall or structure is not equal. For structural analysis, hydrostatic loads on grade level foundations are shown in Figure 3-3. These loads act:

- Laterally, in a horizontal direction on walls, grade slabs, and similar vertical surfaces. (For design purposes, this lateral force is assumed to act on the receiving structure at a point one-third of the water depth above the base of the structure or two-thirds of the distance from the water surface, which correlates to the center of gravity for a triangular pressure distribution.)

- Vertically upward (buoyancy) from the underside of generally horizontal members such as slabs, floor diaphragms, and footings (also known as uplift).

In rare instances where structures, or dry floodproofed vaults, are completely submerged, hydrostatic forces also act vertically downward on flat roofs and similar overhead members having a depth of water above them.

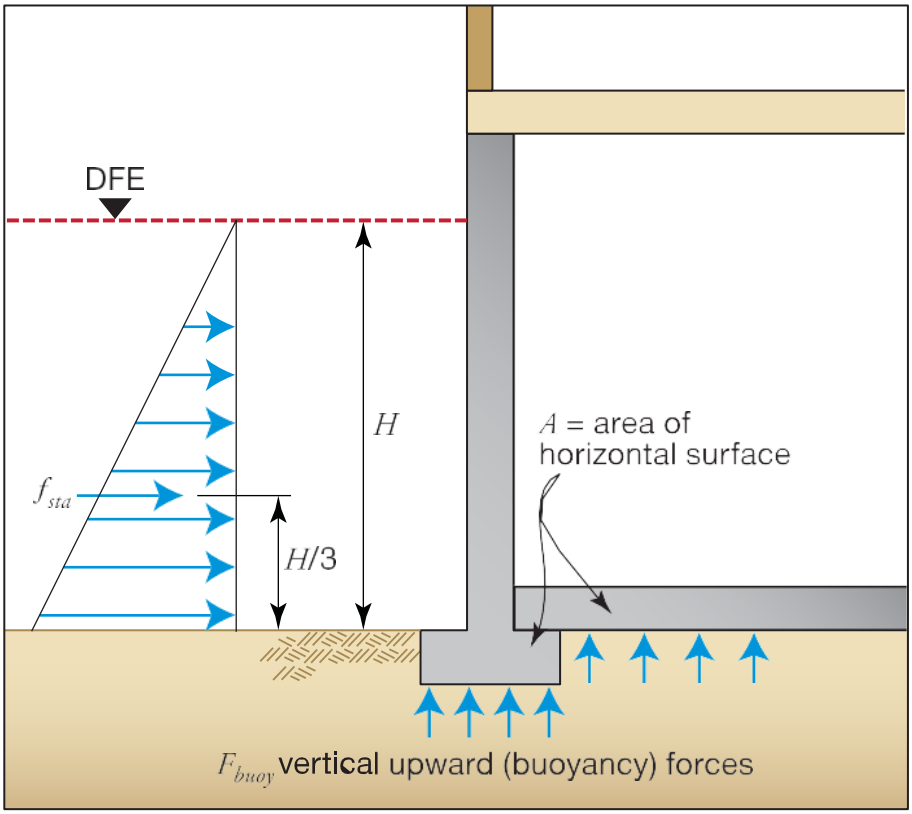


Figure 3-3. Diagram of hydrostatic forces on grade level or open foundation

Hydrostatic forces include lateral water pressures, combined water and soil pressures, equivalent hydrostatic pressures for slow moving water, and vertical (buoyancy) water pressures. The computation of each of these pressures is illustrated in the sections that follow.

Lateral Hydrostatic Forces

The basic equation for analyzing the lateral force due to hydrostatic pressure from standing water at and above the ground surface is illustrated in Equation 3-3. Note that lateral hydrostatic forces are a function of flood depth.

EQUATION 3-3: LATERAL HYDROSTATIC FORCE ABOVE GRADE

$$f_{sta} = \frac{1}{2}P_h H = \frac{1}{2}\gamma_w H^2$$

Where:

f_{sta} = hydrostatic force from standing water (lb/lf) acting at a distance $H/3$ above ground.

P_h = hydrostratic pressure due to standing water at a depth of H (lb/ft^2), $(P_h = \gamma_w H)$

γ_w = specific weight of water ($62.4\ lb/ft^3$ for fresh water and $64.0\ lb/ft^3$ for saltwater)

Extended Lateral Hydrostatic and Saturated Soil Forces

If any portion of the structure or a closed foundation (crawlspace, basement) is below grade with the intent of keeping floodwaters outside the structure, the hydrostatic force must be increased or extended to account for below grade elements, and saturated soil forces must be included in the computation in addition to the hydrostatic force, as illustrated in Figure 3-4. The basic equation for analyzing the increased lateral force due to hydrostatic pressure from standing water above the surface of the ground and extending below grade to the bottom of the submerged structure is shown in Equation 3-4.

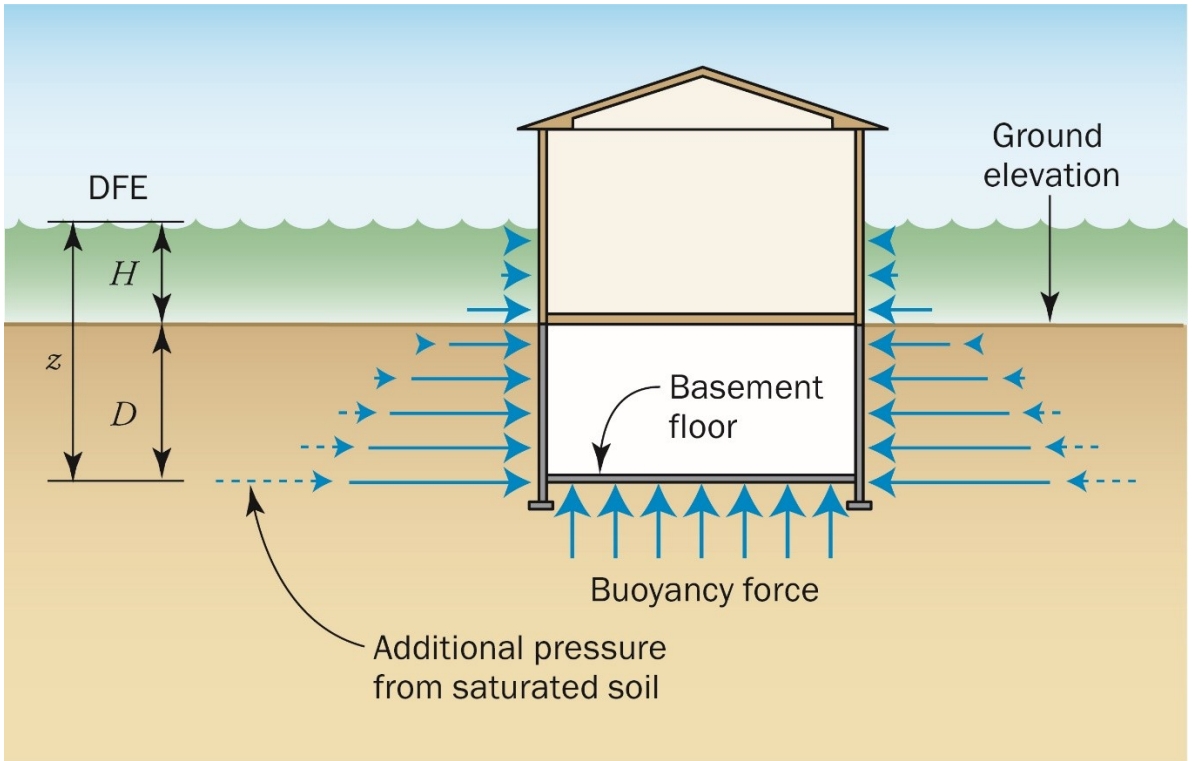


Figure 3-4. Combination of increased hydrostatic forces and combined soil and water forces on submerged building with closed foundation below grade

EQUATION 3-4: LATERAL HYDROSTATIC FORCE EXTENDED BELOW GRADE

$$f_{stae} = \frac{1}{2}(\gamma_w)z^2$$

Where:

f_{stae} = extended hydrostatic force from standing water (lb/lf) acting above grade and extending below grade at a distance $z/3$ above the bottom of the submerged structure.

z = Floodproofing design depth (H) above grade extended to include depth of saturated soil from below grade extending to bottom of submerged structure (D) (ft)

γ_w = Specific weight of water (62.4lb/ft^3 for freshwater and 64.0lb/ft^3 for saltwater)

Combined Soil And Water Forces

When a structure is subject to hydrostatic forces from both saturated soil and standing water (illustrated in Figure 3-4), the resultant combined lateral force, f_{comb}, is the sum of the lateral water hydrostatic force, f_{stae}, and the differential between the water and soil pressures, f_{dif}. The basic equation for computing f_{dif} is shown in Equation 3-5.

EQUATION 3-5: SUBMERGED SOIL AND WATER FORCES

$$f_{dif} = \frac{1}{2}(S - \gamma_w)D^2$$

Where:

f_{dif} = differential soil/water force acting at a distance $D/3$ from the point under consideration (lb/lf)

S = equivalent fluid weight of submerged soil and water (lb/ft^3) as shown in Table 3-3

D = Depth of saturated soil from adjacent grade to the top of the footer (ft)

γ_w = Specific weight of water (62.4lb/ft^3 for freshwater and 64.0lb/ft^3 for saltwater)

The equivalent fluid weight of submerged soil and water for various soil types is presented in Tables 3-3 and 3-4.

Note

The S values in Table 3-1 represent minimum (loose soil) and maximum (dense soil) weights within the specified range. In the absence of geotechnical site data, the maximum values should be used in Equation 3-5 to obtain a conservative estimate.

Table 3-1. Effective Equivalent Fluid Weight of Submerged Soil and Water

Soil Type[1]	Equivalent Fluid Weight of Submerged Soil and Water (Total Unit Weight of Fully Saturated Soil)[2,3] (lb/ft³)
Sand and gravel (GW, GP, GM, GM-GP, SW, SP, SM, SM-SP)	119 - 154
Mixed soils - silts and clays, silty fine sands, clayey sands, and gravels (CL, ML, CH, MH, SM, SC, GC)	124 - 156
Clay and organic soils (CL, ML, OL, CH, CH, OH)	93 - 133

1 Soil types are based on U.S. Department of Agriculture Unified Soil Classification System; see Table 3-2 for soil type definitions.

2 Values derived by adding 62 lb/ft³ to the submerged weight from Table 6 in Soil Mechanics DESIGN MANUAL 7.01 by Naval Facilities Engineering Command (NAVFAC) (NAVFAC 1986).

3 Values represent minimum (loose soil) and maximum (dense soil weights within the specified range.

Table 3-2. Soil Type Definitions Based on USDA Unified Soil Classification System

Soil Type	Group Symbol	Description
Gravels	GW	Well-graded gravels and gravel mixtures
Gravels	GP	Poorly graded gravel-sand-silt mixtures
Gravels	GM	Silty gravels, gravel-sand-silt mixtures
Gravels	GC	Clayey gravels, gravel-sand-clay mixtures
Sands	SW	Well-graded sands and gravelly sands
Sands	SP	Poorly graded sands and gravelly sands
Sands	SM	Silty sands, poorly graded sand-silt-mixtures
Sands	SC	Clayey sands, poorly graded sand-clay mixtures
Fine Grain Silt/Clays	ML	Inorganic silts and clayey silts
Fine Grain Silt/Clays	CL	Inorganic clays of low to medium plasticity
Fine Grain Silt/Clays	OL	Organic silts and organic silty clays of low plasticity
Fine Grain Silt/Clays	MH	Inorganic silts, micaceous or fine sands or silts, elastic silts
Fine Grain Silt/Clays	CH	Inorganic clays of high plasticity, fine clays
Fine Grain Silt/Clays	OH	Organic clays of medium to high plasticity

Vertical Hydrostatic Forces (Buoyancy)

The basic equation for analyzing the vertical hydrostatic force (buoyancy) due to standing water (illustrated by Figures 3-3, 3-4) is shown in Equation 3-6.

The computation of hydrostatic forces is vital to the successful design of floodwalls, sealants, closures, shields, foundation walls, dry floodproofed areas, and a variety of other retrofitting measures. The Hydrostatic Force Computation Worksheet (Figure 3-5) can be used to conduct hydrostatic calculations.

EQUATION 3-6: BUOYANCY FORCES

$$F_{buoy} = \gamma_w(Vol)$$

Where:

F_{buoy} = vertically hydrostatic force resulting from the displacement of a given volume of floodwater (lb)

γ_w = specific weight of water (62.4lb/ft^3 for fresh water and 64.0lb/ft^3 for saltwater)

Vol = volume of water displaced by the building (*Height (H)* x *Area (A)* in ft^3 shown in Figures 3-3, 3-4)

Hydrostatic Force Computation Worksheet

Owner Name:		**Preparer**	
Address:		**Date:**	
Property Details:			

Constants

γ_w = unit weight of water = _____ lbs/ft^3

(62.4 lbs/ft^3 for fresh water and 64.0 lbs/ft^3 for saltwater)

Variables

H = flood design depth (ft) = _____ ft

z = flood design depth extended below grade (ft) = _____ ft

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

Soil Type = USDA Unified Soil Classification = _____

S = equivalent fluid weight of saturated soil (lbs/ft^3) = _____ lbs/ft^3

(see Table 3-1 for S as a function of Soil Type)

Vol = volume of floodwater displaced by a submerged object (ft^3) = _____ ft^3

Summary of Loads

f_{sta} = _____ lbs/LF

f_{stae} = _____ lbs/LF

f_{dif} = _____ lbs/LF

f_{comb} = _____ lbs/LF

F_{buoy} = _____ lbs

Hydrostatic Force Above Grade (see Equation 3-3)

$f_{sta} = 1/2\ P_h H = 1/2\ \gamma_w\ H^2 =$ lbs/LF

Hydrostatic Force Extended Below Grade (see Equation 3-4)

$f_{stae} = 1/2\ \gamma_w\ z^2 =$ lbs/LF

Submerged Soil and Water Force (see Equation 3-5)

$f_{dif} = 1/2\ (S - \gamma_w)\ D^2 =$ lbs/LF

Buoyancy Force (see Equation 3-6)

$F_{buoy} = \gamma_w\ (Vol) =$ lbs

Note: Equations 3-3, 3-4 and 3-5 do not account for equivalent hydrostatic loads due to the low velocity of floodwaters (less than 10 ft/sec). If velocity floodwater exists, use hydrodynamic force Equations 3-7, 3-8, 3-9 and 3-10.

Figure 3-5. Hydrostatic Force Computation Worksheet

3.2.3. HYDRODYNAMIC FORCES

When floodwater flows around a structure, it imposes additional loads on the structure, as shown in Figure 3-6. These loads are a function of flow velocity and structural geometry.

Note

The focus of this section is on frontal impact hydrodynamic forces that maximize the total flood force since they are added to lateral hydrostatic and debris impact forces.

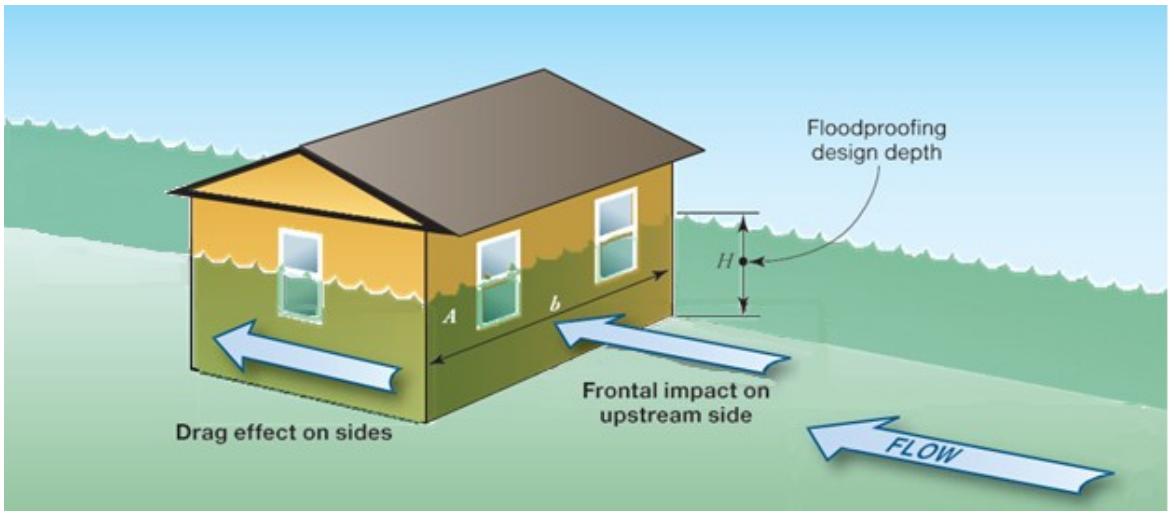


Figure 3-6. Hydrodynamic and impact forces

Low Velocity Hydrodynamic Forces

For buildings subject to low floodwater velocities that do not exceed 10 feet/second, the hydrodynamic effects of moving water can be converted to an equivalent hydrostatic force by increasing the depth of the water (head) above the flood level by an amount dh, which is shown in Equation 3-7.

The drag coefficient used in Equation 3-7 is taken from the Shore Protection Publication, Volume 2 (USACE, 1984). The drag coefficient (C_d) is a function of the shape of the object around which flow is directed. Unless otherwise evaluated, the value of C_d shall not be less than 1.25 and can be determined from the width-to-height ratio, b/H, of the structure in question. The width (b) is the length of the side perpendicular to the flow, and the height (H) is the distance from the floodproofing design depth to the lowest adjacent grade. Table 3-5 gives C_d values for different width-to-height ratios.

Note

Data sources for determining flood flow velocity include floodway velocities from a FIS, historical measurements, and rules of thumb. Floodwater that is one foot deep moving more than five feet/second can knock an adult over and erode stream banks. Overbank velocities are usually less than stream channel (floodway) velocities. If flood flow velocity data does not exist for a site, contact an experienced hydrologist or hydraulic engineer for estimates.

EQUATION 3-7: CONVERSION OF LOW VELOCITY FLOW TO EQUIVALENT HEAD

$$dh = \frac{C_d V^2}{2g}$$

Where:

dh = equivalent head due to low velocity flood flows (ft)

C_d = drag coefficient (from Table 3-3)

V = Velocity of floodwater (ft/sec)

g = Acceleration of gravity (equal to 32.2ft/sec^2)

Table 3-3. Drag Coefficients for Ratios of Width-to-Height

Width-to-Height Ratio (b/H)	Drag Coefficient (Cd)
1–12	1.25
13–20	1.3
21–32	1.4
33–40	1.5
41–80	1.75
81–120	1.8
>120	2.0

The value *dh* is then converted to an equivalent hydrostatic pressure through the use of the basic equation for lateral hydrostatic forces introduced earlier in this chapter and modified, as shown in Equation 3-8.

EQUATION 3-8: CONVERSION OF EQUIVALENT HEAD TO EQUIVALENT HYDROSTATIC FORCE

$$f_{dh} = \gamma_w (dh) H = P_{dh} H$$

Where:

f_{dh} = equivalent hydrostatic force due to low velocity flood flows (lb/lf)

γ_w = specific weight of water (62.4lbft^3 for fresh water and 64.0lb/ft^3 for saltwater)

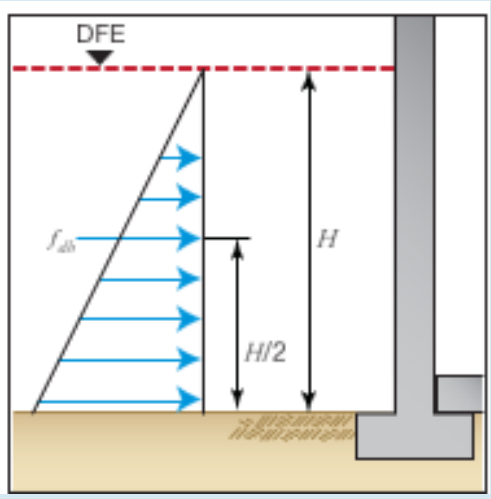
dh = Equivalent head due to low velocity flood flows (ft)

H = Floodproofing design depth (ft)

P_{dh} = hydrostatic pressure due to low velocity flood flows (lb/ft^2)

Note

Although f_{dh} is technically considered a hydrostatic force for velocities under 10 feet/second, it acts at a point $H/2$, similarly to high velocity lateral hydrodynamic forces.



High Velocity Hydrodynamic Forces

For buildings subject to high floodwater velocities greater than 10 feet/second, a more detailed analysis and evaluation should be made utilizing basic concepts of fluid mechanics and/or hydraulic models. The basic equation for hydrodynamic pressure is shown in Equation 3-9.

EQUATION 3-9: HIGH VELOCITY HYDRODYNAMIC PRESSURE

$$P_d = C_d \rho \frac{V^2}{2}$$

Where:

P_d = hydrodynamic pressure (lb/ft^2)

C_d = drag coefficient (Taken from Table 3-3)

ρ = Mass density of fluid (1.94 slugs/ft^3 for fresh water and 1.99 slugs/ft^3 for salt water)

V = Velocity of floodwater (ft/sec)

After determination of the hydrodynamic pressure (Pd), the total hydrodynamic force (Fd) against the structure (see Figure 3-6) can be computed as the pressure times the area over which the water is affecting (see Equation 3-10). The Hydrodynamic Force Calculation Worksheet (Figure 3-7) can be used to compute low or high velocity hydrodynamic loads.

EQUATION 3-10: TOTAL HYDRODYNAMIC FORCE

$$F_d = P_d A$$

Where:

F_d = Total force against the structure (lb)

P_d = hydrodynamic pressure (lb/ft^2)

A = Submerged area of the upstream face of the structure (ft^2)

Hydrodynamic Force Computation Worksheet

Owner Name:		**Preparer**	
Address:		**Date:**	
Property Details:			

Constants

γ_w = unit weight of water = _____ lbs/ft^3

(62.4 lbs/ft^3 for fresh water and 64.0 lbs/ft^3 for saltwater)

g = acceleration of gravity = 32.2 ft/sec^2

ρ = mass density of water = _____ slugs/ft^3

(1.94 slugs/ft^3 for fresh water and 1.99 slugs/ft^3 for saltwater)

Variables

H = flood design depth (ft) = _____ ft

V = velocity of floodwater (ft/sec) = _____ ft/sec

(use Equations 3-7 and 3-8 if V ≤ 10 ft/sec; use Equations 3-9 and 3-10 if V > 10 ft/sec)

b = width of structure perpendicular to flow (ft) = _____ ft

b/H = ratio of width to height = _____

C_d = drag coefficient = _____

(taken from Table 3-3 as a function of b/H)

A = submerged area on upstream face of structure (ft^2) = (b)(H) = _____ ft^2

Summary of Loads

f_{dh} = _____ lbs/LF

f_{sta} = _____ lbs/LF

f_{stae} = _____ lbs/LF

f_{dif} = _____ lbs/LF

f_{comb} = _____ lbs/LF

P_d = _____ lbs/ft^2

F_d = _____ lbs

Conversion of Low Velocity Flood Flow to Equivalent Head (see Equation 3-7)

$dh = C_d V^2/2g =$ ft

Conversion of Equivalent Head to Equivalent Hydrostatic Force (see Equation 3-8)

$f_{dh} = \gamma_w (dh)H = P_{dh} H =$ lbs/LF

High Velocity Dynamic Pressure (see Equation 3-9)

$P_d = C_d \rho V^2/2 =$ lbs/ft^2

Total Hydrodynamic Force (see Equation 3-10)

$F_d = P_d A =$ lbs

Figure 3-7. Hydrodynamic Force Computation Worksheet

3.2.4. IMPACT LOADS

Impact loads are imposed on structures by objects carried by moving floodwater. The magnitude of these loads is difficult to predict, but some reasonable allowance must be made for them in retrofitting design measures for at risk buildings. Particularly in areas with forested upstream watersheds, potential impacts from uprooted trees should be considered. To arrive at a realistic allowance, judgment must be used, along with the designer's knowledge of site-specific debris risk and potential debris damage to the structure. Impact loads are classified as:

- No impact (for areas of little or no velocity or potential source of debris)
- Normal impact
- Special impact
- Extreme impact

Cross Reference

Section 5.4.5 of ASCE 7 and the corresponding commentary contain an extensive discussion on computing riverine and coastal impact loads.

Normal Impact Loads

Normal impact loads relate to isolated occurrences of typically sized debris or floating objects striking the structure (see Figure 3-6 for the location of frontal impact from debris). For design purposes, this can be considered a concentrated load acting horizontally at the flood elevation, or any point below it, equal to the impact force. The normal impact force is created by a typical object traveling at the velocity of the floodwater, acting on a 1-square-foot surface of the submerged structure area, perpendicular to the flow. Typical object size and mass will vary by location, but the ASCE 7 *Commentary,* Section C5.4.5 (Debris Weight), provides some guidance. The calculation of normal impact forces (loads) is shown in Equation 3-11, based on ASCE 7, its commentary, and assumptions for typical residential structures covered in this guidance. Laydown collapse hazards from trees should be considered in forested watersheds.

Often, there are regional differences between the size, shape, and weight of water-borne debris and debris velocity. Designers should consider locally adopted guidance because it may be based on more recent information or data specific to local hazards than the information in ASCE 7.

Warning

Although normal impact loads tend to be relatively small in comparison to other flood loads, they can present a significant risk to structures elevated on open foundations (e.g., piers, posts, columns, or piles). For these structures, in situations where large quantities of debris are being carried at higher velocities, the debris can accumulate and dam up the open spaces between the foundations. This can significantly increase the lateral loads being transferred to the structure, thereby increasing the risk of collapse.

EQUATION 3-11: NORMAL IMPACT LOADS

$$F_i = WVC_D C_B C_{Str}$$

Where:

F_i = impact force acting at the Base Flood Elevation (lb)

W = weight of the object (lb)

V = velocity of water (ft/sec)

C_D = Depth of coefficient (see Table 3-4)

C_B = blockage coefficient (taken as 1.0 for no upstream screening, flow path greater than 30 ft; see Table 3-5 for more information)

C_{Str} = building structure coefficient

= 0.2 for timber pile and masonry pier/column supported structures 3 stories or less in height above grade

= 0.4 for concrete pile or concrete or steel moment resisting frames 3 stories or less in height above grade

= 0.8 for reinforced concrete (including insulated concrete) and reinforced masonry foundation walls

Table 3-4. Depth Coefficient (C_D) by Flood Hazard Zone and Water Depth

Flood Hazard Zone and Water Depth	C_D
Floodway[1]	1.0
Zone A, flood depth > 5 ft	1.0
Zone A, flood depth = 4 ft	0.75
Zone A, flood depth = 3 ft	0.5
Zone A, flood depth = 2 ft	0.25
Zone A, flood depth < 1 ft	0.0

[1]Per ASCE 24, a "floodway" is a "channel and that portion of the floodplain reserved to convey the base flood without cumulatively increasing the water surface elevation more than a designated height."

Table 3-5. Values of Blockage Coefficient (C_B)

Degree of Screening or Sheltering within 100 ft Upstream	C_B
No upstream screening, flow path wider than 30 ft	1.0
Limited upstream screening, flow path 20 ft wide	0.6
Moderate upstream screening, flow path 10 ft wide	0.2
Dense upstream screening, flow path less than 5 ft wide	0.0

Impact forces are critical design considerations that must be thoroughly evaluated. The following Impact Force Computation Worksheet, Figure 3-8, can be used to conduct normal impact force calculations.

Impact Force Computation Worksheet

Owner Name:		**Preparer**	
Address:		**Date:**	
Property Details:			

Variables

W = weight of the object (lbs) = _____ lbs
(see Note 1 for recommended values and guidance)

V = velocity of floodwater (ft/sec) = _____ ft/sec

C_D = depth coefficient = _____
(taken from Table 3-4 as a function of hazard zone and water depth)

C_B = blockage coefficient = _____
(taken from Table 3-5 as a function of flow path and upstream screening)

C_{Str} = building structure coefficient = _____
= 0.2 for timber pile and masonry column-supported structures 3 stories or less in height above grade
= 0.4 for concrete pile or concrete or steel moment-resisting frames 3 stories or less in height above grade
= 0.8 for reinforced concrete (including insulated concrete forms) and reinforced masonry foundation walls

Normal Impact Loads (see Equation 3-11)

$F_i = W V C_D C_B C_{Str}$ = lbs

Notes:

1. Regarding W: ASCE 7-22 Commentary recommends W = 1,000 lbs as a reasonable average weight of the object for normal impact force. Additional guidance from the ASCE 7-22 Commentary is provided below:
   a. Use W = 1,000 to 2,000 lbs for riverine and coastal floodplains with large woody debris.
   b. Use W < 1,000 lbs for arid and semi-arid regions.
   c. Use W = 1,000 to 4,000 lbs for riverine floodplains subject to floating ice.
   d. Use W = 4,000 lbs for the Pacific Northwest to represent larger trees and logs.
   e. Use W < 500 lbs for coastal areas without large pilings.

   Relocation is recommended where more extreme impact forces are a threat.

2. Regarding C_D from Table 3-4: Per ASCE 24-14, a "floodway" is a "channel and that portion of the floodplain reserved to convey the base flood without cumulatively increasing the water surface elevation more than a designated height."

Figure 3-8. Impact Force Computation Worksheet

Special And Extreme Impact Loads

Special impact forces occur when large objects or conglomerates of floating objects, such as ice floes or accumulations of floating debris, strike a structure. Where stable natural or artificial barriers exist that would effectively prevent these special impact forces from occurring, these forces may not need to be considered in the design. Details for calculating special impact loads are outlined in the ASCE 7 commentary Section C5.4.5.

Extreme impact forces occur when large, floating objects, such as runaway barges or collapsed buildings and structures, strike the structure (or a component of the structure). These forces generally occur within the floodway or areas of the floodplain that experience the highest velocity flows. It is impractical to design residential buildings to have adequate strength to resist extreme impact forces.

Note

The assumption that debris velocity is equal to the flood velocity may overstate the velocities of large debris objects; therefore, engineering judgment may be required in some instances. Designers may wish to reduce debris velocity for larger objects.

Note

Where extreme impact loads are a hazard, the preferred retrofitting alternative is relocation.

3.3. Case Study Exercise 2

Use the information provided in the Case Study Introduction (Section 2.3) and Case Study Exercise 1 (Section 2.9) to complete the Hydrostatic, Hydrodynamic, and Impact Force Worksheets (Figures 3-5, 3-7, and 3-8) for Case Studies A and B. Note supporting data and calculations can be found in Appendix A for Case Study A and Appendix B for Case Study B, with all Case Study C data found in Appendix C.

Case Study A – Exercise 2: Residential Retrofit in Riverine Floodplain Using Relocation or Elevation

<u>Flood Load Calculations</u>

Hydrostatic Force for Elevation

The flood loads on the perimeter walls and footings must be evaluated. The first step is to calculate hydrostatic forces. The installation of flood openings in the crawlspace allows water to flow into the crawlspace to enable the hydrostatic forces on the exterior and interior sides of

the walls to be equalized. Likewise, the buoyancy on the footings will not impose significant upward pressure since the crawlspace will fill with water. The density of concrete and masonry is greater than water, and any voids within these materials will be filled with water. Each of the hydrostatic forces is 0 pounds per linear foot. See Figure CSA-11. If the existing building is not elevated, then the flood design depth H = [(697.8 – 692.2) + (2)] = 7.6 feet; the lateral hydrostatic force f_{sta} = [(0.5) x (62.4) x $(7.6)^2$] = 1,802 lbs, and the buoyancy force acting on the first finished floor F_{buoy} = [(62.4) x (694.2 – 692.2) x (1,600)] = 199,680 lbs.

Hydrostatic Force Computation Worksheet

Owner Name:	**John and Jane Doe**	**Preparer**	**JJS-MH**
Address:	**55 Cedar River Road**	**Date:**	**7/6/2026**
Property Details:	**Case Study A**		

Constants

γ_w = unit weight of water = **62.4** lbs/ft^3

(62.4 lbs/ft^3 for fresh water and 64.0 lbs/ft^3 for saltwater)

Variables

H = flood design depth (ft) = **0.0** ft

z = flood design depth extended below grade (ft) = **0.0** ft

D = depth of saturated soil (ft) = **0.0** ft

Soil Type = USDA Unified Soil Classification = **SM**

S = equivalent fluid weight of saturated soil (lbs/ft^3) = **135.0** lbs/ft^3

(see Table 3-1 for S as a function of Soil Type)

Vol = volume of floodwater displaced by a submerged object (ft^3) = **0.0** ft^3

Summary of Loads

f_{sta} = **0.0** lbs/LF

f_{stae} = **0.0** lbs/LF

f_{dif} = **0.0** lbs/LF

f_{comb} = **0.0** lbs/LF

F_{buoy} = **0.0** lbs

Hydrostatic Force Above Grade (see Equation 3-3)

$f_{sta} = 1/2\, P_h H = 1/2\, \gamma_w H^2$ = **0.0** lbs/LF

Hydrostatic Force Extended Below Grade (see Equation 3-4)

$f_{stae} = 1/2\, \gamma_w z^2$ = **0.0** lbs/LF

Submerged Soil and Water Force (see Equation 3-5)

$f_{dif} = 1/2\, (S - \gamma_w)\, D^2$ = **0.0** lbs/LF

Buoyancy Force (see Equation 3-6)

$F_{buoy} = \gamma_w\, (Vol)$ = **0.0** lbs

Note: Equations 3-3, 3-4 and 3-5 do not account for equivalent hydrostatic loads due to the low velocity of floodwaters (less than 10 ft/sec). If velocity floodwater exists, use hydrodynamic force Equations 3-7, 3-8, 3-9 and 3-10.

Figure CSA-11. Hydrostatic Force Computation Worksheet for the Doe house when elevated

Hydrodynamic Force

Hydrodynamic forces are evaluated based on Equations 3-7 and 3-8 presented earlier. The hydrodynamic force can be calculated for the flow velocity of 2.0 feet/second in terms of an equivalent hydrostatic force. A worksheet for the equivalent hydrostatic force due to the flow speed of 2.0 feet/second is shown in Figure CSA-12 below.

Hydrodynamic Force Computation Worksheet

Owner Name:	**John and Jane Doe**	**Preparer**	**JJS-MH**
Address:	**55 Cedar River Road**	**Date:**	**7/6/2026**
Property Details:	**Case Study A**		

Constants

γ_w = unit weight of water = **62.4** lbs/ft^3

(62.4 lbs/ft^3 for fresh water and 64.0 lbs/ft^3 for saltwater)

g = acceleration of gravity = 32.2 ft/sec^2

ρ = mass density of water = **1.94** slugs/ft^3

(1.94 slugs/ft^3 for fresh water and 1.99 slugs/ft^3 for saltwater)

Variables

H = flood design depth (ft) = **7.60** ft

V = velocity of floodwater (ft/sec) = **2.0** ft/sec

(use Equations 3-7 and 3-8 if V ≤ 10 ft/sec; use Equations 3-9 ad 3-10 if V > 10 ft/sec)

b = width of structure perpendicular to flow (ft) = **40.0** ft

b/H = ratio of width to height = **5.3**

C_d = drag coefficient = **1.25**

(taken from Table 3-3 as a function of b/H)

A = submerged area on upstream face of structure (ft^2) = (b)(H **304.0** ft^2

Summary of Loads

f_{dh} =	**37.9**	lbs/LF
f_{sta} =	**0.0**	lbs/LF
f_{stae} =	**0.0**	lbs/LF
f_{dif} =	**0.0**	lbs/LF
f_{comb} =	**0**	lbs/LF
P_d =	**N/A**	lbs/ft^2
F_d =	**N/A**	lbs

Conversion of Low Velocity Flood Flow to Equivalent Head (see Equation 3-7)

$dh = C_d V^2/2g =$ **0.08** ft

Conversion of Equivalent Head to Equivalent Hydrostatic Force (see Equation 3-8)

$f_{dh} = \gamma_w (dh)H = P_{dh} H =$ **37.9** lbs/LF

High Velocity Dynamic Pressure (see Equation 3-9)

$P_d = C_d \rho V^2/2 =$ **N/A** (flow velocity is less than 10 ft/sec)

Total Hydrodynamic Force (see Equation 3-10)

$F_d = P_d A =$ **N/A** (flow velocity is less than 10 ft/sec)

Figure CSA-12. Hydrodynamic Force Computation Worksheet for the Doe house

Impact Force

Impact load is evaluated based on Equation 3-11 and is shown below in the computation worksheet in Figure CSA-13. The flood depth is greater than 5 feet, and there is assumed to be no upstream screening. Hence, CD = 1.0 and CB = 1.0. Since the foundation is constructed with reinforced masonry foundation walls, CStr = 0.8.

Impact Force Computation Worksheet			
Owner Name:	**John and Jane Doe**	**Preparer**	**JJS-MH**
Address:	**55 Cedar River Road**	**Date:**	**7/6/2026**
Property Details:	**Case Study A**		

Variables

W = weight of the object (lbs) = **1,000** lbs
(see Note 1 for recommended values and guidance)

V = velocity of floodwater (ft/sec) = **2.0** ft/sec

C_D = depth coefficient = **1.00**
(taken from Table 3-4 as a function of hazard zone and water depth)

C_B = blockage coefficient = **1.0**
(taken from Table 3-5 as a function of flow path and upstream screening)

C_{Str} = building structure coefficient = **0.8**
= 0.2 for timber pile and masonry column-supported structures 3 stories or less in height above grade
= 0.4 for concrete pile or concrete or steel moment-resisting frames 3 stories or less in height above grade
= 0.8 for reinforced concrete (including insulated concrete forms) and reinforced masonry foundation walls

Normal Impact Loads (see Equation 3-11)

$F_i = W\,V\,C_D\,C_B\,C_{Str}$ = **1,600** lbs

Notes:

1. Regarding W: ASCE 7-22 Commentary recommends W = 1,000 lbs as a reasonable average weight of the object for normal impact force. Additional guidance from the ASCE 7-22 Commentary is provided below:
   a. Use W = 1,000 to 2,000 lbs for riverine and coastal floodplains with large woody debris.
   b. Use W < 1,000 lbs for arid and semi-arid regions.
   c. Use W = 1,000 to 4,000 lbs for riverine floodplains subject to floating ice.
   d. Use W = 4,000 lbs for the Pacific Northwest to represent larger trees and logs.
   e. Use W < 500 lbs for coastal areas without large pilings.

   Relocation is recommended where more extreme impact forces are a threat.

2. Regarding C_D from Table 3-4: Per ASCE 24-14, a "floodway" is a "channel and that portion of the floodplain reserved to convey the base flood without cumulatively increasing the water surface elevation more than a designated height."

Figure CSA-13. Impact Force Computation Worksheet for the Doe house

Flood Force Summary

Hydrostatic Loads = 0

Hydrodynamic Load = Equivalent Hydrostatic Force = 37.9 lbs/linear ft.

Impact Load = 1,600 lbs

Case Study B – Exercise 2: Residential Retrofit Outside of the Floodplain Using Floodwalls or Dry Floodproofing

FLOOD Load Calculations

Hydrostatic Force, Hydrodynamic and Impact Forces for Dry Floodproofing

Mr. Smith may apply a flexible cementitious waterproofing onto the exterior face of the building up to 3 feet above the adjacent grade and install flood shields at the door openings. Mr. Smith's engineer used the following worksheets to evaluate the flood loads on the building exterior. The engineer has determined that 3 feet of water depth produces approximately 281 pounds per linear foot of horizontal hydrostatic pressure. The buoyancy force associated with the footprint of the building could result in approximately 936,000 lbs of upward force (Figure CSB-6).

Hydrostatic Force Computation Worksheet

Owner Name:	**John Smith**	**Preparer**	**JJS-MH**
Address:	**2908 Valley Drive**	**Date:**	**7/6/2026**
Property Details:	**Case Study B**		

Constants

γ_w = unit weight of water = **62.4** lbs/ft^3

(62.4 lbs/ft^3 for fresh water and 64.0 lbs/ft^3 for saltwater)

Variables

H = flood design depth (ft) = **3.0** ft

z = flood design depth extended below grade (ft) = **0.0** ft

D = depth of saturated soil (ft) = **0.0** ft

Soil Type = USDA Unified Soil Classification = **SM**

S = equivalent fluid weight of saturated soil (lbs/ft^3) = **135.0** lbs/ft^3

(see Table 3-1 for S as a function of Soil Type)

Vol = volume of floodwater displaced by a submerged object (ft^3) = **15,000** ft^3

Summary of Loads

f_{sta} = **280.8** lbs/LF

f_{stae} = **0.0** lbs/LF

f_{dif} = **0.0** lbs/LF

f_{comb} = **280.8** lbs/LF

F_{buoy} = **936,000** lbs

Lateral Hydrostatic Force (see Equation 3-4)

$f_{sta} = 1/2\, P_h H = 1/2\, \gamma_w H^2 =$ **280.8** lbs/LF

Hydrostatic Force Extended Below Grade (see Equation 3-4)

$f_{stae} = 1/2\, \gamma_w z^2 =$ **0.0** lbs/LF

Submerged Soil and Water Force (see Equation 3-5)

$f_{dif} = 1/2\, (S - \gamma_w)\, D^2 =$ **0.0** lbs/LF

Buoyancy Force (see Equation 3-6)

$F_{buoy} = \gamma_w\, (Vol) =$ **936,000** lbs

Note: Equations 3-3, 3-4 and 3-5 do not account for equivalent hydrostatic loads due to the low velocity of floodwaters (less than 10 ft/sec). If velocity floodwater exists, use hydrodynamic force Equations 3-7, 3-8, 3-9 and 3-10.

Figure CSB-6. Hydrostatic Force Computation Worksheet for the Dry Floodproofing of The Valley Apartments

For a flood velocity of 2.0 feet/second, the building will experience an equivalent hydrostatic force of approximately 17 pounds per linear foot along the exterior of the building

(Figure CSA-12). The existing brick fence at the edge of the property will serve as a barrier against flood debris so that the impact force on the apartment building itself can be considered 0 pounds (Figure CSA-13). If the brick fence is expected to be destroyed by flood or debris impact loads, then the designer may choose to calculate debris loads on the building itself. This is only one example of engineering judgement that may differ between retrofit projects, based on project specific details.

Hydrodynamic Force Computation Worksheet

Owner Name:	**John Smith**	**Preparer**	**JJS-MH**
Address:	**2908 Valley Drive**	**Date:**	**7/6/2026**
Property Details:	**Case Study B**		

Constants

γ_w = unit weight of water = **62.4** lbs/ft^3

(62.4 lbs/ft^3 for fresh water and 64.0 lbs/ft^3 for saltwater)

g = acceleration of gravity = 32.2 ft/sec^2

ρ = mass density of water = **1.94** slugs/ft^3

(1.94 slugs/ft^3 for fresh water and 1.99 slugs/ft^3 for saltwater)

Variables

H = flood design depth (ft) = **3.00** ft

V = velocity of floodwater (ft/sec) = **2.0** ft/sec

(use Equations 3-7 and 3-8 if V ≤ 10 ft/sec; use Equations 3-9 ad 3-10 if V > 10 ft/sec)

b = width of structure perpendicular to flow (ft) = **100.0** ft

b/H = ratio of width to height = **33.3**

C_d = drag coefficient = **1.50**

(taken from Table 3-5 as a function of b/H)

A = submerged area on upstream face of structure (ft^2) = (b)(H **300.0** ft^2

Summary of Loads

f_{dh} = **16.8** lbs/LF

f_{sta} = **280.8** lbs/LF

f_{stae} = **0.0** lbs/LF

f_{dif} = **0.0** lbs/LF

f_{comb} = **281** lbs/LF

P_d = **N/A** lbs/ft^2

F_d = **N/A** lbs

Conversion of Low Velocity Flood Flow to Equivalent Head (see Equation 3-7)

$dh = C_d V^2/2g =$ **0.09** ft

Conversion of Equivalent Head to Equivalent Hydrostatic Force (see Equation 3-8)

$f_{dh} = \gamma_w (dh)H = P_{dh} H =$ **16.8** lbs/LF

High Velocity Dynamic Pressure (see Equation 3-9)

$P_d = C_d \rho V^2/2 =$ **N/A** (flow velocity is less than 10 ft/sec)

Total Hydrodynamic Force (see Equation 3-10)

$F_d = P_d A =$ **N/A** (flow velocity is less than 10 ft/sec)

Figure CSB-7. Hydrodynamic Force Computation Worksheet for the Dry Floodproofing of The Valley Apartments

Impact Force Computation Worksheet			
Owner Name:	**John Smith**	**Preparer**	**JJS-MH**
Address:	**2908 Valley Drive**	**Date:**	**7/6/2026**
Property Details:	**Case Study B**		

Variables

W = weight of the object (lbs) = **1,000** lbs
(see Note 1 for recommended values and guidance)

V = velocity of floodwater (ft/sec) = **2.0** ft/sec

C_D = depth coefficient = **1.00**
(taken from Table 3-4 as a function of hazard zone and water depth)

C_B = blockage coefficient = **0.0**
(taken from Table 3-5 as a function of flow path and upstream screening)

C_{Str} = building structure coefficient = **0.8**
= 0.2 for timber pile and masonry column-supported structures 3 stories or less in height above grade
= 0.4 for concrete pile or concrete or steel moment-resisting frames 3 stories or less in height above grade
= 0.8 for reinforced concrete (including insulated concrete forms) and reinforced masonry foundation walls

Normal Impact Loads (see Equation 3-11)

$F_i = W V C_D C_B C_{Str}$ = **0** lbs

Notes:

1. Regarding W: ASCE 7-22 Commentary recommends W = 1,000 lbs as a reasonable average weight of the object for normal impact force. Additional guidance from the ASCE 7-22 Commentary is provided below:
   a. Use W = 1,000 to 2,000 lbs for riverine and coastal floodplains with large woody debris.
   b. Use W < 1,000 lbs for arid and semi-arid regions.
   c. Use W = 1,000 to 4,000 lbs for riverine floodplains subject to floating ice.
   d. Use W = 4,000 lbs for the Pacific Northwest to represent larger trees and logs.
   e. Use W < 500 lbs for coastal areas without large pilings.

   Relocation is recommended where more extreme impact forces are a threat.

2. Regarding C_D from Table 3-4: Per ASCE 24-14, a "floodway" is a "channel and that portion of the floodplain reserved to convey the base flood without cumulatively increasing the water surface elevation more than a designated height."

Figure CSB-8. Impact Force Computation Worksheet for the Dry Floodproofing of The Valley Apartments

Hydrostatic Force, Hydrodynamic, and Impact Forces for Floodwall

Mr. Smith's engineer has prepared a preliminary design for the floodwall. To protect to the same elevation as the building's dry floodproofing, the floodwall must be 5 feet high. The floodwall needs to be 2 feet taller than the dry floodproofing because the ground slopes away from the building toward the wall. Mr. Smith prefers a concrete floodwall because of the finishing options it provides. The footing for the concrete floodwall will be approximately 6 feet wide and 20 inches thick. There will be approximately 18 inches of soil cover over the footing. Other than a couple gaps around the perimeter of the property, the concrete floodwall will be continuous except at the 24-foot-wide driveway and 4-foot-wide pedestrian entryway. It is expected that the stem of the floodwall will be 18 inches thick. The hydrostatic loads will be 796 pounds per lineal foot of horizontal load and over 1.8 million pounds of buoyancy force (Figure CSB-9). The equivalent hydrodynamic force produced by a flood velocity of 2 feet/second will result in an additional 28.1 pounds per lineal foot of horizontal load

(Figure CSB-10). The neighborhood around Mr. Smith's property will produce limited screening from impact loads. The impact load will be 960 pounds on the floodwall (Figure CSB-11).

Hydrostatic Force Computation Worksheet

Owner Name:	**John Smith**	**Preparer**	**JJS-MH**
Address:	**2908 Valley Drive**	**Date:**	**7/6/2026**
Property Details:	**Case Study B**		

Constants

γ_w = unit weight of water = **62.4** lbs/ft^3

(62.4 lbs/ft^3 for fresh water and 64.0 lbs/ft^3 for saltwater)

Variables

H = flood design depth (ft) = **5.0** ft

z = flood design depth extended below grade (ft) = **0.0** ft

D = depth of saturated soil (ft) = **1.5** ft

Soil Type = USDA Unified Soil Classification = **SM**

S = equivalent fluid weight of saturated soil (lbs/ft^3) = **135.0** lbs/ft^3

(see Table 3-3 for S as a function of Soil Type)

Vol = volume of floodwater displaced by a submerged object (ft^3) = **29,094.0** ft^3

Summary of Loads

f_{sta} = **780.0** lbs/LF

f_{stae} = **0.0** lbs/LF

f_{dif} = **81.7** lbs/LF

f_{comb} = **861.7** lbs/LF

F_{buoy} = **1,815,466** lbs

Lateral Hydrostatic Force (see Equation 3-4)

$f_{sta} = 1/2\ P_h H = 1/2\ \gamma_w\ H^2 =$ **780.0** lbs/LF

Hydrostatic Force Extended Below Grade (see Equation 3-4)

$f_{stae} = 1/2\ \gamma_w\ z^2 =$ **0.0** lbs/LF

Submerged Soil and Water Force (see Equation 3-5)

$f_{dif} = 1/2\ (S - \gamma_w)\ D^2 =$ **81.7** lbs/LF

Buoyancy Force (see Equation 3-6)

$F_{buoy} = \gamma_w\ (Vol) =$ **1,815,466** lbs

Note: Equations 3-3, 3-4 and 3-5 do not account for equivalent hydrostatic loads due to the low velocity of floodwaters (less than 10 ft/sec). If velocity floodwater exists, use hydrodynamic force Equations 3-7, 3-8, 3-9 and 3-10.

Figure CSB-9. Hydrostatic Force Computation Worksheet for the Floodwall of The Valley Apartments

Hydrodynamic Force Computation Worksheet			
Owner Name:	**John Smith**	**Preparer**	**JJS-MH**
Address:	**2908 Valley Drive**	**Date:**	**7/6/2026**
Property Details:	**Case Study B**		

Constants

γ_w = unit weight of water = **62.4** lbs/ft^3

(62.4 lbs/ft^3 for fresh water and 64.0 lbs/ft^3 for saltwater)

g = acceleration of gravity = 32.2 ft/sec^2

ρ = mass density of water = **1.94** slugs/ft^3

(1.94 slugs/ft^3 for fresh water and 1.99 slugs/ft^3 for saltwater)

Variables

H = flood design depth (ft) = **5.00** ft

V = velocity of floodwater (ft/sec) = **2.0** ft/sec

(use Equations 3-7 and 3-8 if V ≤ 10 ft/sec; use Equations 3-9 ad 3-10 if V > 10 ft/sec)

b = width of structure perpendicular to flow (ft) = **175.0** ft

b/H = ratio of width to height = **35.0**

C_d = drag coefficient = **1.50**

(taken from Table 3-3 as a function of b/H)

A = submerged area on upstream face of structure (ft^2) = (b)(H **875.0** ft^2

Summary of Loads

f_{dh} = **28.1** lbs/LF

f_{sta} = **780.0** lbs/LF

f_{stae} = **0.0** lbs/LF

f_{dif} = **16.4** lbs/LF

f_{comb} = **796** lbs/LF

P_d = **N/A** lbs/ft^2

F_d = **N/A** lbs

Conversion of Low Velocity Flood Flow to Equivalent Head (see Equation 3-7)

$dh = C_d V^2/2g =$ **0.09** ft

Conversion of Equivalent Head to Equivalent Hydrostatic Force (see Equation 3-8)

$f_{dh} = \gamma_w (dh)H = P_{dh} H =$ **28.1** lbs/LF

High Velocity Dynamic Pressure (see Equation 3-9)

$P_d = C_d \rho V^2/2 =$ **N/A** (flow velocity is less than 10 ft/sec)

Total Hydrodynamic Force (see Equation 3-10)

$F_d = P_d A =$ **N/A** (flow velocity is less than 10 ft/sec)

Figure CSB-10. Hydrodynamic Force Computation Worksheet for the Floodwall of The Valley Apartments

Impact Force Computation Worksheet			
Owner Name:	**John Smith**	**Preparer**	**JJS-MH**
Address:	**2908 Valley Drive**	**Date:**	**7/6/2026**
Property Details:	**Case Study B**		

Variables

W = weight of the object (lbs) = **1,000** lbs
(see Note 1 for recommended values and guidance)

V = velocity of floodwater (ft/sec) = **2.0** ft/sec

C_D = depth coefficient = **1.00**
(taken from Table 3-4 as a function of hazard zone and water depth)

C_B = blockage coefficient = **0.6**
(taken from Table 3-5 as a function of flow path and upstream screening)

C_{Str} = building structure coefficient = **0.8**
= 0.2 for timber pile and masonry column-supported structures 3 stories or less in height above grade
= 0.4 for concrete pile or concrete or steel moment-resisting frames 3 stories or less in height above grade
= 0.8 for reinforced concrete (including insulated concrete forms) and reinforced masonry foundation walls

Normal Impact Loads (see Equation 3-11)

$F_i = W V C_D C_B C_{Str}$ = **960** lbs

Notes:

1. Regarding W: ASCE 7-22 Commentary recommends W = 1,000 lbs as a reasonable average weight of the object for normal impact force. Additional guidance from the ASCE 7-22 Commentary is provided below:
   a. Use W = 1,000 to 2,000 lbs for riverine and coastal floodplains with large woody debris.
   b. Use W < 1,000 lbs for arid and semi-arid regions.
   c. Use W = 1,000 to 4,000 lbs for riverine floodplains subject to floating ice.
   d. Use W = 4,000 lbs for the Pacific Northwest to represent larger trees and logs.
   e. Use W < 500 lbs for coastal areas without large pilings.

   Relocation is recommended where more extreme impact forces are a threat.

2. Regarding C_D from Table 3-4: Per ASCE 24-14, a "floodway" is a "channel and that portion of the floodplain reserved to convey the base flood without cumulatively increasing the water surface elevation more than a designated height."

Figure CSB-11. Impact Force Computation Worksheet for the Floodwall of The Valley Apartments

3.3.1. SITE DRAINAGE

The drainage system for the area enclosed by a floodwall or flood berm must accommodate the precipitation runoff from the interior (and any contributing areas such as roofs and higher ground parcels) and the anticipated seepage through or under the floodwall or berm during flooding.



Note

The rational formula $Q = ci_rA$ is used to compute the amount of precipitation runoff from small areas. It is generally not applicable to drainage areas greater than 10 acres in size.

There are two general methods for removing interior drainage. The first is a gravity flow system, which provides a means for interior drainage of the protected area when there is no floodwater

against the floodwall or flood berm. This is accomplished by placing a pipe(s) through the floodwall or flood berm with a flap gate attachment. The flap gate prevents flow from entering the interior area through the drainpipe when floodwater rises above the elevation of the pipe.

The second method, a pump system, removes accumulation of water when the elevation of the floodwater exceeds the elevation of the gravity drain system. A collection system composed of pervious trenches, underground tiles, or sloped surface areas transports accumulating water to a sump area. In the flood berm application, these drains should be incorporated into the collection system. The anticipated seepage from under and through floodwalls and flood berms must also be considered by combining it with flow from precipitation (see Figure 3-9). It is important to verify that the pump system has a reliable power source that can manage the flooding in the area enclosed by the floodwall or flood berm to ensure the systems perform as designed.

Note

The residential terrain runoff coefficient, *c*, is used to model the runoff characteristics of various land uses. Use the value for the predominant land use within a specific area or develop a weighted average for areas with multiple land uses. The most common coefficients are 0.70 for residential areas, 0.90 for commercial areas, and 0.40 for undeveloped land.

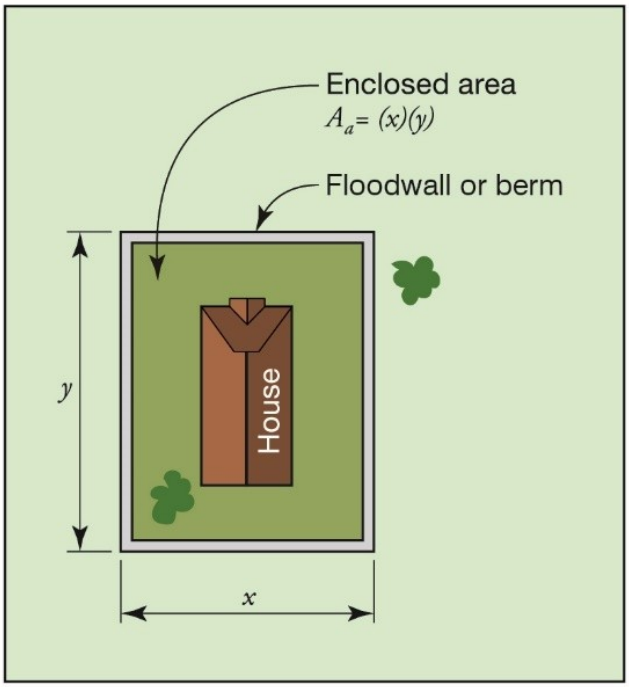


Figure 3-9. Rectangular area enclosed by a floodwall or berm

To determine the amount of precipitation that can collect in the contained area, the rainfall intensity, given in inches per hour, must be determined for the site. This value is multiplied by the enclosed

area, A_a, in square feet, a residential terrain runoff coefficient (c) of 0.7, and a conversion factor of 0.01. The calculated value is in gallons per minute (gpm). See Equation 3-12.

EQUATION 3-12: RUNOFF QUANTITY IN AN ENCLOSED AREA

$$Q_a = 0.01 c i_r A_a$$

Where:

Q_a = runoff from the enclosed area (gpm)

0.01 = factor converting the answer to gpm

c = residential terrain runoff coefficient of 0.7

i_r = intensity of rainfall (in./hr)

A_a = the area enclosed by the floodwall or berm (ft^2)

Note

When determining minimum discharge for pumps within enclosed areas, the designer should consider the impact of lag time between storms that controls the gravity flow mechanism (i.e., inside and outside the enclosed area) and the storage capacity within the enclosed area after the gravity discharge system closes. If the designer is not familiar with storm lag time and the computation of storage within an enclosed area, an experienced hydrologist or hydraulic engineer should be consulted.

In some cases, a flood berm or floodwall may extend only partially around the property and tie into higher ground (see Figure 3-10). For such cases, the amount of precipitation that can flow downhill as runoff into the protected area, A_a, must be included. To calculate this value, the additional area of land that can discharge water into the enclosure, A_b, should be estimated. This value is then multiplied by the previously determined rainfall intensity, i_r, by the most suitable terrain coefficient, and by 0.01. See Equation 3-13.

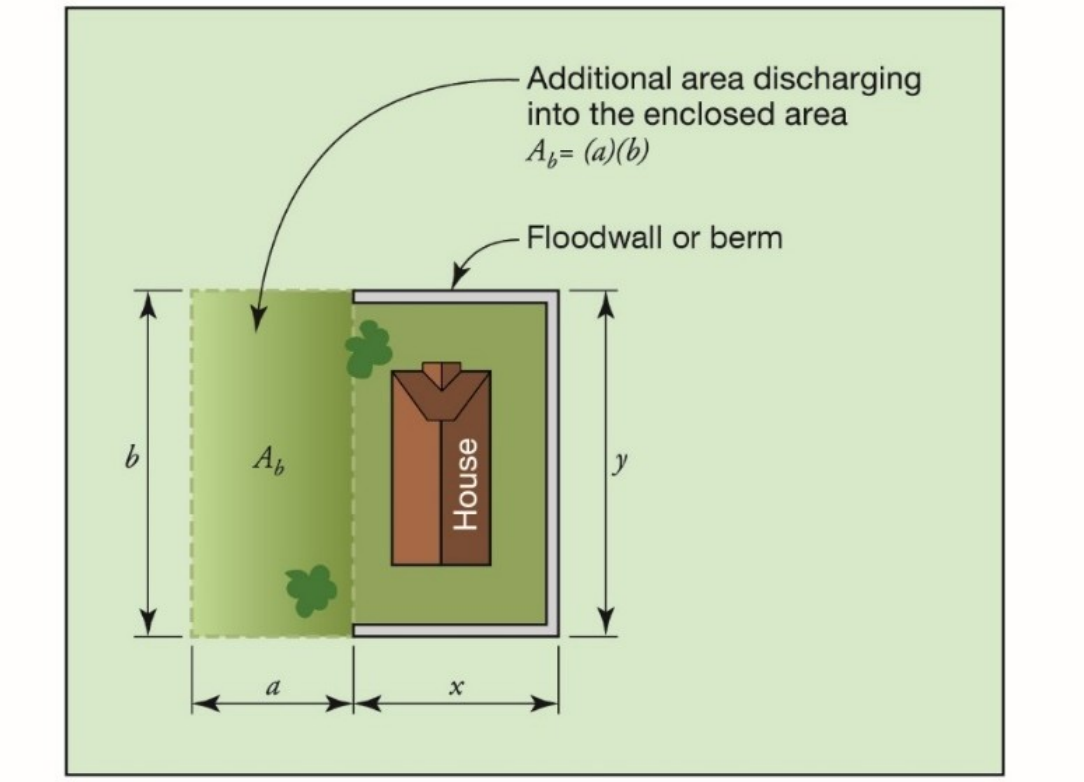


Figure 3-10. Rectangular area partially enclosed by a floodwall or flood berm

EQUATION 3-13: RUNOFF QUANTITY FROM HIGHER GROUND INTO A PARTIALLY ENCLOSED AREA

$$Q_b = 0.01ci_rA_b$$

Where:

Q_b = runoff from the enclosed area (gpm)

0.01 = factor converting the answer to gpm

c = Most suitable terrain runoff coefficient

i_r = intensity of rainfall (in./hr)

A_b = area discharging to the area partially enclosed by the floodwall (ft^2)

Seepage flow rates from the flood berm or floodwall, Q_c, must also be estimated. In general, unless the seepage rate is calculated by a qualified geotechnical engineer, a value of 2 gpm for every 300 feet of flood berm or 1 gpm for every 300 feet of floodwall should be assumed during base 100-year-flood conditions. See Equation 3-14.

EQUATION 3-14: SEEPAGE FLOW RATE THROUGH A FLOODWALL OR FLOOD BERM

$$Q_c = sr(l)$$

Where:

Q_c = seepage rate through the floodwall/berm (gpm)

sr = seepage rate (gpm) per foot of floodwall/berm

l = length of the floodwall/berm (ft)

The values for inflow within the enclosed area, runoff from uphill areas draining into the enclosure, and seepage through the floodwall/flood berm should be added together to obtain the minimum discharge size, Q_{sp}, in gpm for the pump. See Equation 3-15.

EQUATION 3-15: : MINIMUM DISCHARGE FOR PUMP INSTALLATION

$$Q_{sp} = Q_a + Q_b + Q_c$$

Where:

Q_{sp} = minimum discharge for pump installation (gpm)

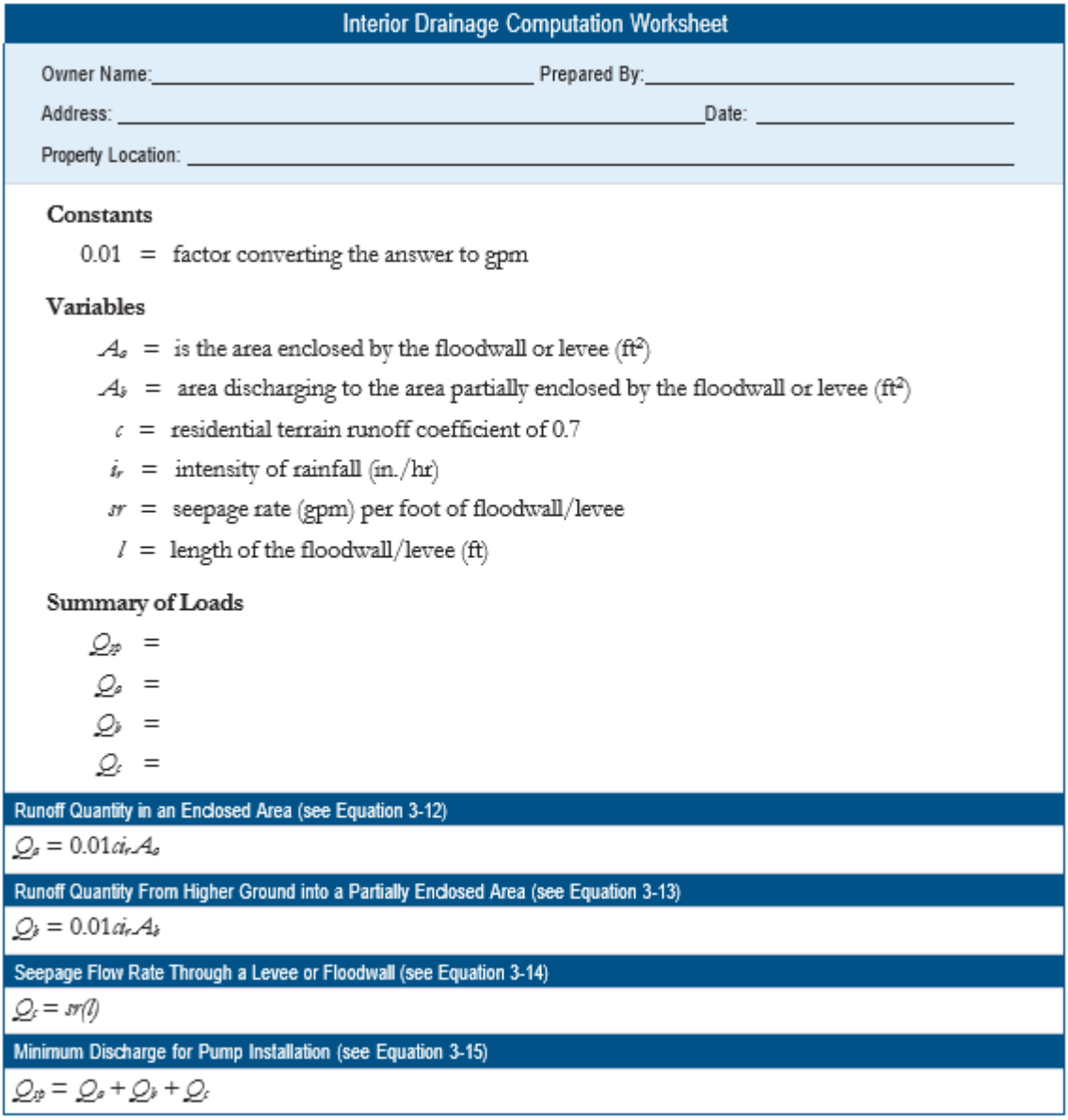
Q_a = discharge from an enclosed area (from Equation 3-12) (gpm)

Q_b = discharge from higher ground to partially enclosed area (from Equation 3-13) (gpm)

Q_c = discharge from seepage through a floodwall or berm (from Equation 3-14) (gpm)

Important factors to determine the minimum discharge size of a pump include storage available within the enclosed area, the lag time between storms that impact the enclosed area, and the area to which the enclosed area drains. Pumps will continue to operate during flooding events (assuming power is uninterrupted, or backup power is available), but gravity drains will close once the floodwater elevation outside of the enclosed area exceeds the elevation of the drainpipe/flap gate. Therefore, the critical design issue is to determine runoff and seepage that occurs once the flap gate closes. Typical design solutions incorporate a freeboard of several inches or more to safely control the 10-year flood event.

The Interior Drainage Computation Worksheet (Figure 3-11) can be used to calculate the minimum discharge for pump installations.



Interior Drainage Computation Worksheet

Owner Name:_____ Prepared By:_____

Address: _____ Date: _____

Property Location: _____

Constants

0.01 = factor converting the answer to gpm

Variables

A_o = is the area enclosed by the floodwall or levee (ft^2)

A_b = area discharging to the area partially enclosed by the floodwall or levee (ft^2)

c = residential terrain runoff coefficient of 0.7

i_r = intensity of rainfall (in./hr)

sr = seepage rate (gpm) per foot of floodwall/levee

l = length of the floodwall/levee (ft)

Summary of Loads

Q_{ip} =

Q_o =

Q_b =

Q_s =

Runoff Quantity in an Enclosed Area (see Equation 3-12)

$Q_o = 0.01 c i_r A_o$

Runoff Quantity From Higher Ground into a Partially Enclosed Area (see Equation 3-13)

$Q_b = 0.01 c i_r A_b$

Seepage Flow Rate Through a Levee or Floodwall (see Equation 3-14)

$Q_s = sr(l)$

Minimum Discharge for Pump Installation (see Equation 3-15)

$Q_{ip} = Q_o + Q_b + Q_s$

Figure 3-11. Interior Drainage Computation Worksheet

3.4. Other Flood Hazards

This section briefly addresses other flood hazards in riverine flood environments, including streambank erosion, closed basin lakes, moveable bed streams, and increased precipitation.

3.4.1. STREAMBANK EROSION

Accounting for streambank erosion or nearby overbank structures is a detailed effort that is usually included in detailed geotechnical investigations. Some of the variables that impact the stability (or erodibility) of stream banks include:

- Critical height of the slope

- Inclination of the slope
- Cohesive strength of the soil in the slope
- Distance of the structure in question from the shoulder of the stream bank
- Degree of stabilization of the surface of the slope
- Level and variation of groundwater within the slope
- Level and variation in level of water on the toe of the slope
- Tractive shear stress of the soil
- Frequency of rise and fall of the surface of the stream

Both FEMA and the U.S. Army Corps of Engineers have researched the stability of stream banks to quantify stream bank erosion. However, concerns over the universal applicability of the research due to site variations prevent inclusion in this publication. If a streambank proximate to the project site is susceptible to erosion, the designer should contact a qualified geotechnical engineer or a hydraulic engineer experienced in channel stability.

Cross Reference

One- to 24-hour rainfall intensities for each state are available from the National Weather Service Technical Memorandum NWS HYDRO-35, *Technical Paper 40, NOAA Atlas 2,* or *NOAA Atlas 14,* available for download at: https://www.weather.gov/media/owp/hdsc_documents/TechnicalMemo_HYDRO35.pdf

Rainfall intensities are available for a range of storm frequencies, including the 2-, 10-, 25-, 50-, and 100-year events. The 2- or 10-year intensity rainfall is considered a minimum design value for pumping rates when floodwater prevents gravity discharge from floodwalls and flood berms. The 100-year intensity rainfall should be the maximum design value for sizing gravity flow pipes and/or closures.

3.4.2. CLOSED BASIN LAKES

Closed basin lakes include lakes without outlets, such as Utah's Great Salt Lake and California's Salton Sea. Lakes with inadequate or elevated outlets, such as the Great Lakes, are also closed basin lakes. Closed basin lakes are subject to large elevation fluctuations and can retain persistent high water levels that pose special hazards to adjacent development.

Closed basin lakes occur in almost every part of the United States for a variety of reasons:

- Lakes in the northern tier of States and Alaska were scoured out by glaciers.
- Lakes with no outlets (playas) formed in the west due to tectonic action.
- Oxbow lakes along the Mississippi and other large rivers formed because of channel migration.
- Sinkhole lakes form in areas with large limestone deposits at or near the surface, where surface water and rainfall dissolve the limestone (Karst topography).

Determination of flood elevations for closed basin lakes follows accepted hydrological methods that incorporate statistical data, historical high water mark determinations, stage-frequency analysis, topographical analysis, water balance analysis, and combinations of these methods. The flood-prone area around a closed basin lake is referred to in affected DFIRM panels as an Area of Special Consideration. The Area of Special Consideration may include the 1% and 0.2% annual chance floodplains and additional areas to account for the continuous and often uncertain fluctuations in the water surface elevation due to the closed basin lake phenomenon. The Area of Special Consideration is an area subject to flooding, but the percent chance of being flooded in any given year may not be defined.

3.4.3. MOVEABLE BED STREAMS

Erosion and sedimentation are factors in the delineation and regulation of almost all riverine floodplains. In many rivers and streams, these processes are predictable and steady. In other streams, sedimentation and erosion are continual processes that have a greater impact on flood extent and damage than the peak flow.

Moveable bed streams include streams where erosion (degradation of the streambed), sedimentation (aggradation of the streambed), or channel migration cause a change in the topography of the stream sufficient to change the flood elevation or delineation of the floodplain or floodway. Analysis of moveable bed streams includes a study of the sources of sediment, changes in those sources, and the impact of sediment transport through the floodplain.

3.4.4. INCREASED PRECIPITATION

Many communities are experiencing greater damage from higher rates of precipitation that exceed the capacity of local drainage systems and can increase the risk of local flooding. When increased precipitation rates occur in existing floodplains, the depth and area of flood damage above the Base Flood Elevation can increase.

3.5. Analysis of Non-Flood-Related Hazards

While floods continue to be a major threat to homes nationwide, they are not the only natural hazard that damages residential buildings. Areas of the United States are subject to high winds that accompany thunderstorms, derechos, hurricanes, tornadoes, and frontal boundaries. Additionally, many regions are threatened by earthquake fault areas, land subsidence, wildfire, and snow hazards.

Retrofitting measures can be designed to modify structures to reduce the chance of damage from wind and other non-flood-related hazards. Fortunately, strengthening a home to resist wind or earthquake damage can often increase its ability to withstand flood-related impact and velocity forces.

3.5.1. HIGH WINDS

High winds impose significant forces on a home and the structural elements of its foundation. Damage potential is increased when the wind forces occur in combination with flood forces, often in coastal areas. In addition, as a structure is elevated to minimize the effects of flood forces, the wind loads on the elevated structure may be increased, depending on the amount of elevation and the structure's exposure to wind forces.



Note

The designer should be aware that retrofitting actions may trigger requirements or considerations for multiple other natural hazards, and they should be prepared to address these issues.

Wind forces exert pressure on structural components such as walls, roofs, connections, and foundations, as well as components and cladding (C&C), such as roof shingles, windows, doors, siding, and soffits, among others. Wind loads should be considered in the design process at the same time as hydrostatic, hydrodynamic, impact, building dead and live loads, and loads from other natural hazards such as earthquakes.

A detailed discussion of the computation of wind forces is beyond the scope of this publication. However, the listed resources do provide details on the basic parameters for determining wind loads:

- Basic wind speed (see ASCE 7 or International Residential Code wind speed map, V)
- Wind directionality factor, K_d (see ASCE 7)
- Building exposure category, B, C, or D (see ASCE 7)
- Topographic factor, K_{zt} (see ASCE 7)
- Gust effect factor, G, typically 0.85 (see ASCE 7)
- Enclosure classification, open, partially enclosed, or enclosed (see ASCE 7)
- Internal pressure coefficient, GC_{pi} (see ASCE 7)

When wind interacts with a building, both positive and negative pressures simultaneously occur (Figure 3-12). To prevent wind induced building failure, buildings must have sufficient strength to resist applied loads from these pressures. As previously mentioned, the magnitude of pressure is a function of several primary factors: exposure, basic wind speed, topography, building height, building shape, and internal pressure classification. Once these parameters are defined, the engineer can determine the design pressures and apply these pressures to the appropriate tributary area for the element or connection to be analyzed.

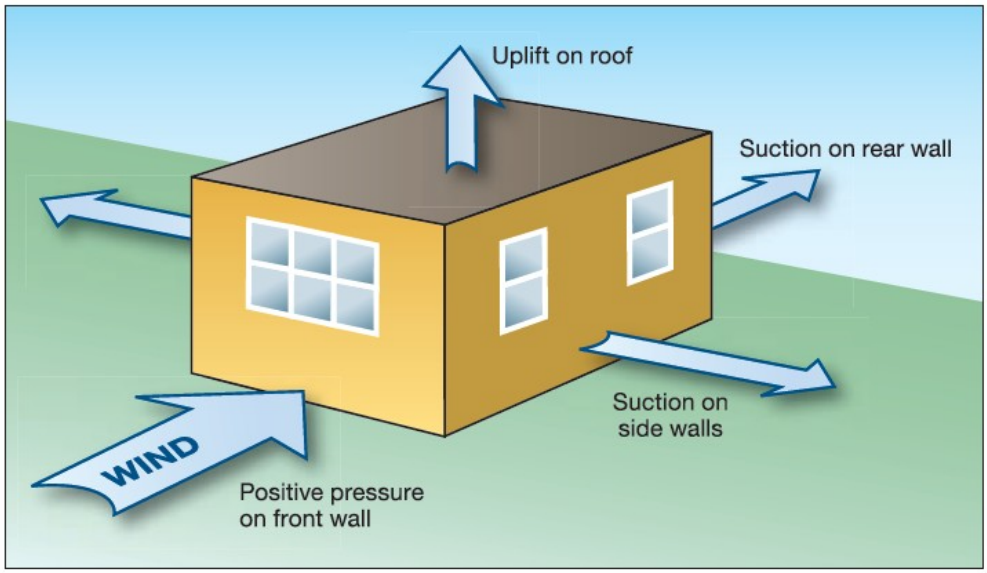


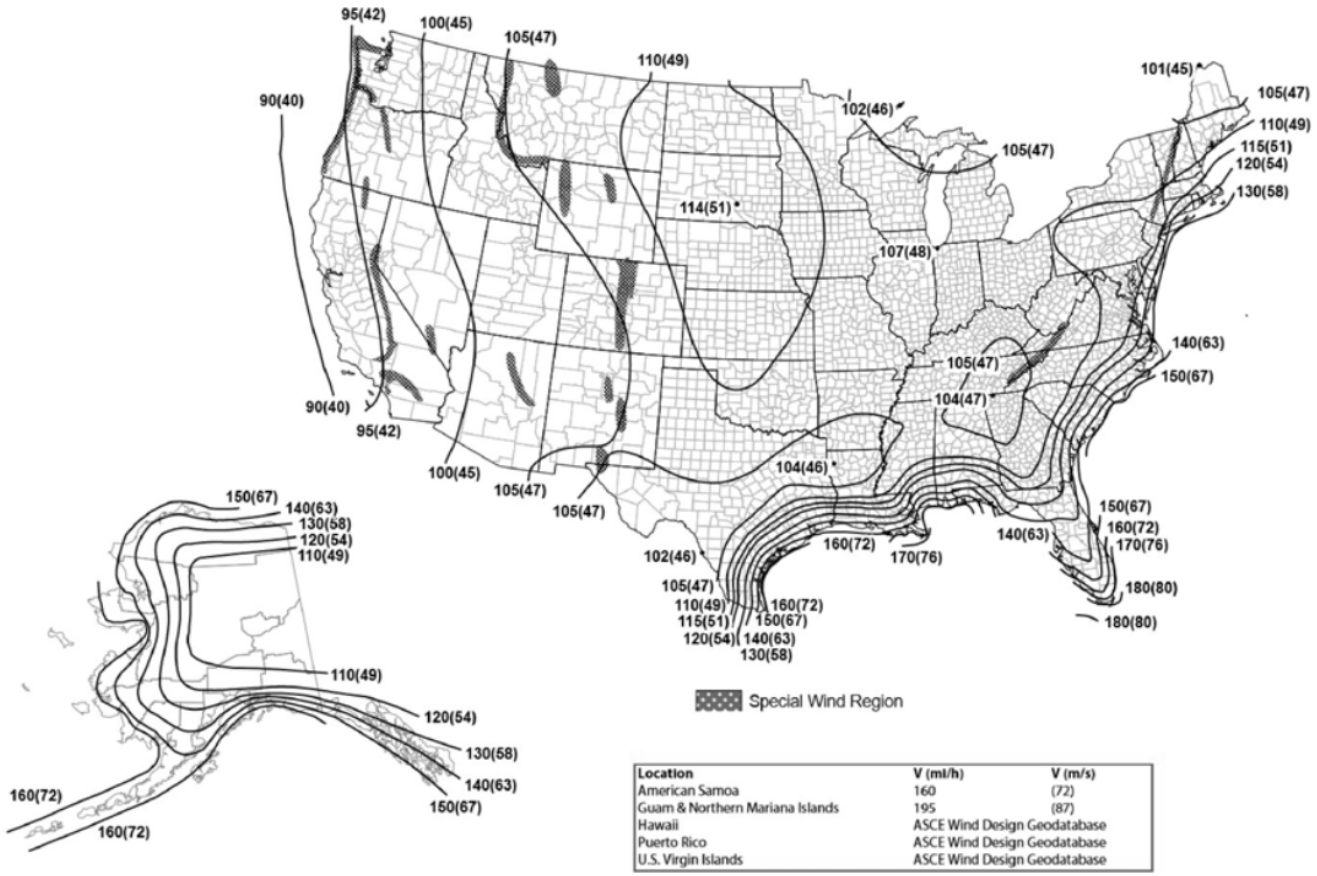
Figure 3-12. Wind pressures on a building

The concept of wind producing significant forces on a structure is based on the velocity difference of a medium (air) striking an obstruction (the structure). Wind speeds vary, depending on the location within the United States and the frequency with which these loads occur. ASCE 7 and the International Residential Code provide basic wind speed maps showing these wind velocities and frequencies. The design velocity for a particular site can be determined from these maps. If the local code enforced for a residential property is the International Residential Code, the designer should refer to the International Residential Code wind speed maps (Figure 3-13). If no local code is adopted, the designer should refer to ASCE 7, *Minimum Design Loads for Buildings and Other Structures* (see Figure 3-13).

Wind-resistant Construction Techniques

Based on observations from numerous FEMA Mitigation Assessment Teams (MATs) deployed following hurricanes and tornadoes, the most effective wind retrofit techniques for residential buildings include:

- Strengthening floor, wall, and roof framing connections that make up the wind load path.
- Securing roof covering, roof sheathing, and gable end walls to prevent failure under positive and negative wind pressures.
- Protecting windows and other openings with shutters or impact-resistant glazing.
- Constructing a safe room or storm shelter in locations subject to frequent hurricanes or tornado events.



Notes:

1. Values are 3-second gust wind speeds in miles per hour (m/s) at 33 feet (10 m) above ground for Exposure Category C.
2. Linear interpolation is permitted between contours. Point values are provided to aid with interpolation.
3. Islands, coastal areas and land boundaries outside the last contour shall use the last wind speed contour.
4. Location-specific basic wind speeds shall be permitted to be determined using the ASCE Wind Design Geodatabase.
5. Wind speeds for Hawaii, US Virgin Islands and Puerto Rico shall be determined from the ASCE Wind Design Geodatabase.
6. Mountainous terrain, gorges, ocean promontories and special wind regions shall be examined for unusual wind conditions. Site specific values for selected special wind regions shall be permitted to be determined using the ASCE Wind Design Geodatabase.
7. Wind speeds correspond to approximately a 7-percent probability of exceedance in 50 years (Annual Exceedance Probability = 0.00143, MRI = 700 years).
8. The ASCE Wind Design Geodatabase can be accessed at the ASCE 7 Hazard Tool (https://asce7hazardtool.online) or approved equivalent.

SOURCE: International Residential Code Figure R301.2(2) – Ultimate Design Wind Speeds, Used with permission

Figure 3-13. Basic residential wind speed map, International Residential Code 2024

These reports present detailed engineering discussions of building failure modes along with successful building performance guidance supplemented with design sketches. Please refer to these documents for specific engineering recommendations.

3.5.2. EARTHQUAKES (SEISMIC)

Seismic forces on a home and its structural elements and foundation can be significant. Seismic forces may also trigger additional hazards such as landslides and soil liquefaction, which can increase the damage potential on a home. These forces act on structural components such as walls, roofs, connections, and foundations. Like wind forces, seismic forces should be considered in the design process along with gravity loads from building dead, live, snow, and rain loads, as well as uplift and lateral loads from flooding and high winds. Requirements for seismic design are normally available in locally adopted building codes. Requirements in ASCE 7 and model building codes, such as the IBC, are often the basis of seismic requirements contained in locally adopted building codes.

Figures 3-14 and 3-15 illustrate steps of a seismic design process that includes estimating seismic loads and determining the ability of existing structural components to withstand these loads.

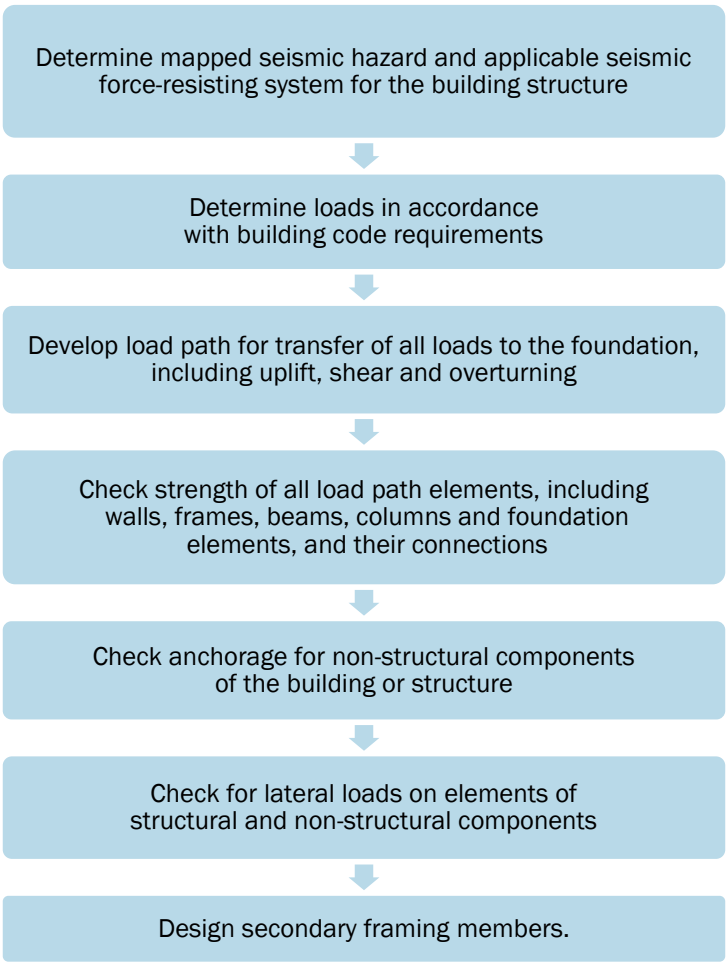


Figure 3-14. Seismic design process

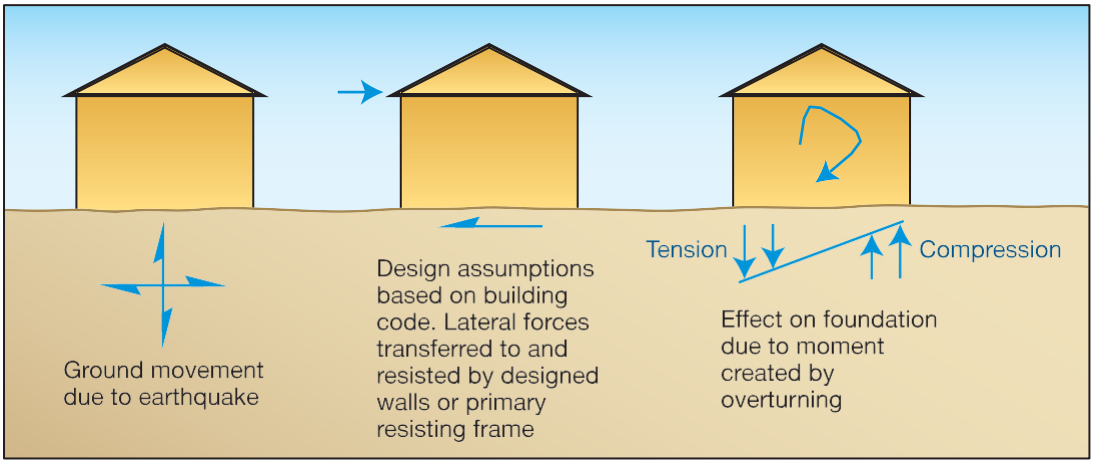


Figure 3-15. Seismic design causes and effects

When repairing a flood-damaged home or considering retrofitting structures to minimize the impact of future flooding events, certain practical steps can be taken to reduce the chance of damage from other hazards. Earthquake protection can be divided into two categories: mitigation that strengthens the building structure itself, and measures to protect nonstructural building components and contents.

Flood-related and non-flood-related forces need to be evaluated using applicable load combinations. Analysis of load combinations is covered in detail in Chapter 4 of this publication and ASCE 7.

Cross Reference

If provisions of the local code do not address seismic loads or if a local code is not adopted for use, the designer should, by default, refer to the ASCE 7, *Minimum Design Loads and Associated Criteria for Buildings and Other Structures,* or I-Code requirements.

Refer to Section 4.2 of this document for a detailed discussion of load combination scenarios and design methods.

Earthquake-resistant Construction Techniques

To protect residences, the most important mitigation measure is assuring that the structure is professionally designed and built for earthquake loads. This includes proper design of the foundation. An engineered design is required when the foundation of the house is raised above Base Flood Elevation, and the foundation is designed to enable the entire structure to withstand seismic forces. This includes proper bracing of wood-framed crawlspace walls (cripple walls) to prevent collapse during earthquakes.

Additional earthquake retrofits for residential buildings may include:

- Strengthening the lateral load elements of the building that make up the seismic load path by adding shear walls, cross walls, and steel moment frames.
- Bracing utility equipment to keep them from being damaged or destroyed by earthquakes.
- Securing masonry building elements. Key portions of masonry block foundations usually require strengthening by installing reinforcing bars in the blocks and then filling them with concrete grout. FEMA has developed a sample plan for strengthening a masonry block foundation wall. This type of work can be complicated and normally requires the expertise of a design professional, such as an engineer or architect.

For nonstructural building components and contents, earthquake protection usually involves simple measures that homeowners can undertake themselves. These include anchoring and bracing of fixtures, appliances (e.g., hot water heaters and furnaces), chimneys, tanks, cabinets, shelves, and other items that may tip over or become damaged when subjected to earthquake ground shaking.

Additional resources related to seismic mitigation measures can be found in Appendix E.

3.5.3. WILDLAND-URBAN INTERFACE FIRES

While the number of reported wildfires has remained consistent since the 1990s, the severity of wildfire events has grown. Casualties, property damage, and post-fire impacts such as erosion, flash floods, mudslides, and landslides increase total wildfire damage and hinder forest regeneration.

The wildland-urban interface is the area where structures and other human development meet or intermingle with wildland vegetation. Numerous agencies and organizations have established more comprehensive and substantive definitions for the wildland-urban interface to encompass the broad range of environmental settings (e.g., topography, vegetation, weather) and built environment conditions (e.g., rural, semi-rural, urban, building typologies) where wildfires pose a major threat.

As more homes are constructed in wildland areas, the relative wildfire risk continues to increase. As of 2024, roughly 99 million residents, or 29% of Americans, live in the wildland-urban interface.[1] These trends underline increased wildfire severity, threatening more people living in wildfire-prone areas. Additionally, while wildfire incidence in the western United States has been exacerbated by warmer and drier fire seasons, other regions of the United States are likely to see increased susceptibility as environmental conditions change (e.g., increases in drier, warmer weather, longer droughts, and insect infestation), increasing the likelihood of wildfire ignitions[2].

[1] U.S. Fire Administration, *U.S. Fire Administration Launches New Tools to Raise Awareness on Wildland Urban Interface Fire,* posted July 17, 2024.
[2] U.S. Global Change Research Program, 2018.

Fuel, weather, and topography all impact wildfire risk and are key in determining where wildfire is likely to occur and how it behaves, burns, and spreads. Reducing one or more of these components is the basis of fire prevention, suppression, and mitigation. Wildfire mitigation actions focus on fuel management actions because neither weather nor topography can be controlled or managed. Variation in topography and seasonally changing fuel conditions further challenge wildfire probability analysis.



Note

Wildfire Risk Assessment: To attempt to quantify the risk of wildfire, various groups have developed wildfire hazard and risk maps; however, there is no national consensus-based wildfire risk map for community planning and wildfire building safety. Where local wildfire hazard maps are not available in every community, there are resources to support risk determination. Community hazard mitigation plans include wildfire history and risk analysis. Additionally, the FEMA Hazard Risk Index and state and local forestry officials are resources for community wildfire risk information.

The following factors affect the probability that a building will survive a wildfire:

- Weather conditions
- Topography
- Defensible space
- Building envelope
- Community infrastructure and design

When weather conditions are optimal for wildfire spread, fire generally follows terrain. Buildings at the top of a canyon or ridgeline, at mid-slope, or in a ravine have a higher risk of fire damage than at locations such as valley bottoms, due to topographic and vegetative features combined with strong winds. Drainage areas in canyons and ravines with high flood risk often have increased wildfire risk during dry seasons due to topography. When a construction site is selected, the topographic features on and surrounding the site should be evaluated for wildfire risk exposure. A building's configuration and location on a site should be predicated on minimizing the risk from these topographic features.

Wildfire travels quickly where vegetation is dry and abundant. A defensible space around a building can improve the probability that the building will survive a wildfire. A defensible space is an area where combustible material, including vegetation, has been cleared or modified to slow the rate and intensity of an advancing wildfire. Buildings surrounded by zones of non-vegetated areas or areas landscaped with fire-resistant vegetation are less likely to sustain fire damage.

Wildland-Urban Interface Fire-resistant Construction Techniques

The risk of wildfire varies greatly and is determined by local fuels, weather, and topography. The risk at a building site must be evaluated to inform fire-resistant design, construction methods, and building materials for new buildings or renovations. Consultation with both a wildfire/fire safety

specialist and an environmental protection specialist is recommended if a flood mitigation project is planned in an area with wildfire risk.

FEMA recommends following the design and construction guidance for flood resistance provided in this publication, locally adopted building codes, and wildfire-specific building and fire codes. In some cases, it may not be technically or financially possible to incorporate every recommended flood and wildfire mitigation measure for multi-hazard resistance. It is recommended that building owners and designers in high wildfire hazard areas consult with local fire and building code officials or other fire management specialists as they develop flood mitigation strategies to include wildfire resistance measures in the renovation project.

Cost-effective wildfire mitigation can include:

- Creation of defensible space up to 100 feet from the structure through landscape maintenance.
- Selection of fire-resistant deck, fencing, and support structure materials.
- Use of fire-resistant sheathing, trim, windows, doors, vents, soffit, and roofing materials.
- Avoiding storage of flammable materials under elevated buildings.



Cross Reference

Helpful information about the vulnerabilities of the building envelope is available through the Insurance Institute of Business and Home Safety at https://ibhs.org/wp-content/uploads/member_docs/wildfire-primer-series-part-2_environment.pdf. The Homeowner's Wildfire Assessment survey on this website is a helpful tool to determine specific risks of a particular building and measures to mitigate those risks.

The location of a building or development is a major driver of its wildfire risk. Wildfire severity and rate-of-spread of fire increase at specific topographic features such as saddles, ridge lines, drainages, canyons, and steep slopes. This can present a significant threat to homes or developments in those locations. Some communities provide additional siting requirements (e.g., minimum setbacks, additional defensible space requirements, additional structural hardening measures, development of a fire protection plan) for buildings and developments located in higher hazard topographies. However, this is not consistently provided locally where neighborhood-, community- or regional-level planning, or wildfire zoning requirements in high-risk landscapes are lacking.

Additional resources related to wildfire mitigation measures can be found in Appendix G.

3.5.4. LAND SUBSIDENCE (LANDSLIDES)

Land subsidence affects flooding and flood damage. It occurs in more than 17,000 square miles in 45 States. Land subsidence is typically a slow lowering of the land surface, but includes landslides that involve sudden, catastrophic collapses of the land surface. Land subsidence and landslides increase damage from other hazards to structures and infrastructure. Since causes of land subsidence vary, specific mitigation techniques are required in different situations.

Land subsidence is typically a function of withdrawal of fluids or gases, the existence of organic soils, or other geotechnical factors; it requires an extensive engineering/geotechnical analysis. While National Flood Insurance Program regulations do not specifically address land subsidence, communities that develop mapping and regulatory standards addressing these hazards may receive flood insurance premium credits through the National Flood Insurance Program Community Rating System. The designer should determine if a local community has mapped or enacted an ordinance covering this special hazard.

3.5.5. SUMMARY: ASSESSING RISK AND POTENTIAL MITIGATION MEASURES FOR NON-FLOOD HAZARDS

For this publication, assessment of non-flood hazards is limited to a basic assessment of high wind, earthquake, and wildfire hazard risk. Hazard risk is a function of the probability and impact of the hazard. High winds and wildfires, which are likely to cause building damage, occur more frequently than earthquakes. However, hazard impacts due to high wind, earthquakes, and wildfires vary significantly based on design wind speeds, wildfire risk, and seismic design accelerations. These risk factors can be determined for specific building sites using online resources. Figure 3-16 provides a non-flood hazard matrix that can be used to determine high wind and seismic hazard impacts and risks at a building site using links to existing online resources available from ASCE, estimate community risk of wildfire using online resources available from the U.S. Forest Service, and assess the risk of these non-flood hazards relative to one another.

Once the relative risk of high wind, earthquake, and wildfire is assessed, designers can establish priorities for retrofitting the building to address these hazards. The higher the hazard risk, the greater the priority for hazard mitigation. Since this publication focuses on retrofitting flood-prone residential buildings and the availability of other references that address non-flood hazards, discussion has been limited to basic retrofitting techniques for high wind, earthquake, and wildfire hazards that can be addressed based on relative cost, level of effort, and potential for multi-hazard benefits.

Resources providing additional information on hazard mitigation and retrofitting techniques for non-flood hazards in residential buildings are listed in Appendix E.

Non-Flood Hazard Worksheet - Hazard Risk Assessment			
Owner Name:		**Preparer**	
Address:		**Date:**	
Property Details:			

Non-Flood Hazard Risk Assessment Variables

Wind Hazard Risk:

Estimate V_{wind} using the ASCE Hazard Tool website (https://ascehazardtool.org) by inputting the property location, selecting the applicable version of ASCE 7 for the location, checking Risk Category II (Residential), and checking the Design Wind Speed; which assumes a Mean Recurrence Interval (MRI) = 700 years.

V_{wind} = Design Wind Speed (mph) _____ mph

Site Located in Wind-Borne Debris Region? (Yes/No) _____ (Check by clicking Wind Details on ASCE Hazard Tool)

Tornado Design Wind Speed (mph) _____ mph

Seismic (Earthquake) Hazard Risk:

Estimate S_{DS} using the ASCE Hazard Tool website (https://ascehazardtool.org) by inputting the property location, selecting the applicable version of ASCE 7 for the location, checking Risk Category II (Residential) and assuming Default Site Class (Site Class D unless better geotechnical data is available), then click Details. Note this is tied to a design earthquake event with a 2% chance of occurrence in the next 50 years; which equates to a Mean Recurrence Interval (MRI) of 2,475 years.

S_{DS} = Seismic Design Value at 0.2s Spectral Acceleration (%g) _____ g

Seismic Design Category: _____

Wildfire Hazard Risk:

Estimate Wildfire Hazard Risk using the USDA-USFS Wildfire Risk to Communities website (https://wildfirerisk.org/explore) by searching community location.

Overall Wildfire Risk _____ Indicates the overall risk of wildfire in comparison to other communities throughout the US.

Risk to Homes: _____ Indicates the risk of wildfire damage to homes in comparison to other US communities.

Wildfire Likelihood _____ Indicates the likelihood of a wildfire in comparison to other US communities.

Assessment of Non-Flood Hazard Risks

Conduct a qualitative assessment of non-flood hazard risks relative to one another based on the Non-Flood Hazard Risk Assessment Variables collected for Wind, Seismic and Wildfire

Wind Hazard Risk _____ (Low/Medium/High based on Design Wind Speed and potential for Wind-Borne Debris/Tornado)

Seismic Hazard Risk _____ (Low/Medium/High based on Seismic Design Value at 0.2s Spectral Acceleration)

Wildfire Hazard Risk _____ (Low/Medium/High based on Overall Wildfire Risk)

Purpose:	The purpose of the Non-Flood Hazard Matrix - Part A: Hazard Risk Assessment is to determine the relative risk of flood hazards in comparison to non-flood hazards (wind, earthquake and wildfire) to help prioritize building retrofits.
Instructions:	Step 1: Start Non-Flood Hazard Risk Assessment Variables section by following the instructions and inputting Wind Hazard Risk data for the project site based on the ASCE Hazards Tool website for Wind and Tornado. Step 2: Continue Non-Flood Hazard Risk Assessment Variables section by following the instructions and inputting Earthquake Hazard Risk data for the project site based on the ASCE Hazards Tool website for Seismic. Step 3: Complete Non-Flood Hazard Risk Assessment Variables section by following the instructions and inputting Wildfire Hazard Risk data for the project community based on the USDA-USFS Wildfire Risk to Communities website. Step 4: Complete Assessment of Non-Flood Hazard Risks section by following the instructions and conducting a qualitative risk assessment of Wind, Seismic and Wildfire Risks based on the Non-Flood Hazard Risk Assessment Variables collected in Steps 1, 2 and 3.
Evaluation of Results:	The hazards with higher Hazard Risk Levels should be prioritized for retrofitting over hazards with lower Hazard Risk Levels.

Figure 3-16. Risk Assessment Matrix for Non-Flood Hazards

3.6. Case Study Exercise 3 – Assessment of Non-Flood Hazards

Case Study A – Exercise 3

Case Study A – Exercise 3: Residential Retrofit in Riverine Floodplain Using Relocation or Elevation

Non-Flood Hazard Assessment

Natural hazards such as high winds, earthquakes, and wildfires can pose a threat to Mr. and Mrs. Doe's house. Each of these hazards was assessed to establish priorities for retrofitting the building (see Figure CSA-14). The house is located in Linn County, Iowa, and has a basic wind speed of 109 miles per hour. The seismic design category associated with the property is Seismic Design Category B and considered a low risk. The U.S. Department of Agriculture-U.S. Fire Administration Wildfire Risk to Communities website shows his house has a low risk to wildfire. The home does have direct exposure to being ignited by adjacent vegetation, flying embers, or nearby structures. However, it should be noted that Northern Midwest snowstorms can create significant snowfall that is reflected in the ground snow load of 51 pounds per square foot for the Doe's house.

Non-Flood Hazard Matrix - Hazard Risk Assessment			
Owner Name:	**John and Jane Doe**	**Preparer**	**JJS-MH**
Address:	**55 Cedar River Road**	**Date:**	**7/6/2026**
Property Details:	**Case Study A**		

Non-Flood Hazard Risk Assessment Variables

Wind Hazard Risk:

Estimate V_{wind} using the ASCE Hazard Tool website (https://ascehazardtool.org) by inputting the property location, selecting the applicable version of ASCE 7 for the location, checking Risk Category II (Residential), and checking the Design Wind Speed; which assumes a Mean Recurrence Interval (MRI) = 700 years.

V_{wind} = Design Wind Speed (mph)	**109**	mph
Site Located in Wind-Borne Debris Region? (Yes/No)	**No**	(Check by clicking Wind Details on ASCE Hazard Tool)
Tornado Design Wind Speed (mph)	**N/A**	mph

Seismic (Earthquake) Hazard Risk:

Estimate S_{DS} using the ASCE Hazard Tool website (https://ascehazardtool.org) by inputting the property location, selecting the applicable version of ASCE 7 for the location, checking Risk Category II (Residential) and assuming Default Site Class (Site Class D unless better geotechnical data is available), then click Details. Note this is tied to a design earthquake event with a 2% chance of occurrence in the next 50 years; which equates to a Mean Recurrence Interval (MRI) of 2,475 years.

S_{DS} = Seismic Design Value at 0.2s Spectral Acceleration (%g)	**0.2**	g
Seismic Design Category:	**B**	

Wildfire Hazard Risk:

Estimate Wildfire Hazard Risk using the USDA-USFS Wildfire Risk to Communities website (https://wildfirerisk.org/explore) by searching community location.

Overall Wildfire Risk	**Low**	Indicates the overall risk of wildfire in comparison to other communities throughout the US.
Risk to Homes:	**Low**	Indicates the risk of wildfire damage to homes in comparison to other US communities.
Wildfire Likelihood	**Low**	Indicates the likelihood of a wildfire in comparison to other US communities.

Assessment of Non-Flood Hazard Risks

Conduct a qualitative assessment of non-flood hazard risks relative to one another based on the Non-Flood Hazard Risk Assessment Variables collected for Wind, Seismic and Wildfire

Wind Hazard Risk	**Low**	(Low/Medium/High based on Design Wind Speed and potential for Wind-Borne Debris/Tornado)
Seismic Hazard Risk	**Low**	(Low/Medium/High based on Seismic Design Value at 0.2s Spectral Acceleration)
Wildfire Hazard Risk	**Low**	(Low/Medium/High based on Overall Wildfire Risk)

Purpose:	The purpose of the Non-Flood Hazard Matrix - Part A: Hazard Risk Assessment is to determine the relative risk of flood hazards in comparison to non-flood hazards (wind, earthquake and wildfire) to help prioritize building retrofits.

Non-Flood Hazard Matrix - Part A: Hazard Risk Assessment (continued)	
Instructions:	Step 1: Start Non-Flood Hazard Risk Assessment Variables section by following the instructions and inputting Wind Hazard Risk data for the project site based on the ASCE Hazards Tool website for Wind and Tornado.
	Step 2: Continue Non-Flood Hazard Risk Assessment Variables section by following the instructions and inputting Earthquake Hazard Risk data for the project site based on the ASCE Hazards Tool website for Seismic.
	Step 3: Complete Non-Flood Hazard Risk Assessment Variables section by following the instructions and inputting Wildfire Hazard Risk data for the project community based on the USDA-USFS Wildfire Risk to Communities website.
	Step 4: Complete Assessment of Non-Flood Hazard Risks section by following the instructions and conducting a qualitative risk assessment of Wind, Seismic and Wildfire Risks based on the Non-Flood Hazard Risk Assessment Variables collected in Steps 1, 2 and 3.
Evaluation of Results:	The hazards with higher Hazard Risk Levels should be prioritized for retrofitting over hazards with lower Hazard Risk Levels.

Figure CSA-14. Non-Flood Hazard Matrix for the Doe house



Note

The ASCE Hazard Tool website is a valuable resource that can provide design loads for buildings and other structures, available at https://ascehazardtool.org/.

Case Study B – Exercise 3

Case Study B – Exercise 3: Residential Retrofit Outside of the Floodplain Using Floodwalls or Dry Floodproofing

Non-Flood Hazard Assessment

The Valley Apartments is located in Mesa, Arizona, which has low risk to high winds and earthquakes, but a high risk of wildfire compared to many other locations in the U.S., as shown in Figure CSB-12. The ASCE Hazard Tool using ASCE 7-22 provides a wind speed of 102 miles per hour, a seismic design category B, and a negligible snow load. However, the wildfire risk for Mesa, Arizona, is high as described by the U.S. Department of Agriculture-U.S. Fire Administration Wildfire Risk to Communities website at https://wildfirerisk.org/explore. There is concern that Mr. Smith's building may be ignited by adjacent flammable vegetation. He plans to review FEMA publications such as FEMA P-737 to gain a better understanding of wildfire mitigation so that he can begin to mitigate this hazard as well. The implementation of guidance on defensible space can be a cost-effective way for him to reduce the building's risk of ignition through proper site management. The site management may include the removal of dead branches and moving the location of trees farther away from the building.

Non-Flood Hazard Matrix - Hazard Risk Assessment			
Owner Name:	**John Smith**	**Preparer**	**JJS-MH**
Address:	**2908 Valley Drive**	**Date:**	**7/6/2026**
Property Details:	**Case Study B**		

Non-Flood Hazard Risk Assessment Variables

Wind Hazard Risk:

Estimate V_{wind} using the ASCE Hazard Tool website (https://ascehazardtool.org) by inputting the property location, selecting the applicable version of ASCE 7 for the location, checking Risk Category II (Residential), and checking the Design Wind Speed; which assumes a Mean Recurrence Interval (MRI) = 700 years.

V_{wind} = Design Wind Speed (mph)	**102**	mph
Site Located in Wind-Borne Debris Region? (Yes/No)	**No**	(Check by clicking Wind Details on ASCE Hazard Tool)
Tornado Design Wind Speed (mph)	**N/A**	mph

Seismic (Earthquake) Hazard Risk:

Estimate S_{DS} using the ASCE Hazard Tool website (https://ascehazardtool.org) by inputting the property location, selecting the applicable version of ASCE 7 for the location, checking Risk Category II (Residential) and assuming Default Site Class (Site Class D unless better geotechnical data is available), then click Details. Note this is tied to a design earthquake event with a 2% chance of occurrence in the next 50 years; which equates to a Mean Recurrence Interval (MRI) of 2,475 years.

S_{DS} = Seismic Design Value at 0.2s Spectral Acceleration (%g)	**0.2**	g
Seismic Design Category:	**B**	

Wildfire Hazard Risk:

Estimate Wildfire Hazard Risk using the USDA-USFS Wildfire Risk to Communities website (https://wildfirerisk.org/explore) by searching community location.

Overall Wildfire Risk	**High**	Indicates the overall risk of wildfire in comparison to other communities throughout the US.
Risk to Homes:	**High**	Indicates the risk of wildfire damage to homes in comparison to other US communities.
Wildfire Likelihood	**High**	Indicates the likelihood of a wildfire in comparison to other US communities.

Assessment of Non-Flood Hazard Risks

Conduct a qualitative assessment of non-flood hazard risks relative to one another based on the Non-Flood Hazard Risk Assessment Variables collected for Wind, Seismic and Wildfire

Wind Hazard Risk	**Low**	(Low/Medium/High based on Design Wind Speed and potential for Wind-Borne Debris/Tornado)
Seismic Hazard Risk	**Low**	(Low/Medium/High based on Seismic Design Value at 0.2s Spectral Acceleration)
Wildfire Hazard Risk	**High**	(Low/Medium/High based on Overall Wildfire Risk)

Purpose:	The purpose of the Non-Flood Hazard Matrix - Part A: Hazard Risk Assessment is to determine the relative risk of flood hazards in comparison to non-flood hazards (wind, earthquake and wildfire) to help prioritize building retrofits.

Non-Flood Hazard Matrix - Part A: Hazard Risk Assessment (continued)	
Instructions:	Step 1: Start Non-Flood Hazard Risk Assessment Variables section by following the instructions and inputting Wind Hazard Risk data for the project site based on the ASCE Hazards Tool website for Wind and Tornado.
	Step 2: Continue Non-Flood Hazard Risk Assessment Variables section by following the instructions and inputting Earthquake Hazard Risk data for the project site based on the ASCE Hazards Tool website for Seismic.
	Step 3: Complete Non-Flood Hazard Risk Assessment Variables section by following the instructions and inputting Wildfire Hazard Risk data for the project community based on the USDA-USFS Wildfire Risk to Communities website.
	Step 4: Complete Assessment of Non-Flood Hazard Risks section by following the instructions and conducting a qualitative risk assessment of Wind, Seismic and Wildfire Risks based on the Non-Flood Hazard Risk Assessment Variables collected in Steps 1, 2 and 3.
Evaluation of Results:	The hazards with higher Hazard Risk Levels should be prioritized for retrofitting over hazards with lower Hazard Risk Levels.

Figure CSB-12. Non-Flood Hazard Matrix for The Valley Apartments

3.7. Geotechnical Considerations

Soil properties during conditions of flooding are important factors in the design of any surface intended to resist flood loads. These properties include:

- Saturated soil forces (see Section 3.1.5)
- Allowable bearing capacity
- Potential for scour
- Frost zone location

- Permeability
- Shrink-swell potential

The computation of lateral soil forces and determination of soil bearing capacity are critical in the design of foundations. These forces, plus the frost zone location and potential scour, play an important role in determining the type of foundation to use. Likewise, the permeability and compatibility of soils are key factors in selecting borrow materials for backfill or flood berm construction.

Site investigations for soils include surface and subsurface investigations. Surface investigations can identify evidence of landslides, areas affected by erosion or scour, and accessibility for equipment needed for subsurface testing and construction. Surface investigations can also help identify the suitability or unsuitability of each foundation style based on the past performance of existing structures. Subsurface exploration provides invaluable data on soils at and below grade, including soil classifications and other data that can help quantify soil properties. Since subsurface exploration is too complicated and site-dependent to be covered fully in one document, consulting a geotechnical engineer familiar with the site is recommended.



Cross Reference

Additional information on landslides and other geotechnical-related natural hazards can be found at https://www.usgs.gov/programs/landslide-hazards.



Note

The physical properties of soil are critical to the design, suitability, and overall stability of floodproofing measures. Therefore, the designer should consult a geotechnical engineer if the soil properties at a site do not support the use of the chosen retrofitting method. A geotechnical engineer should also be consulted for any information that cannot be obtained from the Soil Survey or the local office of the Natural Resources Conservation Service.

If unsure of local soil conditions, obtain a copy of the U.S. Department of Agriculture, Natural Resources Conservation Service Soil Survey of the general area. This survey provides valuable information needed to conduct a preliminary evaluation of the soil properties, including:

- Type, location, and description of soil types
- Use and management of the soil types
- Engineering and physical properties, including plasticity indexes, permeability, shrink/swell potential, erosion factors, potential for frost action, and other information

This information can be compiled to enable the designer to determine the suitability of the specific soil type to support the various retrofitting methods. It is important to note that, while the soil

properties may not be optimum for specific retrofitting methods, facilities can often be designed to overcome soil deficiencies.

The following sections begin a discussion of the various soil properties, providing the information necessary to fill out the Geotechnical Considerations Decision Matrix (Figures 3-17 and 3-18), understanding the relationship between these soil properties and retrofitting measures.

Geotechnical Considerations Decision Matrix											
Owner Name:								Preparer			
Address:								Date:			
Soil Description (USDA Soil Type):											
	Retrofitting Measures										
	Structural Elevation			Elevation Alternatives			Relocation	Floodproofing		Flood Barriers	
Geotechnical Consideration	Stem Wall (Fill)	Perimeter Wall/ Piers	Piles	Basement Infill	Abandon/ Repurpose Lowest Floor	Elevate Lowest Interior Floor		Dry	Wet	Floodwall	Berm
Pre-Screening from Preliminary Homeowner Preference Matrix											
Measure Not Feasible (NF)											
Allowable Bearing Capacity, Q_{BC} (see Table 3-6)											
High (Q_{BC} > 2,500 psf)											
Moderate (Q_{BC} = 1,000 to 2,500 psf)											
Low (Q_{BC} < 1,000 psf)	NS	NS								NS	NS
Potential for Scour											
High (Soil Types GW, GP, SW, SP and V > 5 ft/sec)	NS	NS		NS		NS				NS	NS
Moderate to Low (All Other Soil Types or V ≤ 5 ft/sec)											
Shrink/Swell Potential											
Severe (Soil Types CH, CL, ML-CL, MH, SC)	NS										NS
Moderate to Low (All Other Soil Types)											
Permeability, *K* (see Table 3-8)											
High (*K* > 1 ft/day)								NS		NS	NS
Moderate (*K* = 0.0015 to 1 ft/day)								NS		NS	NS
Low (*K* < 0.0015 ft/day)											
Scoring											
Subtotal S's											
Subtotal NS's											
Suitability Determination (Yes if NS's = 0, No if NS's ≥ 1)											

Purpose: The purpose of the Geotechnical Considerations Decision Matrix is to help the designer identify situations where soil conditions are unsuitable when applied to certain retrofitting measures, therefore eliminating infeasible measures. It is not intended to select the most suitable alternative. See next page for Matrix Notes, Instructions, and Evaluation of Results.

Matrix Notes:

NF Not Feasible: indicates the retrofit measure was pre-screened to be not allowed or not feasible based on the configuration of the existing structure and/or property. Refer to the Preliminary Homeowner Preference Matrix for details.

NS Not Suitable: indicates the retrofit measure is not suitable for this soil property.

Lateral Soil Pressure and Frost Action were not considered in this matrix since both can be generally addressed using a properly reinforced foundation design placed at the appropriate frost depth.

Refer to FEMA P-259 Table 3-2 for Soil Types and descriptions based on the USDA Unified Soil Classification System.

Page 1 of 2. See next page for Instructions and Evaluation of Results.

Figure 3-17. Geotechnical Considerations Decision Matrix

Geotechnical Considerations Decision Matrix (continued)		
Instructions:	Step 1:	Complete pre-screening by placing an "NF" in the box for each measure which is not allowed or is not feasible based on the configuration of the existing structure and/or property using the Preliminary Homeowner Preference Matrix. For these measures, skip Steps 2 through 8 and put an "NF" for Not Feasible under the Suitability Determination.
	Step 2:	Review the Allowable Bearing Capacity section and circle the row that best matches the foundation soil properties. Place a "S" (Suitable) for each measure along the Allowable Bearing Capacity row you circled unless there is an NF in the top row or an NS already in that measure's box.
	Step 3:	Review the Potential for Scour section and circle the row that best matches the foundation soil properties and flood velocity. Place a "S" (Suitable) for each measure along the Potential for Scour row you circled unless there is an NF in the top row and an NS already in that measure's box.
	Step 4:	Review the Shrink/Swell Potential section and circle the row that best matches the foundation soil properties. Place a "S" (Suitable) for each measure along the Shrink/Swell Potential row you circled unless 1) Shrink/Swell Potential is Severe and 2) Retrofit foundation depth is not below Frost Depth required by the local building code.
	Step 5:	Review the Permeability section and circle the row that best matches the foundation soil properties. Place a "S" (Suitable) for each measure along the Permeability row you circled unless there is an NF in the top row and an NS already in that measure's box.
	Step 6:	In the Subtotal S's row, add up the total number of "S's" for each measure and input the subtotal in each column.
	Step 7:	In the Subtotal NS's row, add up the total number of "NS's" for each measure and input the subtotal in each column.
	Step 8:	In the Suitability Determination row, input a "Yes" for each measure where the Subtotal NS's is equal to zero. Input a "No" for each measure where the subtotal NS's is equal to one or greater.
Evaluation of Results:	Retrofit measures with a Suitability Determination of "Yes" are considered suitable for addressing the site soil conditions. Retrofit measures with a Suitability Determination of "No" or "NF" are considered not suitable for addressing the site soil conditions.	

Figure 3-18. Instructions for Completing the Geotechnical Considerations Decision Matrix (Figure 3-17)

3.7.1. ALLOWABLE BEARING CAPACITY

The weight of the structure, along with the weight of backfilled soil (if present), creates a vertical pressure under the footing that must be resisted by the soil. The term "allowable bearing pressure" refers to the maximum unit load that can be placed on a soil deposit without causing excessive deformation, shear failure, or consolidation of the underlying soil.

Bearing capacity has a direct effect on the design of shallow foundations. Soils with lower bearing capacities require proportionately larger foundations to effectively distribute gravity loads to the supporting soils. For deep foundations, like piles, bearing capacity has less effect on the ability of the foundation to support gravity loads because most of the resistance to gravity loads is developed by shear forces along the pile.

Bearing capacity is generally measured in pounds per square foot (lb/ft^2) and occasionally in tons per square foot. Soil bearing capacity typically ranges from 1,000 lb/ft^2 (relatively weak soils) to more than 10,000 lb/ft^2 (bedrock). The allowable bearing capacity is the ultimate bearing capacity divided by an appropriate factor of safety. The factor of safety depends on whether the soils have been assessed. Soil bearing capacity testing will result in detailed soil characteristics, producing a reasonable and accurate factor of safety. An appropriate factor of safety between 2 and 3 should be used if soil testing has not been completed. See Equation 3-16.

EQUATION 3-16: ALLOWABLE BEARING CAPACITY

$$Q_{BC} = \frac{Q_u}{FS}$$

Where:

Q_{BC} = allowable bearing capacity (lb/ft^2)

Q_u = ultimate bearing capacity (lb/ft^2)

FS = factor of safety (as prescribed by code)

Table 3-6 presents estimated allowable bearing capacities for various soil types to be used for preliminary sizing of footings only. The actual allowable soil bearing capacity should be determined by a geotechnical engineer. Most local building codes specify an allowable bearing capacity to be utilized in design if the soil properties have not been specifically determined.

Once the allowable bearing capacity is determined by the geotechnical engineer or a conservative estimate prescribed by code is made, the designer can determine the capacity of the existing foundation to support the expected loads. Depending on the outcome of that evaluation, the designer may need to supplement the existing footing to support the expected loading condition (i.e., keep the actual bearing pressure below the allowable bearing pressure of the soil) because of the retrofitting project.

Table 3-6. Typical Allowable Bearing Capacity by Soil Type from USDA Unified Soil Classification System (Table 3-2)

Soil Type (Symbol)	Allowable Bearing Capacity, Q_{BC} (lb/ft^2)
Clay, Soft (CL, CH)	600 to 1,200
Clay, Firm (CL, CH)	1,500 to 2,500
Clay, Stiff (CL, CH)	3,000 to 4,500
Loose Sand, Wet (SP, SW, SM)	800 to 1,600
Firm Sand, Wet (SP, SW, SM, SC)	1,600 to 3,500
Gravel (GW, GP, GM, GC)	2,700 to 3,000

The ability of soils to bear loads, usually expressed as shearing resistance, is a function of many complex factors, including some that are site-specific. A significant factor affecting shearing resistance is the presence and movement of water within the soil. Under conditions of submergence, some shearing resistance may decrease due to the buoyancy effect of the interstitial water or, in the case of cohesive soils, to physical or chemical changes brought about in clay minerals.

Note

Certain types of soil – loose sands and soft clays (SP, SW, SM, SC, CL, CH) exhibit extremely poor bearing capacities when saturated; therefore, foundation, floodwall, and flood berm applications in those conditions would not be feasible without special treatment.

While there are many possible site-specific effects of saturation on soil types, some classes of soil can be identified that have generally low shearing resistances under most conditions of saturation. These include:

- Fine, silty sands of low density that in some localities may suddenly compact when loaded or shaken, resulting in a phenomenon known as liquefaction.
- Sand or fine gravel, in which the hydraulic pressure of upward-moving water within the soil equals the weight of the soil, causing the soil to lose its shear strength and become "quicksand," which will not support loads at the surface.
- Soils below the water table have lower bearing capacity than the same soils above the water table.

Other types of saturated soils may also have low shearing resistances under loads, depending on numerous site-specific factors such as slope, hydraulic head, gradient stratigraphic relationships, internal structures, and density. Generally, the soils noted above should not be considered suitable for structural support or backfill for retrofitting purposes. When they are known to be present, a geotechnical engineer should be consulted for site-specific solutions.

Warning

Attempts to construct water- or saturated soil-retaining structures without a thorough understanding of soil mechanics and analysis of on-site soils can result in expensive repairs and project failure.

3.7.2. SCOUR POTENTIAL

Scour is localized loss of soil caused by the movement of soil or sediment around an obstruction to flow, resulting in acceleration and changing flow patterns as flow is constricted. Where flow impinging on a structure is affected by diversion and constriction due to nearby structures or other obstructions, flow conditions estimated for the calculation of depths of scour should be evaluated by a qualified geotechnical engineer.

Note

Erosion is a loss of soil over a large area, resulting in a lowering of the ground surface or embankment failure; while scour is a localized erosion immediately around an object or obstruction. In riverine areas, erosion is a complex process that includes many factors, such as fluvial hydraulics, soil stability, sediment transport, and watershed characteristics, including hydrology and sediment yield, past and future land use, and vegetation, among others. FEMA riverine flood maps do not include storm- or event-driven erosion, nor long-term erosion.

The effect of flood loads on buildings can be exacerbated by flood-induced erosion and localized scour, as well as long-term erosion, all of which can lower the ground surface around foundation elements and cause the loss of load-bearing capacity and resistance to lateral and uplift loads. This can render structural retrofit designs ineffective, possibly resulting in failure. Figures 3-19 and 3-20 illustrate scour at open foundation systems (piers and posts) and closed foundation systems (walls or grade slabs).

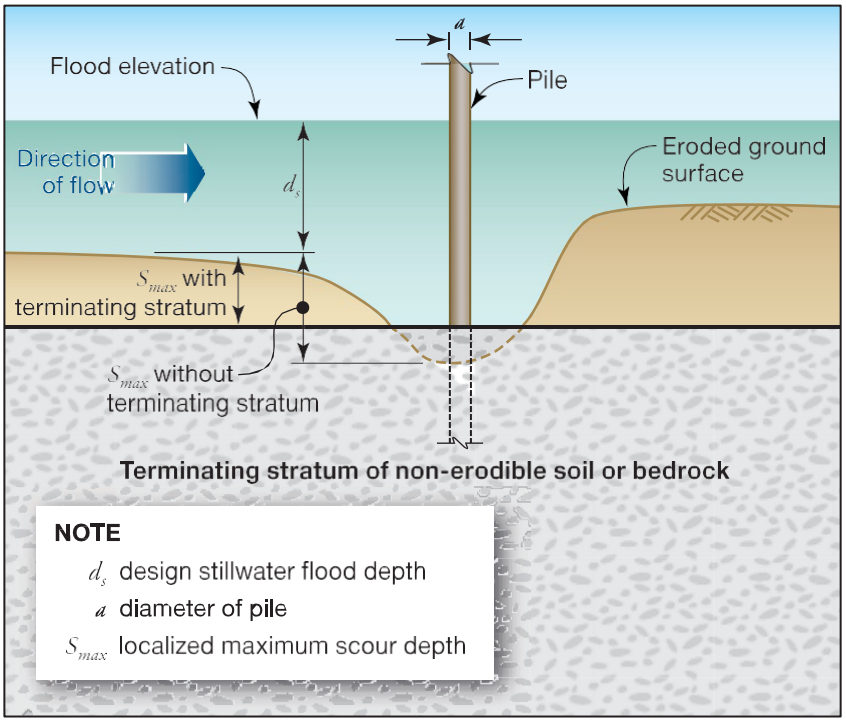


Figure 3-19. Scour action on open foundations (piers, posts, and piles)

Determining the maximum potential scour is critical for designing an elevated foundation system to ensure that failure does not occur due to loss of bearing capacity or anchoring resistance around piers, posts, or piles. If a pier or post was not designed to withstand a maximum potential scour, and was exposed to scour from a flood, the column will be subjected to loading in a condition it was not designed for, which may result in a failure of the foundation. If a pier or post experienced 4 feet of unplanned scour around its base, and the structural element was designed to have an embedment

depth of 5 feet, the resulting embedment depth would be 1-foot which would compromise the lateral and uplift resistance of the structural element.

The potential for foundation scour is a complex problem. Granular and other consolidated soils in which the individual particles lack cohesion (i.e., are not cemented to one another) are subject to scour, erosion, and transport by the force of moving water. The greater the velocity or turbulence of the moving water, the greater the scour potential. Soils that contain sufficient proportions of compacted clay add cohesion and are more resistant to scour than the same grain sizes without clay as an intergranular bond. Likewise, soils with angular particle shapes tend to lock in place and resist scour forces.

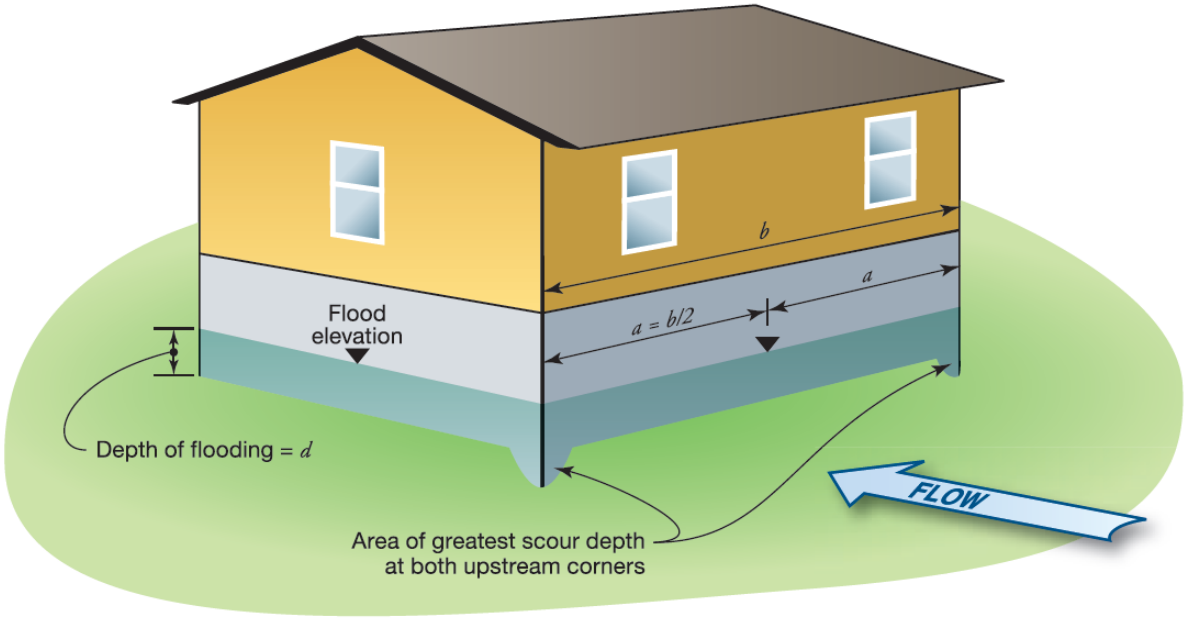


Figure 3-20. Scour action on closed foundations (walls or grade slabs)

Shallow foundations in areas subject to flood velocity flow may be subject to scour, and appropriate safeguards should be undertaken. These safeguards may include the use of different, more erosion-resistant soils, deeper foundations, surface armoring of the foundation and adjacent areas, and the use of piles or other foundations that present less obstruction to floodwater.

The calculation for estimating maximum potential scour depth at an elevated or ground level foundation member (Equation 3-19) is based upon the foundation (or foundation member) shape and width, as well as the water velocity and depth, and type of soil.

Where elevation on fill is the primary retrofitting measure, embankments must be protected against erosion and scour. Scour at the embankment toe may be calculated as shown in Equation 3-17.

EQUATION 3-17: MAXIMUM POTENTIAL SCOUR AT EMBANKMENT TOE

$$S_{max} = d\left[1.1\left(\frac{a}{d}\right)^{0.4}\left(\frac{V}{(gd)^{0.5}}\right)^{0.33}\right]$$

Where:

S_{max} = maximum potential depth of scour hole (ft)

d = depth of flow upstream of structure (ft)

a = diameter of the pier, post, or pile, or half the frontal length of the blockage (ft)

V = diameter of pier, post, or pile, or half the frontal length of the blockage (ft)

g = velocity of flow approaching the structure (ft/sec)

Note

The factor "*a*" in Equation 3-17 is the diameter of an open foundation member or half of the width of the solid foundation perpendicular to flood flow.

The maximum potential scour depth predicted by the following equation represents a maximum depth that could be achieved if the soil material were of a nature that could be displaced by the water's action. However, in many cases, a stronger underlying stratum will terminate the scour at a shallower elevation. Figure 3-21 illustrates the process of determining the potential scour depth affecting a foundation system.

Warning

The scour information presented is the best available; however, there is no general consensus within the scientific community that these scour equations are valid. Research continues into this area.

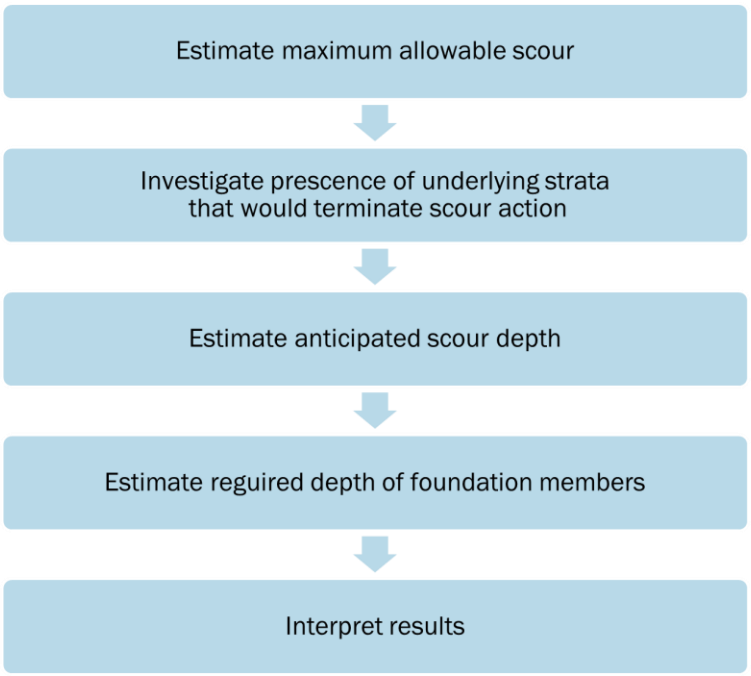


Figure 3-21. Process of estimating potential scour depth

Step 1: Estimate maximum allowable scour. The scour depth at square and circular pier, post, and pile foundation members can be calculated as shown in Equation 3-18.

EQUATION 3-18: LOCALIZED SCOUR AROUND VERTICAL PILE

$S_{max} = 2.2a$

Where:

S_{max} = maximum potential depth of scour hole (ft)

a = diameter of a round foundation element, or the maximum diagonal cross-section dimension for a rectangular element (ft)

Note

Equation 3-18 can also be used to approximate local scour beneath grade beams – set "*a*" equal to the depth (vertical thickness) of the grade beam.

Localized scour around vertical walls and enclosed areas (e.g., typical Zone A construction) can be greater than that around vertical piles and should be calculated as shown in Equation 3-19 (see Note).

EQUATION 3-19: LOCALIZED SCOUR AROUND VERTICAL ENCLOSURE

$$S_{max} = d_s \left[2.2 \left(\frac{a}{d_s} \right)^{0.65} \left(\frac{V}{(g d_s)^{0.5}} \right)^{0.43} \right] K$$

Where:

S_{max} = maximum potential depth of scour hole(ft)

d_s = design still water flood depth upstream of the structure (ft)

a = diameter of a round foundation element, or the maximum diagonal cross-section dimension for a rectangular element (ft)

V = velocity of flow approaching the structure (ft/sec)

g = acceleration of gravity (equal to 32.2 ft/sec^2)

K = factor applied for flow angle of attack (see Figure 3-22)

Note

The above scour equation applies to average soil conditions (2,000–3,000 lb/ft^2 bearing capacity), including gravels (GW, GP, GM, and GC), sands (SW, SP, SM, and SC), and silts and clays (ML, CL, MH, and CH). For loose sand and hard clay, the maximum scour values may be increased and decreased, respectively, to reflect their lower and higher bearing capacities. However, the assistance of a geotechnical engineer should always be sought when making this adjustment, computing scour depths, and/or designing foundations subject to scour effects.

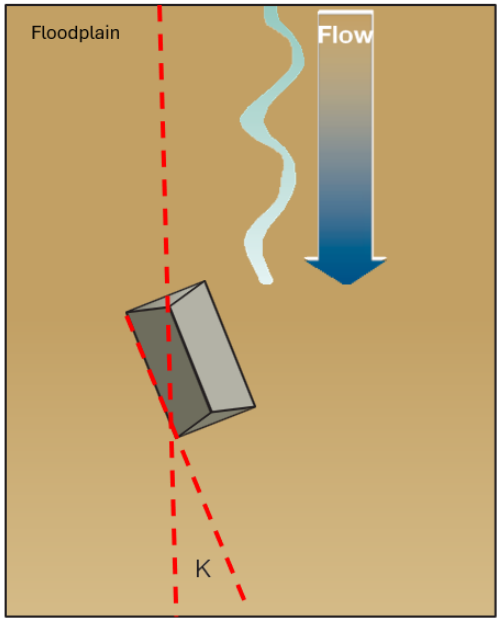


Figure 3-22. Flow Angle of Attack

If a wall or foundation member is oriented at an angle to the direction of flow, a multiplying factor, *K*, can be applied to the scour depth to account for the resulting increase in scour as presented in Table 3-7.

Table 3-7. Scour Factor for Flow Angle of Attack, *K*

	Length to Width Ratio of Structural Member in Flow			
Angle of Attack	**4**	**8**	**12**	**16**
0	1	1	1	1
15	1.15	2	2.5	3
30	2	2.5	3.5	4.5
45	2.5	3.5	4.5	5
60	2.5	3.5	4.5	6

Step 2: Investigate underlying soil strata. Once the maximum potential scour depth has been established, the designer should investigate the underlying soil strata at the site to determine if the underlying soil is of sufficient strength to terminate scour activities. Information from the Natural Resource Conservation Service Web Soil Survey may be used to make this assessment (https://websoilsurvey.nrcs.usda.gov/app/).



Note

The U.S. Department of Transportation recommends a factor of safety of 1.5 for predicting building scour depth.

Figure 3-23 illustrates a scour-terminating stratum. If an underlying terminating stratum does not exist at the site, the maximum potential scour estimate will become the anticipated scour depth. However, if an underlying terminating stratum exists, the maximum potential scour depth will be modified to reflect this condition, as shown in Step 3.

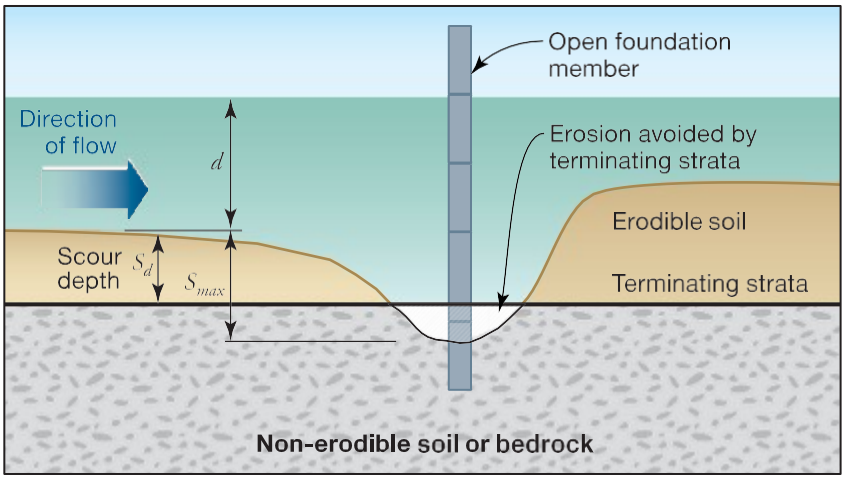


Figure 3-23. Terminating stratum

Step 3: Estimate anticipated scour depth. Based on the results of Step 2, the designer will determine the anticipated scour depth to be used in determining the depth to which the foundation element must be placed to resist scour effects. If a terminating stratum exists, the expected scour will stop at the depth at which this stratum starts, and the distance from this point to the surface is the potential scour depth (S_d). If no terminating stratum exists, the maximum potential scour (S_{max}) computed earlier becomes the S_d.

Step 4: Estimate required depth of foundation members. Scour will increase the height above grade of the vertical member since the grade level will be lowered due to erosion and scour (see Figure 3-24). As this occurs, the depth of burial (D_b) of the vertical foundation member also decreases an identical distance. This can result in a foundation failure because the loss of supporting soils would change the assumed conditions under which the elevated foundation system was designed. To account for this, the vertical foundation member depth used for the purpose of determining an acceptable design must be increased by the amount of S_d.

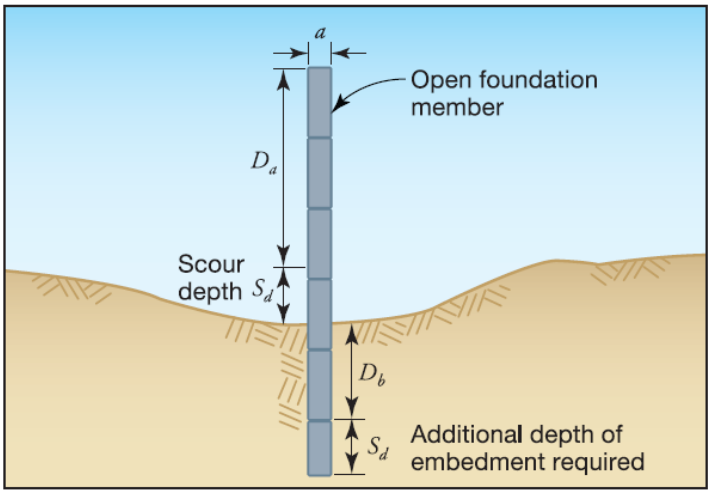


Figure 3-24. Additional embedment for foundation member

Step 5: Interpret results. Foundations, footings, and any supporting members should be protected at least to the anticipated scour depth. If the structural member cannot be buried deeper than the anticipated scour depth, the member should be protected from scour by placing riprap (or other erosion-resistant material) around the member, or by diverting flow around the foundation member with grading modification or construction of an erosion protection measure. For situations in which the anticipated scour depth is minimal, the designer should use engineering judgment to determine the required protective measures. Whenever the designer is unsure of the appropriate action, a qualified geotechnical engineer should be consulted.

3.7.3. FROST PROTECTION CONSIDERATIONS

Because certain soils under specific conditions expand upon freezing, the retrofitting designer must consider the frost heave impact in the design of shallow foundations. When frost-susceptible soils are in contact with moisture and subjected to freezing temperatures, they can absorb water and undergo large expansions (both horizontally and vertically). In colder regions of Alaska, the upper Midwest, and the Northeast United States, such heave or expansion exerts forces strong enough to move and/or crack adjacent structures (foundations, footings, etc.). The thawing of frozen soil usually proceeds from the top downward. The melted water cannot drain into the frozen subsoil and thus becomes trapped, possibly weakening the soil. Normally, footing movements caused by frost action can be avoided by placing part of a foundation below the zone of maximum frost penetration.



Cross Reference

Local building codes generally specify the depth of the zone of maximum frost penetration. Frost penetration depths typically range between 0 and 8 feet within the United States, with the largest depths occurring in Alaska, the upper Midwest, and the Northeast. In the absence of guidance in the local building code, refer to the National Weather Service or the U.S. Department of Agriculture's Natural Resources Conservation Service Soil Survey.

3.7.4. PERMEABILITY

A principal concern for the construction of retrofitting measures, such as floodwalls and flood berms, is the properties of the proposed fill material and/or underlying soils. These properties will have an impact on stability and will determine the need for seepage and other drainage control measures.

Permeability is a measure of how easily water can flow through soil. Where soil is highly permeable (i.e., sandy soils), significant seepage through an embankment and under a floodwall foundation can occur. Various soil types and their permeabilities are provided in Table 3-8.

Table 3-8. Typical Values of Coefficient of Permeability *K* for Soils

Soil Type and Description	Symbol	Typical Coefficient of Permeability (ft/day)
Well-graded clean gravels, gravel-sand mixtures	GW	75
Poorly graded clean gravels, gravel-sand-silt	GP	180
Silty gravels, poorly graded gravel-sand-silt	GM	1.5×10^{-3}
Clayey gravels, poorly graded gravel-sand-clay	GC	1.5×10^{-4}
Well-graded clean sands, gravelly sands	SW	4.0
Poorly graded clean sands, sand-gravel mix	SP	4.0
Silty sands, poorly graded sand-silt mix	SM	2.0×10^{-2}
Sand-silt clay mix with slightly plastic fines	SM-SC	3.0×10^{-3}
Clayey sands, poorly graded sand-clay mix	SC	7.5×10^{-4}
Inorganic silts and clayey silts	ML	1.5×10^{-3}
Mixture of inorganic silt and clay	ML-CL	3.0×10^{-4}
Inorganic clays of low to medium plasticity	CL	1.5×10^{-4}
Organic silt and silt-clays, low plasticity	OL	Quite Variable
Inorganic clayey silts, elastic silts	MH	1.5×10^{-4}
Inorganic clays of high plasticity	CH	1.5×10^{-2}
Organic clays and silty clays	OH	Quite Variable

1 cm/sec = 24,680 ft/day = 2 ft/min 1 ft/year = 1×10^{-6} cm/sec

The coefficient of permeability provides an estimate of the ability of a specific soil to transmit seepage. Equation 3-20 uses this coefficient to make a rough approximation of the volume of seepage. Equation 3-20 may be used in lieu of Equation 3-14 for large flood berm/floodwall applications when the coefficient of permeability for the specific site soil is known.

Since most retrofitting projects are constructed using locally available materials, it is possible that homogenous and impermeable materials will not be available to construct embankments and/or backfill floodwalls and foundations. Therefore, it is essential that the designer determine the physical properties of the underlying and borrowed soils.

Note

While impervious cutoffs such as compacted impervious core, sheet pile metal curtains, or cementitious grout curtains can be designed to reduce or eliminate seepage, their costs are beyond the financial capabilities of most homeowners. However, several lower cost measures to control seepage include pervious trenches, pressure relief wells, drainage blankets, and drainage toes.

EQUATION 3-20: VOLUME OF SEEPAGE

$$Q = k i_{hg} A$$

Where:

Q = the discharge by unit of time (ft^3/unit of time)

k coefficient of permeability for the soil foundation (ft/unit of time)

i_{hg} = hydraulic gradient ($\frac{h}{L}$) which is the difference in head between two points divided by the length of path between two points

A = gross area of the foundation through which flow takes place (ft^2)

Warning

It is important that the designer keep the units in this equation consistent. The results of Equation 3-20 depend on the homogeneity of the foundation and the accuracy of the coefficient of permeability. The results should be considered as an indication only of the order of magnitude of seepage through a foundation.

3.7.5. SHRINK-SWELL POTENTIAL

As mentioned earlier in this chapter, due to the continual shrink and swell of expansive soil backfills and the variation of their water content, the stability and elevation of these soils and overlaying soil layers may vary considerably. Some geographic areas are more prone to shrink and swell than others. These characteristics make the use of these soils in engineering/ construction applications imprudent. The Natural Resources Conservation Service Soil Survey for a specific area offers

guidance on the shrink/swell potential of each soil group in the area, as well as guidance on the suitability of their use in a variety of applications, including engineering, construction, and water retention activities. If the designer is unsure of the type or nature of soil at the specific site, a qualified geotechnical engineer should be contacted for assistance.

The physical soil parameters at the retrofitting and potential borrow sites are an important design consideration. Homeowners and designers should clearly understand that the advice of a professional geotechnical engineer is vital when planning retrofitting measures that are not ideal for the physical soil parameters at a given site.

Note

Soils that exhibit severe shrinking-swell characteristics include clays and clay mixtures such as Soil Types CH, CL, ML-CL, SC, and MH.

Chapter 4 provides guidance on how to apply the anticipated loads and calculate load combinations developed in this chapter to the existing site/structure.

3.7.6. CASE STUDY EXERCISE 4: ANALYSIS OF GEOTECHNICAL CONSIDERATIONS

Use the Geotechnical Considerations Matrix (Figures 3-17 and 3-18) to assess potential flood retrofit measures based on site soil properties.

Case Study A – Exercise 4

Case Study A – Exercise 4: Residential Retrofit in Riverine Floodplain Using Relocation or Elevation

Geotechnical Considerations

Mr. and Mrs. Doe's house should be evaluated for geotechnical considerations such as bearing capacity, shrinkage or swell issues from the soils, and potential scour of the foundations. The Doe's house is located in an area with suitable soil that provides a bearing capacity of 2,000 psf. Generally, soils with clay or clay mixture characteristics are susceptible to shrink and swell issues. Mr. and Mrs. Doe's property has a mixture of silty sand (Soil Type SM), which is suitable for foundations and does not require special attention. Additionally, the top of the foundations will be 3 feet below grade to account for proper frost depth in accordance with the local building code to alleviate shrink/swell concerns during the cold months. Since the flood velocity is expected to be 2.0 feet/second under base flood conditions - which is less than 5.0 feet/second - there is limited risk of scour. Soil permeability is typically not a major concern for the foundations of a house that is relocated or elevated; it is more relevant to dry floodproofing, floodwalls, and berms. Overall, the geotechnical considerations demonstrate appropriate suitability for relocation and elevation as shown in Figure CSA-15.

Geotechnical Considerations Decision Matrix											
Owner Name:	John and Jane Doe							Preparer		JJS-MH	
Address:	55 Cedar River Road							Date:		7/6/2026	
Soil Description (USDA Soil Type):	SM										
	Retrofitting Measures										
	Structural Elevation			Elevation Alternatives			Relocation	Floodproofing		Flood Barriers	
Geotechnical Consideration	Stem Wall (Fill)	Perimeter Wall/ Piers	Piles	Basement Infill	Abandon/ Repurpose Lowest Floor	Elevate Lowest Interior Floor		Dry	Wet	Floodwall	Berm
Pre-Screening from Preliminary Homeowner Preference Matrix											
Measure Not Feasible (NF)				NF	NF	NF					
Allowable Bearing Capacity, Q_{BC} (see Table 3-8)											
~~High (Q_{BC} > 2,500 psf)~~											
Moderate (Q_{BC} = 1,000 to 2,500 psf)	S	S	S				S	S	S	S	S
~~Low (Q_{BC} < 1,000 psf)~~	~~NS~~	~~NS~~								~~NS~~	~~NS~~
Potential for Scour											
~~High (Soil Types GW, GP, SW, SP and V > 5 ft/sec)~~	~~NS~~	~~NS~~		~~NS~~		~~NS~~				~~NS~~	~~NS~~
Moderate to Low (All Other Soil Types or V ≤ 5 ft/sec)	S	S	S				S	S	S	S	S
Shrink/Swell Potential											
~~Severe (Soil Types CH, CL, ML-CL, MH, SC)~~	~~NS~~										~~NS~~
Moderate to Low (All Other Soil Types)	S	S	S				S	S	S	S	S
Permeability, *K* (see Table 3-10)											
~~High (K > 1 ft/day)~~								~~NS~~		~~NS~~	~~NS~~
Moderate (K = 0.0015 to 1 ft/day)	S	S	S				S	NS	S	NS	NS
~~Low (K < 0.0015 ft/day)~~											
Scoring											
Subtotal S's	4	4	4	0	0	0	4	3	4	3	3
Subtotal NS's	0	0	0	0	0	0	0	1	0	1	1
Suitability Determination (Yes if NS's = 0, No if NS's ≥ 1)	Yes	Yes	Yes	NF	NF	NF	Yes	No	Yes	No	No

Purpose: The purpose of the Geotechnical Considerations Decision Matrix is to help the designer identify situations where soil conditions are unsuitable when applied to certain retrofitting measures, therefore eliminating infeasible measures. It is not intended to select the most suitable alternative. See next page for Matrix Notes, Instructions, and Evaluation of Results.

Matrix Notes:

NF Not Feasible: indicates the retrofit measure was pre-screened to be not allowed or not feasible based on the configuration of the existing structure and/or property. Refer to the Preliminary Homeowner Preference Matrix for details.

NS Not Suitable: indicates the retrofit measure is not suitable for this soil property.

Lateral Soil Pressure and Frost Action were not considered in this matrix since both can be generally addressed using a properly reinforced foundation design placed at the appropriate frost depth.

Refer to FEMA P-259 Table 3-2 for Soil Types and descriptions based on the USDA Unified Soil Classification System.

Page 1 of 2. See next page for Instructions and Evaluation of Results.

Figure CSA-15. Geotechnical Considerations Decision Matrix for the Doe house

Case Study B – Exercise 4

Case Study B – Exercise 4: Residential Retrofit Outside of the Floodplain Using Floodwalls or Dry Floodproofing

Geotechnical Considerations

The soil associated with The Valley Apartments should be suitable for dry floodproofing or a floodwall. There is adequate bearing capacity. The site has a low potential for scour since the velocity is 2 feet per second. The silty clay soil has moderate to low shrink/swell issues and low permeability for the Soil Type SM-SP, as shown in Figure CSB-13. Mr. Smith's engineer has advised that additional geotechnical details should be ascertained through a geotechnical study.

A critical component of properly dry floodproofing the building will include an evaluation of the buoyancy forces as they are applied to the building. A geotechnical study can help to understand the groundwater table under surface water flood conditions. The engineer has mentioned the option of developing a flow model of groundwater conditions as part of the report. He has concerns that floodwater of a longer duration than recent flooding could result in an elevated water table that could exert uplift (buoyancy) forces on the building slab-on-grade. This could cause the slab to heave or crack and thereby allow water to enter the building. Mitigating buoyancy may require reinforcement of the slab-on-grade, the construction of soil anchors for the slab, additional concrete thickness at the slab, or construction of a cutoff wall to extend the depth of the perimeter footings.

The geotechnical study will include the anticipated seepage under the floodwall. Mr. Smith's engineer will use this information, along with precipitation runoff inside the protected area, to estimate the minimum discharge size for pumping floodwater over the floodwall.

Geotechnical Considerations Decision Matrix											
Owner Name:	John Smith							Preparer		JJS-MH	
Address:	2908 Valley Drive							Date:		7/6/2026	
Soil Description (USDA Soil Type):	SM										
	Retrofitting Measures										
	Structural Elevation			Elevation Alternatives			Relocation	Floodproofing		Flood Barriers	
Geotechnical Consideration	Stem Wall (Fill)	Perimeter Wall/ Piers	Piles	Basement Infill	Abandon/ Repurpose Lowest Floor	Elevate Lowest Interior Floor		Dry	Wet	Floodwall	Berm
Pre-Screening from Preliminary Homeowner Preference Matrix											
Measure Not Feasible (NF)	NF	NF	NF	NF	NF	NF	NF				
Allowable Bearing Capacity, Q_{BC} (see Table 3-8)											
~~High (Q_{BC} > 2,500 psf)~~											
Moderate (Q_{BC} = 1,000 to 2,500 psf)								S	S	S	S
~~Low (Q_{BC} < 1,000 psf)~~	~~NS~~	~~NS~~								~~NS~~	~~NS~~
Potential for Scour											
~~High (Soil Types GW, GP, SW, SP and V > 5 ft/sec)~~	~~NS~~	~~NS~~		~~NS~~		~~NS~~				~~NS~~	~~NS~~
Moderate to Low (All Other Soil Types or V ≤ 5 ft/sec)								S	S	S	S
Shrink/Swell Potential											
~~Severe (Soil Types CH, CL, ML-CL, MH, SC)~~	~~NS~~										~~NS~~
Moderate to Low (All Other Soil Types)								S	S	S	S
Permeability, *K* (see Table 3-10)											
~~High (K > 1 ft/day)~~								~~NS~~		~~NS~~	~~NS~~
~~Moderate (K = 0.0015 to 1 ft/day)~~								~~NS~~		~~NS~~	~~NS~~
Low (K < 0.0015 ft/day)								S	S	S	S
Scoring											
Subtotal S's	0	0	0	0	0	0	0	4	4	4	4
Subtotal NS's	0	0	0	0	0	0	0	0	0	0	0
Suitability Determination (Yes if NS's = 0, No if NS's ≥ 1)	NF	NF	NF	NF	NF	NF	NF	Yes	Yes	Yes	Yes

Purpose: The purpose of the Geotechnical Considerations Decision Matrix is to help the designer identify situations where soil conditions are unsuitable when applied to certain retrofitting measures, therefore eliminating infeasible measures. It is not intended to select the most suitable alternative. See next page for Matrix Notes, Instructions, and Evaluation of Results.

Matrix Notes:

NF Not Feasible: indicates the retrofit measure was pre-screened to be not allowed or not feasible based on the configuration of the existing structure and/or property. Refer to the Preliminary Homeowner Preference Matrix for details.

NS Not Suitable: indicates the retrofit measure is not suitable for this soil property.

Lateral Soil Pressure and Frost Action were not considered in this matrix since both can be generally addressed using a properly reinforced foundation design placed at the appropriate frost depth.

Refer to FEMA P-259 Table 3-2 for Soil Types and descriptions based on the USDA Unified Soil Classification System.

Page 1 of 2. See next page for Instructions and Evaluation of Results.

Figure CSB-13. Geotechnical Considerations Decision Matrix for The Valley Apartments

Chapter 4. General Design Practices

Chapter 3 introduced the analyses necessary to quantify the flood- and non-flood-related hazards that control the design of a specific retrofitting measure. The objective of this chapter is to apply the anticipated loads to the existing site/structure and design an appropriate retrofitting measure.

4.1. Introduction: General Design Process Flow Chart

The design process begins with general design practices that apply to the various retrofitting projects—site visit and analysis of the existing structure—and then presents separate sections for each retrofit measure. These sections guide the designer through the process of developing construction details and specifications and provide tools to customize retrofitting measures to local requirements and homeowner preferences. Many homeowners decide to go above and beyond minimum requirements, strengthening their homes to resist natural hazard damage (see Figure 4-1).



Figure 4-1. Homes that are elevated perform better during flood events.

The design of these retrofitting measures is a straightforward but technically intensive approach that will yield construction plans that may receive building permits and mitigate potential flooding and other natural hazards. This general design process is illustrated in Figure 4-2.

As previously noted, the following section describes elements of the design process that are common to many retrofitting measures. The two main common design elements are site visit (which includes surveys, documentation, and homeowner coordination) and the analysis of the existing structure.

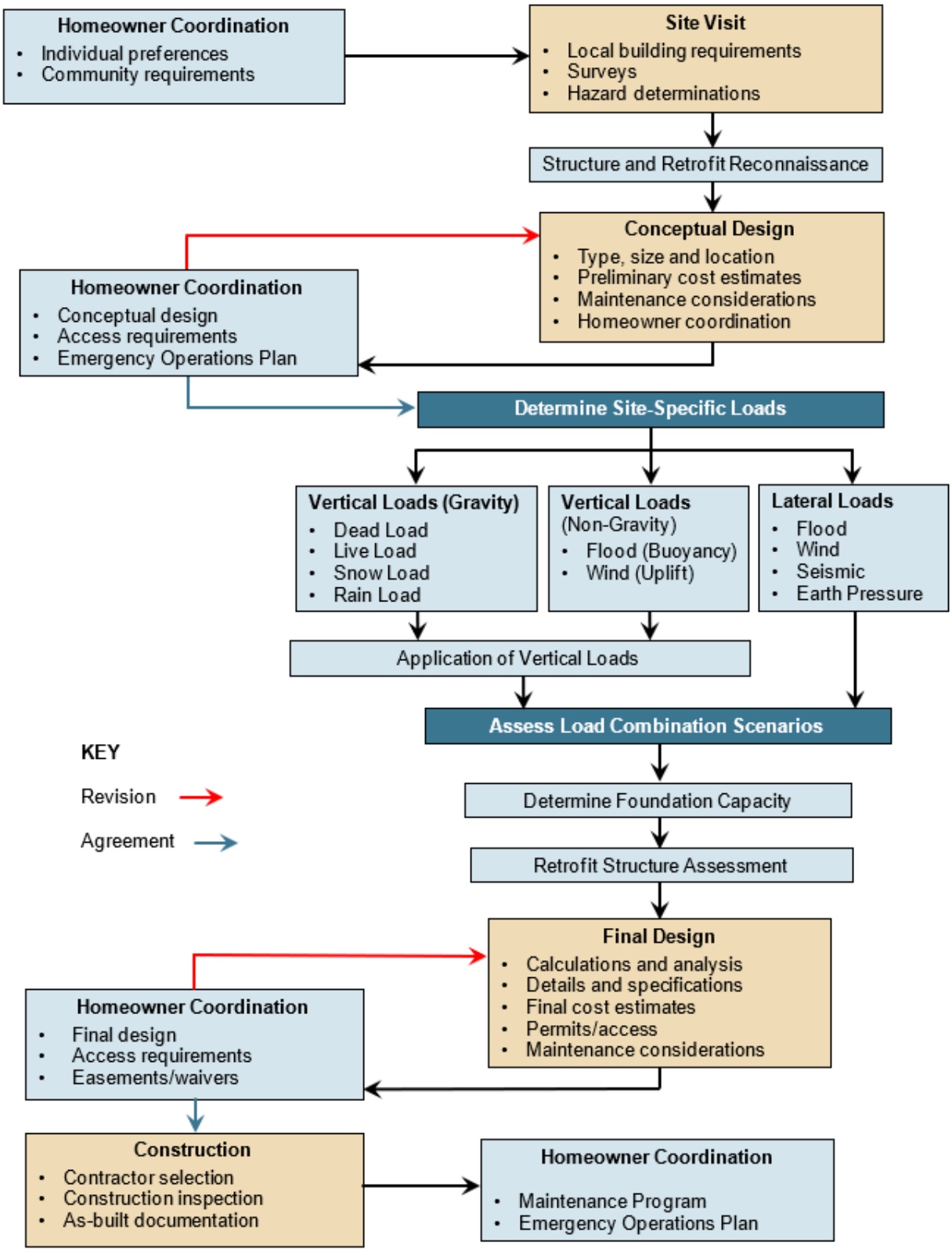


Figure 4-2. General design process flow chart

4.2. Site Visit

Detailed information must be obtained about the site and existing structure to make decisions and calculations concerning the design of a retrofitting measure. The designer should obtain the following information prior to developing retrofitting measure concepts for the owner's consideration:

- Local requirements
- Site and building surveys (elevation, topographic, site utilities)
- Hazard determinations and performance goals
- Documentation of existing mechanical, electrical, and plumbing systems
- Structural assessment
- Homeowner preferences and coordination
- Maintenance programs and emergency action plans

4.2.1. LOCAL BUILDING REQUIREMENTS

Close coordination with the local building code official is critical to obtaining approval of a retrofitting measure design. The designer should review the selected retrofitting measure concept with the local building official to identify local design standards or practices that must be integrated into the design. This discussion may also identify and provide an opportunity to resolve issues where the construction of the retrofitting measure may conflict with local building regulations.

4.2.2. SURVEYS (LOW POINT OF ENTRY, TOPOGRAPHIC, SITE UTILITIES)

A detailed survey of the site should be completed to supplement the information gathered during the low point of entry determination (discussed in Chapter 3) and to identify and locate structure, site, and utility features that will be needed for the design of the retrofitting measure.

Low Point of Entry Survey

The low point of entry survey is a vertical elevation assessment at potential openings throughout the structure, whereby floodwater may enter the residence. It may include:

- Basement slab elevation
- Windows, doors, and vents below the Design Flood Elevation
- Mechanical/electrical equipment and meters
- Finished floor elevation
- Drains and other floor penetrations
- Water spigots, sump pump discharges, and other wall penetrations
- Other site provisions that potentially may require flood protection, such as storage tanks and outbuildings
- Establishment of a stable vertical datum or elevation benchmark near the house

Topographic Survey

A detailed retrofitting design should not be developed without a site plan or map of the area. A Registered Professional Land Surveyor can prepare a site plan of the area to document the general topographic and physical features of the site. The entire site and/or building lot should be mapped for design purposes. For flood mitigation, the survey should also identify and determine the locations in the building where floodwater can enter. Elevations for points of entry should be determined, and the lowest point of floodwater entry should be considered in the development and design of the mitigation. General surveying practices should be observed, but as a minimum, the site plan should include:

- Spot elevations within potential work areas
- 1-foot or 2-foot contours, depending on degree of topographic relief
- Boundary markers, property lines, setbacks, easements, and/or lines of division
- Perimeter of house
- Driveways, sidewalks, patios, mailbox, fences, light poles, etc.
- Exposed utility service (meters, valves, manholes, service boxes, hydrants, etc.)
- Exposed storm drain features (yard inlets, junction boxes, curb inlets)
- Ditches and culverts
- Road or streets (centerline, edge or curb and gutter, curb inlets)
- Trees of significant diameter (size varies per community
- Large shrubs and other site landscaping features
- Mechanical units such as A/C and heat pumps
- Other appropriate data that could identify flood risks and influence the flood mitigation



Note

Field surveys for design purposes should be performed by a Registered Professional Land Surveyor. In addition to the main structure, survey site plans may include ancillary structures such as pools, sheds, and/or storage tanks.



Warning

The location and elevation of all drainage features are critical for flood protection.

Additionally, the site plan should extend at least 50 to 100 feet beyond the estimated construction work area. The purpose of extending the site map beyond the estimated work limits is to ensure that potential drainage and/or grading problems can be resolved. Construction site material and equipment access, as well as sediment and erosion control measures, can impact work areas. Local building code mapping issues should also be addressed.

Site Utilities Survey

As part of the site visit, above, at grade, and below ground site utilities should be identified. Above ground and at grade utilities, such as electrical utility lines, information technology and communication lines, manhole covers, wells, electric and gas meters, etc., can be located on the topographic map. Their elevations may also need to be measured and documented. Underground utilities, such as sanitary and storm drain lines, septic tanks, and electric or gas lines, may require an investigation through the appropriate utility agency, particularly when flood mitigation will involve ground disturbance that can damage or disrupt utilities. Local utility companies, county, and municipal officials may be able to assist in identifying underground utilities. In many cases, field personnel will be dispatched to mark the ground surface above buried utilities. Sometimes, a copy of the topographic map and area can be submitted to the utility agency, which will prepare a sketch of its underground service. Underground services may include:

- Electric service
- Gas lines
- Water main and sanitary sewer pipes
- Cable television, telephone cables, and fiber optics
- Storm drain fixtures, pipes, and water wells
- Septic tanks and septic drain fields
- Local property drainage systems, pipes.

In some instances, exact horizontal and vertical locations of the utility services may be required. A small hole, more commonly referred to as a test pit, can be dug to unearth the utility service in question. Typically, this service is performed by a licensed contractor or the utility provider.

Identification of utility services and units will inform methods to protect utilities and keep them operational during flooding. Design provisions for utility relocation, encasement, elevation, anchoring, and, in some instances, new services can be prepared.

4.2.3. HAZARD DETERMINATIONS

The designer (with the homeowners) should review the risk determinations previously conducted in Chapter 3 and confirm the flood protection design level of the retrofitting measures selected. This analysis should consider the protection of all components below the design elevation (i.e., below grade basement walls and associated appurtenances).

Note

Chapter 3 of ASCE 24 addresses high risk flood hazard areas, including alluvial fans, flash flood, erosion-prone, high velocity flow and ice jam, and debris areas. These high risk flood hazard areas are not typically delineated on Flood Insurance Rate Maps or Flood Insurance Studies; so designers may need to collect additional data to document the existence of such conditions and their expected impacts. Additional retrofit measures may be required to address high risk flood hazard areas that exceed the floodplain management requirements of the National Flood Insurance Program. Refer to ASCE 24 Chapter 3 and Appendix E of this publication for additional details regarding these high risk flood hazard areas.

The analysis of flood- and non-flood-related hazards was presented in Chapter 3. The designer should utilize the calculation templates presented there to finalize expected design forces.

4.2.4. DOCUMENTATION OF EXISTING BUILDING SYSTEMS

While documenting the building's elevation and structural condition is an important part of successful flood mitigation, documenting the style, condition, and elevation of the mechanical, electrical, and plumbing systems within the building is also critical. FEMA P-348, *Protecting Building Utility Systems from Flood Damage,* contains guidance on how to mitigate the flood risk of mechanical, electrical and plumbing systems, and utilities. FEMA P-348 provides guidance for both residential and non-residential buildings. Much of the guidance provided for non-residential buildings is appropriate for multi-unit residential buildings.

The enclosed Mechanical, Electrical, Plumbing, and Related Building Systems Data Sheet (Figure 4-3) can be used to document the results of this examination. When completing this data sheet, the elevation of key mechanical, electrical and plumbing system components should be determined and documented. Additionally, any component located below the lowest point of entry should be identified since floodwater reaching the lowest point of entry will rapidly inundate and most likely destroy the component.

Note

The data checklists provided in this publication are generalized for residential housing applications and request information that may not be applicable to a specific retrofitting measure. Therefore, the designer should exercise judgment in collecting information cited on the checklists.

4.3. Homeowner Preferences and Coordination

A discussion of homeowner preferences was presented in Chapter 2. The designer should confirm the homeowner's preferences regarding:

- Retrofitting measure type, size, and location(s)
- Project design desires/preferences
- Limitations on construction area
- Required household access or other accommodations
- Estimated construction budget
- Potential future site improvements

Once the designer has collected the above-mentioned information, a conceptual design of the proposed retrofitting measure can be discussed with the homeowner. At this time, the designer should also review and confirm coordination and future maintenance requirements with the homeowner to ensure that the selected retrofitting measure is indeed suitable.

Homeowner coordination involves reviewing design options, costs, specific local requirements, access and easement requirements, maintenance requirements, construction documents, and other information with the homeowner and regulatory officials to present the alternatives, resolve critical issues, and obtain necessary approvals.

Mechanical, Electrical, Plumbing, and Related Building Systems Data Sheet

(Note: Collect only the data necessary for your project)

Owner Name:_____ Prepared By:_____

Address: _____ Date: _____

Property Location: _____

A. Exterior Utilities and Appurtenances

Water

☐ On-site well or spring ☐ Public water system

Water purveyor's name: _____

Sanitary

☐ On-site septic and drain field ☐ Public sewerage

Storm

☐ On-site ☐ Public sewerage

Incoming Electrical Service

☐ Overhead ☐ Underground ☐ Voltage ☐ 120/240 volt 10 ☐ 120/208 volt 10

☐ Direct burial size: _____

☐ Service entrance cable amps: _____

☐ PVC (Polyvinylchloride) conduit ☐ RGS (Rigid Galvanized Steel) conduit

Transformer #:

☐ Power company:

Power meter #:

Contact: _____

Estimated transformer rating: _____

Fault current rating: _____

Telephone service: _____

☐ Company: ☐ Overhead ☐ Underground ☐ Cable pair ☐ Pedestal ☐ Grounded ☐ Direct burial

CATV

☐ Company: _____

☐ Overhead ☐ Underground # of channels: _____ ☐ PVC CATV #:

☐ Direct Burial ☐ RGS

Contact: _____

Page 1 of 3

Figure 4-3. Mechanical, Electrical, Plumbing, and Related Building Systems Data Sheet

Other Utilities

☐ Natural gas

Utility company name: _____

Location of service entrance: _____

Meter location: _____

☐ LPG (Liquefied Petroleum Gas)

Utility company name: _____

Location of gas bottle: _____

How is tank secured? ☐ Oil

Oil Supplier: _____

☐ Aboveground tank ☐ Underground tank

Size (in gallons [GAL]): _____ Location: _____

Vent terminal: _____

Elevation: feet or elevation above grade? _____ feet Fill cap type: _____

B. Domestic Plumbing

Water

☐ Location of service entrance

Main service valve? ☐ Yes ☐ No

Backflow preventer? ☐ Yes ☐ No

Type of water pipe ☐ Copper ☐ Iron ☐ Plastic

☐ Domestic water heater ☐ Gas BTU/HR ☐ Oil GAL/HR ☐ Other Specify units

Size (GAL): _____ Location: _____

☐ **Sanitary Drainage**

Floor served? _____

Fixtures below base flood elevation(BFE) ☐ Yes ☐ No

Backwater valve installed in fixtures below BFE? ☐ Yes ☐ No

Backwater valves needed (if none exist) ☐ Yes ☐ No

☐ **Storm Drainage**

Basement floor drains connected? ☐ Yes ☐ No

Is storm combined w/sanitary? ☐ Yes ☐ No

C. Heating System

Type: ☐ Central System ☐ Space heaters

Central System

☐ Warm air ☐ Hot water ☐ Steam

Warm Air Furnace

Location: ☐ Basement ☐ 1st floor ☐ ___floor ☐ Attic

Page 2 of 3

Figure 4-3. Mechanical, Electrical, Plumbing, and Related Building Systems Data Sheet (continued)

Type: ☐ Upflow ☐ Downflow ☐ Horizontal ☐ Low Boy

Fuel: ☐ Natural Gas ☐ LPG ☐ Electric ☐ Coal ☐ Wood

Burner: ☐ Atmospheric ☐ Fan assisted

Condensing: ☐ Yes ☐ No

Venting: ☐ Natural draft ☐ Forced draft ☐ Direct vent

Air Distribution: ☐ Gravity ☐ Ducted

☐ Sheet metal ductwork ☐ Flexible, non-metallic runouts ☐ Fiberglass ductboard ☐ Location

Air Outlets: ☐ Floor ☐ Low sidewall ☐ High sidewall ☐ Ceiling ☐ 2nd floor

Hot Water/Steam:

Boiler: ☐ Hot Water ☐ Steam

Location: ☐ Basement ☐ 1st Floor ☐ ___floor ☐ Attic

Fuel: ☐ Natural Gas ☐ LPG ☐ Electric ☐ Coal ☐ Wood

Terminal Units: ☐ Baseboard ☐ Radiators ☐ Other

In-Space Heating Equipment

Gas: ☐ Room heater ☐ Vented ☐ Unvented

☐ Wall furnace ☐ Conventional ☐ Direct vent

☐ Floor furnace

Oil/Kerosene: ☐ Vaporizing oil pot heater ☐ Powered atomizing heater ☐ Portable kerosene heater

Electric Heaters: ☐ Wall ☐ Floor ☐ Toe space ☐ Baseboard

Radiant Heat: ☐ Panels ☐ Embedded fireplace ☐ Portable cord and plug

Stoves: ☐ Conventional ☐ Advanced design ☐ Fireplace insert ☐ Pellet stove

D. Cooling System

Type: ☐ Central ☐ In-space air conditioners (ACs)

Central Systems: ☐ Split system A/C ☐ Unitary A/C ☐ A-Coil add-on

☐ Split system heat pump

Split Systems:

Indoor unit location: ☐ Basement ☐ 1st Floor ☐ ___Floor ☐ Attic

Type: ☐ Upflow ☐ Downflow ☐ Horizontal

Air distribution: ☐ Sheet metal ductwork ☐ Fiberglass ductboard ☐ Flexible non-metallic runouts

Air outlets: ☐ Floor ☐ Low sidewall ☐ High sidewall ☐ Ceiling

Outdoor unit location:

In-space air conditioners: ☐ Window air conditioners ☐ Ductless split systems

Page 3 of 3

Figure 4-3. Mechanical, Electrical, Plumbing, and Related Building Systems Data Sheet (concluded)

4.4. Maintenance Programs and Emergency Action Plans

Development of appropriate maintenance programs for retrofitting measures is critical to the continued success of retrofitting efforts. Refer to FEMA's National Flood Insurance Program Technical Bulletin 3 *Non-Residential Floodproofing – Requirements for the Design and Certification for Dry Floodproofed Non-Residential and Mixed-use Buildings* (January 2021) for additional guidance concerning minimum recommendations for Emergency Operations Plans and Inspection and Maintenance Plans. While this bulletin was prepared for non-residential structures, it contains sound advice for the development of emergency operations, inspection, and maintenance plans.

Design information presented in this chapter relates to site visit, design calculations, construction details, and construction issues. Only those issues that are critical to the design and successful construction of the retrofitting measures are included in the next sections.

4.5. Analysis of Existing Structure and Retrofitting

The ability of an existing structure to withstand additional loads created by retrofitting is an important design consideration. Accurate estimates of the capacity of the foundation and other structural systems are the first steps in the design of retrofitting measures. The objective of this analysis is to identify the extent to which structural systems must be modified or redesigned to accommodate retrofitting measures such as elevation, relocation, and dry and wet floodproofing. The basic steps involved in this analysis are listed below and follow the basic process listed in Figure 4-4:

- Structural and retrofitting reconnaissance (Section 4.5.1)
- Determining the vertical loads imposed by gravity and the retrofitting measure (Section 4.5.2), as well as non-gravity loads from flood and wind (Section 4.5.3)
- Application of vertical loads to be carried by walls, girders, and columns to the foundation (Section 4.5.4)
- Analysis and application of the additional lateral loads imposed by flood, wind, and earthquake forces (Section 4.5.5)
- Assessment of load combination scenarios (Section 4.5.6)
- Determination of foundation capacity (Section 4.5.7)
- Comparison of the capacity of the existing structure to resist the vertical and lateral loads imposed by the proposed retrofit (Section 4.5.8)

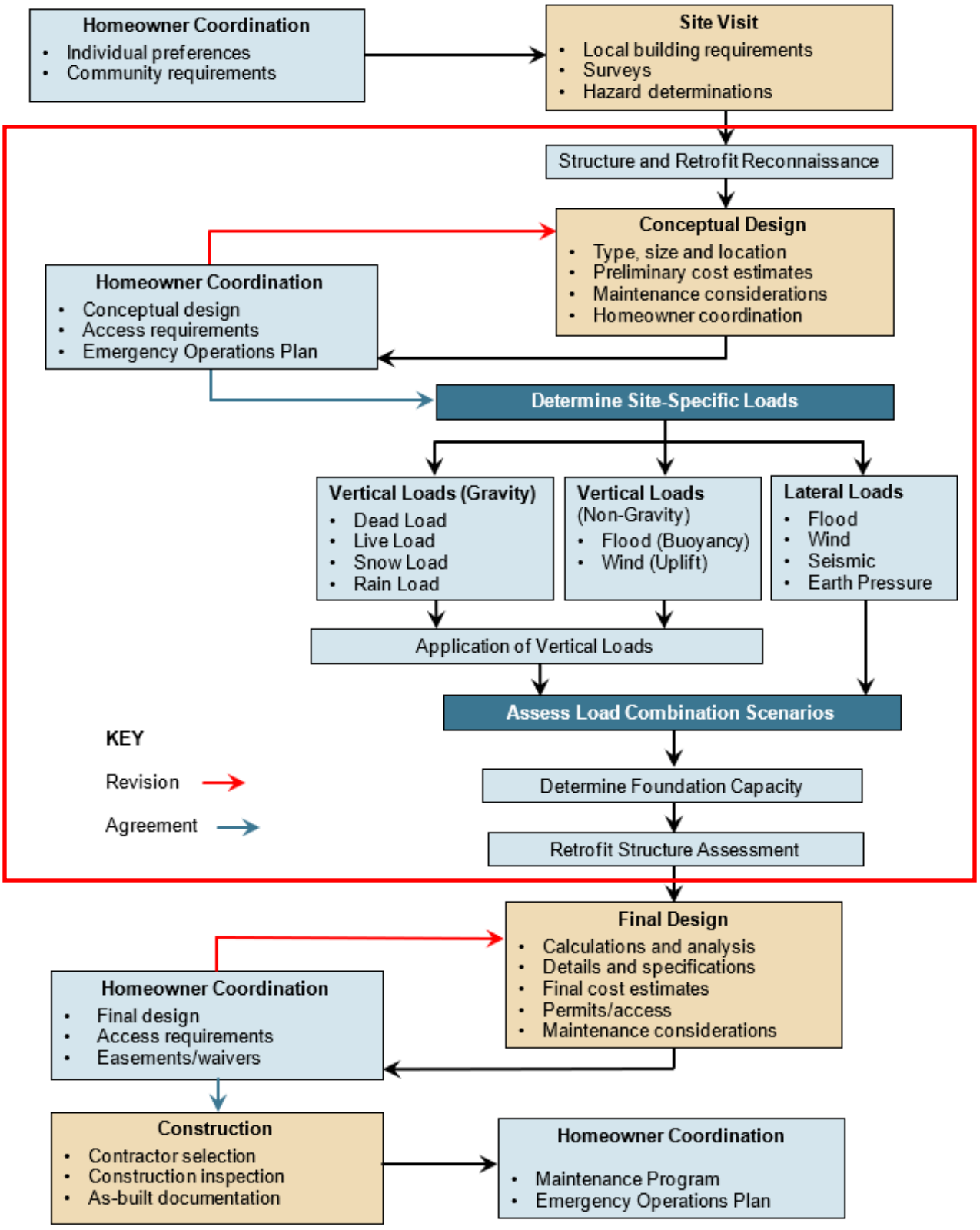


Figure 4-4. Basic Analysis Process in red box as part of General Design Process (Figure 4-2)

4.5.1. STRUCTURAL AND RETROFITTING RECONNAISSANCE

To determine whether a structure is suited to the various retrofitting measures being considered, the type and condition of the existing structure must be assessed. The assessment will determine the ability of the structure to resist the applied loads as well as the feasibility of the proposed mitigation. Some structural systems are more adaptable to modifications than others. For example, buildings constructed over basements and crawl spaces are inherently easier to elevate than buildings constructed with slabs on grade. Some retrofitting methods are more suited for, or specifically designed for, various construction types. Of the retrofitting methods discussed, elevation, relocation, and dry floodproofing most directly affect a home's structure and the loads imposed on it as described below.

- Elevation of the existing structure on an extended foundation system significantly increases the dead load imposed on the foundation and may impact wind and seismic forces imposed on the structure.

- Relocation exposes the structure to temporary but significant forces imposed by removing the structure from its existing foundation, transporting the structure, and placing it on a new foundation.

- Dry floodproofing has minimal impact on the dead load or exposure to wind and seismic forces but significantly increases the magnitude of flood forces on the structure including uplift from buoyancy and lateral hydrostatic forces.

Wet floodproofing and flood barriers (floodwalls and berms) have less impact on a home's structure and the loads imposed on it, as described below:

- Wet floodproofing the existing structure maintains the same elevation allows floodwaters to enter the structure while protecting key equipment and contents. Although this can expose parts of the structure to more significant post-flood clean up, wet floodproofing has minimal impact on dead loads and exposure to wind and seismic loads and can actually reduce hydrostatic flood forces imposed on the structure.

- Floodwalls and berms are designed to prevent water from reaching the home and thus have little impact on the structure being mitigated.

Several sources of information concerning the building's construction details include:

- Construction drawings, particularly as-built drawings, are usually the best and most reliable resource for assessing the structural systems, when available.

- Information available from the building permits office.

- Plans for any renovations or room additions, and a recent record of existing conditions.

- Home inspection reports if the home has been recently purchased. While these reports are not highly detailed, they can provide an overview of the existing condition of the home, the general system types that exist, age of structure, and other basic information for context, including major deficiencies for situational awareness and point out.

If this information is not available, the designer (with the permission of the owner) should determine the type and size of the critical structural elements. The Structural Reconnaissance Worksheet provided in Figure 4-5 can be used to document and assess this information.

Owner Name: _____

Address: _____

Property Location: _____

Prepared By: _____

Date: _____

Structural Reconnaissance Worksheet

Sketch and Description of Existing Structure

Item	Material	Size	Condition (Excellent, Good, Fair, Unacceptable)	Notes
Flooring	Concrete			
Foundation Wall	Concrete			
	Concrete Masonry			
	Brick Masonry			
Walls	Wood Frame			
	Masonry			
	Metal Frame			
Floor System	Wood Joist			
	Post and Beam			
	Wood Truss			
Roof System	Truss			
	Rafter			
Exterior Finishes	Wood Siding			
	Brick Veneer			
	Stucco			
Interior Finishes	Drywall			
	Plaster			
	Wood			

Figure 4-5. Structural Reconnaissance Assessment Worksheet

4.5.2. VERTICAL (GRAVITY) LOADS

Dead Load (D)

Dead loads are the weight of all permanent structural and nonstructural components of a building, such as walls, floors, roofs, ceilings, stairways, and fixed service equipment. The sum of the dead loads should equal the unoccupied weight of the building. The weight of a house can be determined by quantifying the wall and surface areas and multiplying by the weights of the materials or

assemblies. A list of the weights of home construction components and assemblies is provided in. In addition to the weight of the structure, any permanent service equipment located in the house must be added to the total. The worksheet provided in Figure 4-6 can be used to make a preliminary estimate of the weight of a structure. To use Figure 4-6, the designer should:

Step 1: Determine the construction of the various components of the building, quantify them, and enter this information in the second column.

Step 2: Look up the weight of these assemblies and enter that figure into the third column.

Step 3: Multiply the quantities by the unit weights to obtain the construction component weights and enter the result in the fourth column.

Step 4: Add these component weights in column four to obtain an estimate of the total weight of the structure. Enter the result in the box at the bottom of column four.

Note

The total dead load should reflect the weight of the existing structure and the weight of the proposed retrofit. This additional retrofit weight for measures such as elevation on an extended foundation may significantly impact the total dead load and the bearing capacity requirements.

Live Loads (L, L_r)

Live loads are produced by the occupancy of the building, not including environmental loads such as wind loads, flood loads, snow loads, earthquake loads, or dead loads. For residential one- and two-family dwellings, a typical floor live load (L) is a uniformly distributed load, L_o, of 40 pounds per square foot. Live loads are calculated using Equation 4-1. Additionally, a roof live load (L_r), calculated with the same equation, is used to account for the weight of people and equipment on the building's roof during construction and maintenance. Residential buildings typically specify a minimum uniform roof live load, L_r, of 20 pounds per square foot, but some communities may specify different loads for steeper roof slopes (4:12 or greater).

EQUATION 4-1: CALCULATION OF LIVE LOAD

$$L = AL_o$$

Where:

L = live load (lb)

A = area of each floor of the residence (ft^2)

L_o = minimum uniformly distributed live load (lb/ft^2)

Table 4-1. Weights of Construction Types

Construction	Weight, lb/ft² surface area
Interior, wood or metal stud wall, 2x4, interior, 1/2-in. drywall 2S	8
Interior, wood or metal stud wall, 2x4, plaster 2S	20
Exterior, drywall; 4-in. batt insulation; wood siding	11
Exterior, drywall; 4-in. batt insulation; 4-in. brick (MW)	48
Exterior, drywall; 4-in. batt insulation; 8-in. concrete block	60-65
Exterior, drywall; 4-in. batt insulation; 1-in. stucco	23
Exterior, metal stud wall, drywall; 4-in. batt insulation; 1/2-in. drywall	18
Exterior, drywall; 4-in. batt insulation; 3-in. granite or 4-in. brick	55
Plaster, per face, wall, or ceiling, on masonry or framing	8
Ceramic tile veneer, per face	10
MW, 4-in. brick, MW, per wythe (continuous vertical section of masonry, one unit in thickness)	39
4-in. hollow concrete block, heavy aggregate, per wythe	29
8-in. hollow concrete block, heavy aggregate, per wythe	39-61
Glass block wall, 4-in. thick	18
Windows, glass, frame, and sash	8
Floor or ceiling, 2x10 wood joist, 16 in. o.c.	6
Concrete flat slab, unfinished floor; suspended ceiling	80-90
Concrete pan joist (25 in. o.c., 12-in. pan depth, 3-in. slab), unfinished floor; suspended ceiling	90-100
Concrete on metal deck on steel frame, unfinished floor; suspended ceiling	65-70
Finished floors, add to above:	
Hardwood flooring, 7/8 in.	4

Construction	Weight, lb/ft² surface area
Terrazzo (1-1/2 in.) directly on slab	19
Wall-to-wall carpet	2.5
Roofing, add to above:	
Roof, sloping rafters or timbers, sheathing; 10-in. batt insulation; ½-in. drywall	12-15
Five-ply felt and gravel, add to roof	6
Deck, metal, 18 gauge, add to roof	3
Asphalt shingles, add to roof	2
Slate ¼ in. thick, add to roof	10
Wood shakes and shingles, add to roof	3
Insulation, add to above:	
Insulation, batt, per 4-in. thickness	1
Insulation, rigid (per 1/8-in. thickness)	0.1875
Stairways:	
Concrete	80-95
Steel	40-50
Wood	15-25

2S = 2 sides
MW = Masonry walls
o.c. = on centers

Building Weight Estimating Worksheet	
Owner Name:	**Preparer:**
Address:	**Date:**
Current Location Flood Risk:	

Element	Area (ft^2)	Unit Weight (lb/ft^2)	Total Weight (lbs)
Exterior Walls: (type of construction)			
Interior walls: (type of construction)			
1st Floor: (type of construction)			
1st Floor Cover: (type of cover)			
2nd Floor: (type of construction)			
2nd Floor Cover: (type of cover)			
Roof Structure: (type of construction)			
Roof Cover: (type of cover)			
Roof, Special Items: (describe)			
Fireplace and Chimney: (If it does not have its own foundation)			
Plan Area of House (ft^2)			
Total Weight of House Excluding Foundation (lbs)		*	

* Unit weight is total weight divided by plan area of house.

Figure 4-6. Building Weight Estimating Worksheet



Cross Reference

Check local codes for guidance on acceptable live loads and roof live loads. In the absence of code information, use ASCE 7.

Snow Load (S) and Rain Load (R)

In addition to dead and live loads, buildings must account for additional roof loads imposed by snow and rain. Residential roof snow loads typically vary from 10 to 70 pounds per square foot, depending on geography, roof slope, and other exposure factors. Local building codes should be consulted to find the snow load and how to apply it to the structure. Take particular care to account for drift and unbalanced snow loads. If no local code is available, the designer should refer to ASCE 7 for information. In areas with little snowfall, codes may require a minimum roof snow load.

Rain loads are intended to allow buildings to sustain loads of rainwater from a design level event. Residential rain loads typically range from 20 to 30 pounds per square foot based on the regional 100-year hourly rainfall rate and other factors such as roof shape. As with snow loads, the designer should look to ASCE 7 for rain loads if no local code is available.

4.5.3. VERTICAL (NON-GRAVITY) LOADS FROM FLOOD AND WIND

In addition to vertical (gravity) loads from dead, live, snow, and rain, there also may be vertical (non-gravity) loads from flood and wind that act in the opposite direction or create moments that may increase vertical downward acting loads on the downstream side of the foundations. These uplift loads and downward acting loads due to moments are specified below.

Flood (F_a) - Buoyancy

Buildings with enclosed spaces below the Design Flood Elevation may be subject to uplift forces during flood events due to buoyancy. Buoyancy forces are discussed in detail in Chapter 3. Buoyancy forces on residential structures can be extremely large, depending on the depth of flooding and the volume of the enclosed space, and must either be neutralized by elevating or adding hydrostatic openings, strengthening connections, or counteracted by the weight of the structure.

Wind (W) – Uplift and Overturning Moments

Just as air flowing across an airplane wing generates lift, wind blowing across a flat or low sloped roof generates uplift pressures on the building. Wind uplift forces on residential structures will impact the design of the connections between the house and the foundations and can affect the design of the foundations, depending on local wind speeds, roof shape, and height of the walls.

4.5.4. APPLICATION OF VERTICAL LOADS

Dead, live, and snow loads act vertically downward and are directed by the vertical load path through the load-bearing walls, floor system, and/or columns to the foundation system.

Starting with the roof, roof loads are directed to the load bearing walls of the top floor. Using the simple house example shown in Figure 4-7, where the roof trusses or ceiling joists and rafters run perpendicular to the two exterior load bearing walls, the roof loads would be distributed to the tops of the load bearing exterior walls. The roof load distributed to each load bearing wall will then be passed through the exterior load bearing walls to the foundation elements directly below each wall

and distributed using the relative sizes of the tributary areas assigned to these foundation elements. Similarly, the weights of the exterior walls on all sides would be directed to the foundation elements directly below these walls and distributed using the relative sizes of the tributary areas assigned to these foundation walls, piers, or columns.

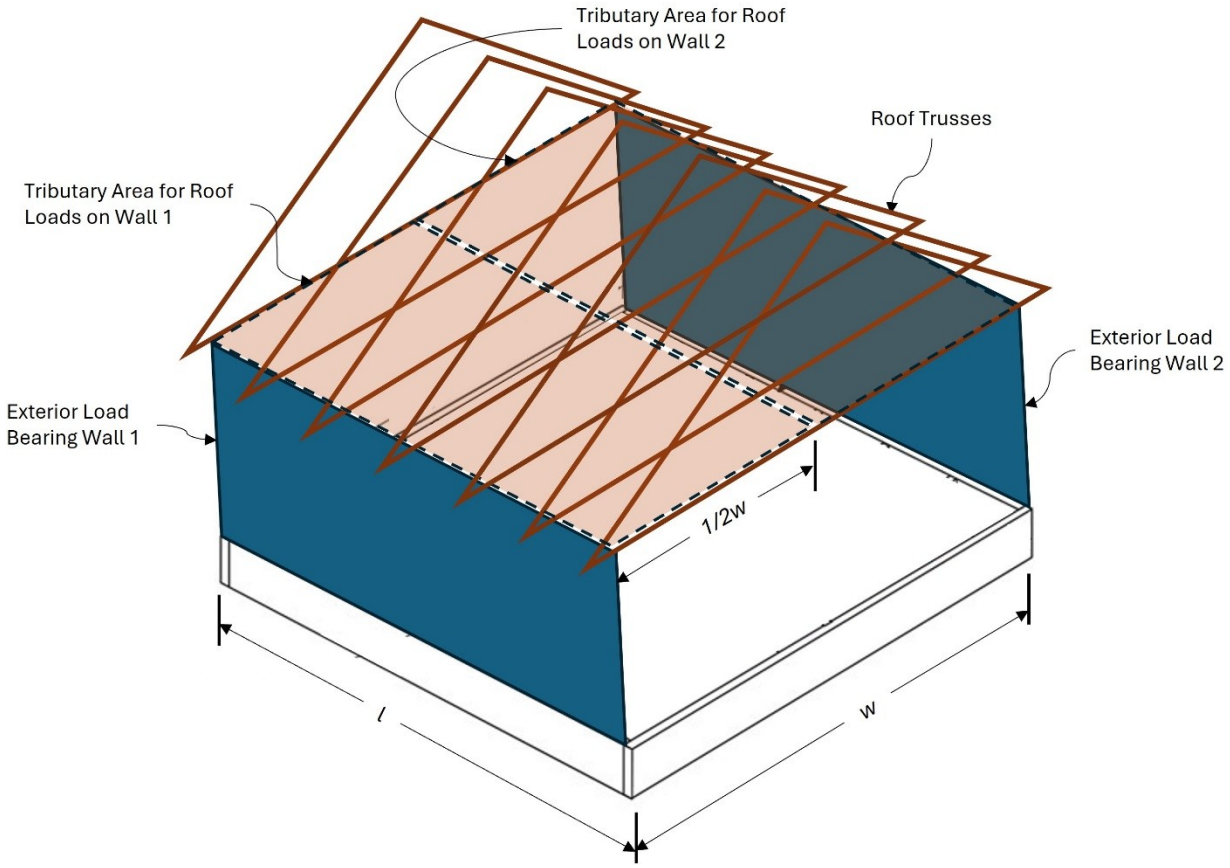


Figure 4-7. Exterior load bearing wall tributary area for roof load (no intermediate supports)

EQUATION 4-2: CALCULATION OF TRIBUTARY AREA FOR LOAD-BEARING WALLS

Case 1: Two load-bearing walls at opposite sides of roof structure: (Figure 4-7)

$$A_w = \frac{lw}{2}$$

Where:

A_w = wall tributary area (ft^2)

l = length of the exterior load bearing walls– per Figure 4-7 (ft)

w = span length between exterior walls– per Figure 4-7 (ft)

Case 2: Multiple parallel load bearing walls: (Figure 4-8)

For exterior wall:

$$A_w = \frac{l(\text{a or b})}{2}$$

EQUATION 4-3: CALCULATION OF TRIBUTARY AREA FOR CENTER GIRDER

For support of interior central girder, spliced ceiling joists or truss system with interior supports:

$$A_g = \frac{l(a+b)}{2}$$

Where:

A_g = center girder tributary area (ft²)

l = length of the girder (ft)

$(a + b)$ = length between adjacent parallel supports – wall or girder – per Figure 4-8 (ft)

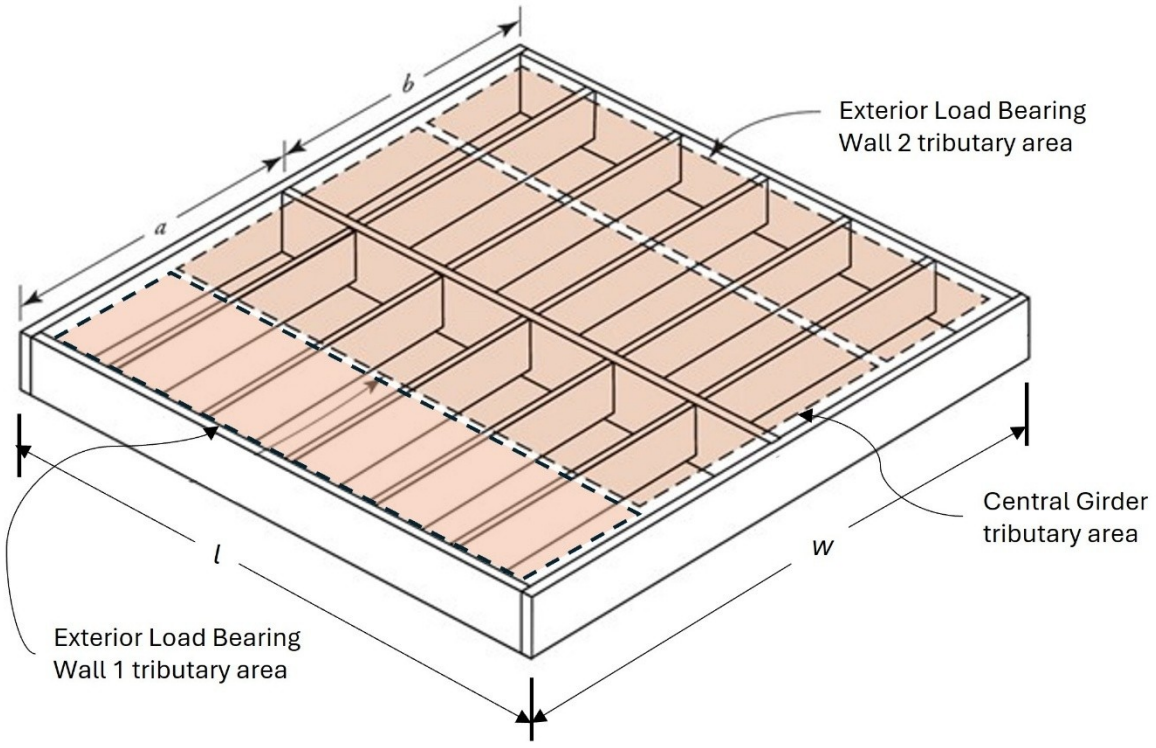


Figure 4-8. Wall/girder tributary area – multiple parallel supports

For each element of the foundation, whether walls, piers, or columns, the tributary area is the area bounded by imaginary lines drawn halfway between each element and the adjacent elements in each direction. The tributary areas of the columns in the simple example are shown in Figure 4-9, and their tributary areas are calculated using Equation 4-4.

EQUATION 4-4: CALCULATION OF TRIBUTARY AREA FOR COLUMNS

$$A_t = \frac{(wl)}{4}$$

Where:

A_t = column tributary area (ft²)

l = length of the wall surrounding the column (ft)

fraction of w = span length between adjacent support(s) surrounding the support of interest in a direction perpendicular to l (ft) (Figure 4-9)

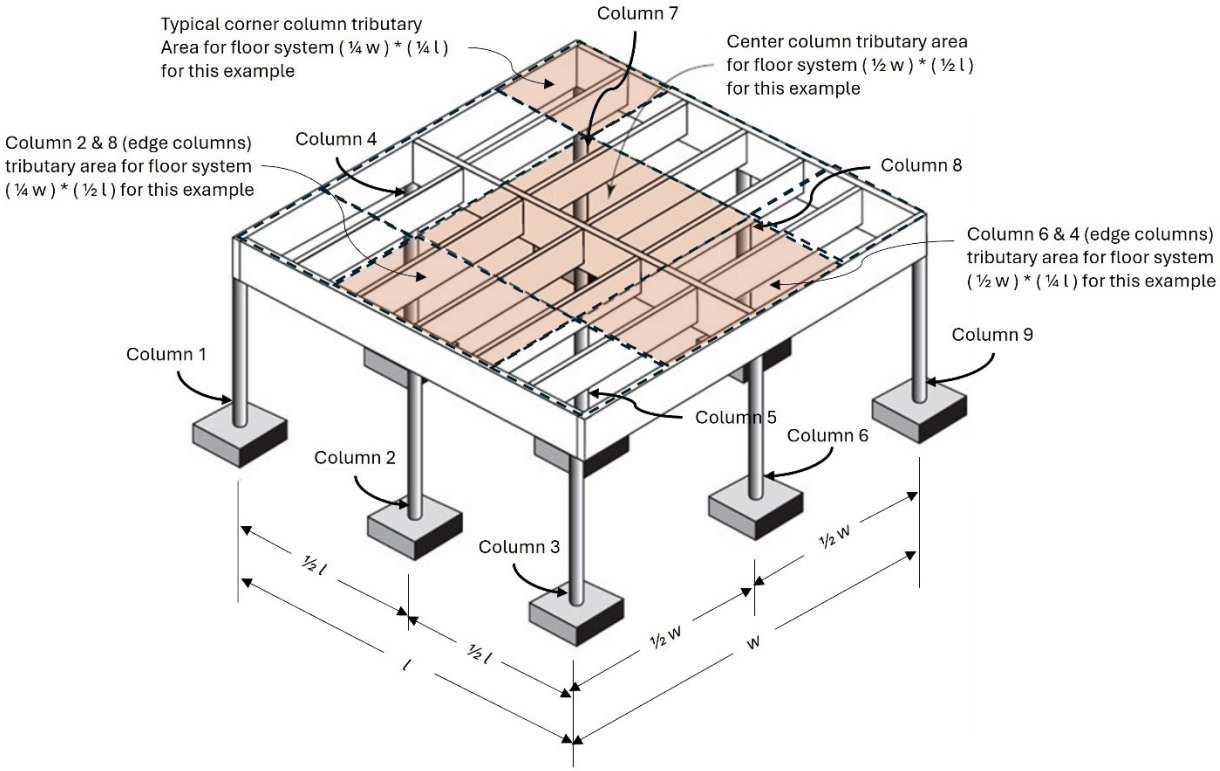


Figure 4-9. Column tributary areas

4.5.5. LATERAL LOADS

Lateral loads from various hazards, including flood, wind, and earthquake, play a significant role in the design and construction of strong residential buildings.

Flood Load (F_a)

Lateral flood loads in riverine floodplains are discussed in Section 3.1 and may include hydrostatic, hydrodynamic, and flood-borne debris impact forces. The impact of the lateral loads can typically be reduced by elevating the structure at or above the Base Flood Elevation or relocation. Refer to Chapter 5 for details. Lateral hydrostatic loads can be reduced by installing hydrostatic openings to equalize the pressure. Refer to Section 6.1 on wet floodproofing for details.

Wind Load (W)

Lateral forces from high wind pressures are discussed in Section 2.11.1. Wind loads on residential structures are primarily a function of location but are also influenced by other factors, including site characteristics and building configuration.

Earthquake Load (E)

Lateral shear forces imposed on the building by earthquake ground accelerations from seismic events are discussed in Section 2.11.2. Earthquake loads on residential structures are primarily a function of location and site soil types, but are also influenced by other factors including building configuration and site characteristics.

Other Loads: Lateral Earth Pressure (H), Self-Restraining Force (T)

Less common lateral loads on residential buildings include lateral earth pressure (H) typically imposed on below grade foundation walls, and self-restraining force (T) associated with prestressed concrete beams. Lateral forces imposed on below grade portions of flood-prone buildings from saturated soils are discussed in Section 3.2.2.

Application of Lateral Loads

Due to the large number of wall types and situations that can be encountered, which would make a comprehensive examination of this subject unwieldy for this manual, only procedural and reference information for lateral load resistance is provided. The process of analyzing foundation and interior walls is outlined below:

Step 1: Determine the type, size, material, and location of the walls to be analyzed.

Step 2: Determine the code-allowable overturning, bending, and shear stresses for the wall in question.

Step 3: Compare the stresses caused by the expected loadings versus code-allowable stresses (capacities) for each wall being analyzed. If the stresses caused by the expected loadings are less than the code-allowable stresses, the design is acceptable; if not, reinforcement is required, or another method should be considered.

Note

Lateral loads are distributed to the shear walls via the diaphragms of the floor or roof. Distribution is based upon relative stiffnesses of the walls. Use extreme care in the design of diaphragm-to-wall connections. Most codes require that an additional eccentricity (factor of safety) be considered in the location of the resultant lateral loads.

Cross Reference

For additional information on loading conditions for exterior and shear walls, refer to ASCE 7.

4.5.6. ASSESS LOAD COMBINATION SCENARIOS

Once the vertical (gravity and non-gravity) and lateral loads are established, the next step in the basic analysis process flow chart (Figure 4-4) is to determine the load combinations of the applicable vertical and lateral loads. ASCE 7-22 prescribes how to analyze flood loads in concert with other loading conditions. This guidance involves the use of two methods that provide a factor of safety: load and resistance factor design (LRFD) and allowable stress design (ASD). In the case of load and resistance factor design, design specifications provide load factors, and, in some instances, resistance factors (i.e., factored loads and resistance contain a factor of safety). For allowable stress design, design specifications define allowable stresses that may not be exceeded by load effects due to unfactored loads (i.e., allowable stresses contain a factor of safety). The analysis of loading conditions may be checked using either method (but see Note) if that method is used exclusively for proportioning elements of that construction material.

Note

Given the increased usage of the Load and Resistance Factor Design method in current design, the Load and Resistance Factor Design method will be used for example calculations in this document.

It is the purpose of the load combinations to identify critical stresses in structural members (or nonstructural members) and critical conditions used to design the support system. Since every conceivable situation cannot be covered by standard load cases, sound engineering judgment must be used.

The designer should consult ASCE 7 for guidance in analyzing the multi-hazard loading conditions. The following symbols are currently used in ASCE 7-22 to define the various load combinations.

D = Dead Load

E = Earthquake Load (E_h for horizontal and E_v for vertical)

F = Load due to fluids with well-defined pressures and maximum heights

F_a = Flood Load

H = Load due to lateral earth pressure, groundwater pressure, or pressure of bulk materials

L = Live Load

L_r = Roof Live Load

R = Rain Load

S = Snow Load

T = Self-Straining Force

W = Wind Load

W_T =Tornado Load

The most unfavorable effects from combinations of wind loads, tornado loads, and earthquake loads should be considered, where appropriate, but they need not be assumed to act simultaneously. For some buildings, this may require that the effects of one or more loads not be included. Refer to Sections 1.4, 2.3.6, 12.4, and 12.14.3 of ASCE 7-22 for the specific definition of the earthquake load effect E. Each relevant strength limit state shall be investigated.

Load Combinations from Load and Resistance Factor Design Method

The load combinations for LRFD from ASCE 7-22 are listed below. Since buildings are exposed to a variety of loads, but probabilistically not all loads act directly on a building simultaneously, the load combination equations from ASCE 7-22 include adjustment factors for various hazards to model the overall load combinations.

1a. $1.4D$

2a. $1.2D + 1.6L + (0.5L_r \text{ or } 0.3S \text{ or } 0.5R)$

3a. $1.2D + (1.6L_r \text{ or } 1.0S \text{ or } 1.6R) + (L \text{ or } 0.5W)$

4a. $1.2D + 1.0(W \text{ or } W_T) + L + (0.5L_r \text{ or } 0.3S \text{ or } 0.5R)$

5a. $0.9D + 1.0(W \text{ or } W_T)$

6. $1.2D + E_V + E_h + L + 0.15S$

7. $0.9D - E_v + E_h$

Additional Load and Resistance Factor Design Requirements for Flood Zones

When a structure is in a non-coastal flood zone, the following load combinations should be considered in addition to the basic combinations:

4b. $1.2D + 0.5W + 1.0F_a + L + (0.5L_r \text{ or } 0.3S \text{ or } 0.5R)$

5b. $0.9D + 0.5W + 1.0F_a$

The guidance in ASCE 7-22 Section 2.3 for Strength Design indicates which load combinations the flood load should be applied to. ASCE 7-22 Section 5.3.1 details which flood loads are applicable. In riverine flood zones the non-coastal portions of Zone A where waves are not present, the flood load F_a is a combination of hydrostatic, hydrodynamic, and debris impact loads. All these loads could be lateral loads; only hydrostatic will be a vertical load (buoyancy). When designing for global forces that will create overturning, sliding, or uplift reactions, F_a should be the flood load that creates the most restrictive condition. In the case of sliding and overturning, F_a should be determined by the type of flooding expected. Hydrostatic forces will govern if the flooding is primarily from standing water, possibly saturating the ground surrounding a foundation; hydrodynamic forces will govern if the flooding is primarily from moving water.

When designing a building element such as a foundation, F_a should be the greatest of the flood forces that affect that element (F_{sta} or F_{dyn}) + F_i (impact loads on that element acting at the still water level). The combination of these loads must be used to develop the required resistance that must be provided by the building element.

A load combination worksheet with instructions is included in Figures 4-10 and 4-11.

The symbols, load combinations, and exceptions presented are based upon information from ASCE 7-22, but do not share full documentation; only those necessary to the content of this manual are shown. Refer to ASCE 7-22 for clarification and additional information (i.e., seismic load effect with overstrength, atmospheric ice, and wind-on-ice loads).

Exceptions:

- The load factor on live load L in combinations (3a) and (4a) is permitted to equal 0.5 for all occupancies in which L_o in Table 4.3-1 of ASCE 7-22 is less than or equal to 100 lb/ft^2, with the exception of garages or areas occupied as places of public assembly.
- In combinations (2a) and (4a), the companion snow load S shall be taken as either the flat roof snow load (p_f) or the sloped roof snow load (p_s).
- Where using tornado wind load W_T in combination (4a), load grouping ($0.5L_r$ or $0.3S$ or $0.5R$) can be replaced with 0.5 (L_r or R).
- Where fluid loads F are present, they shall be included with the same load factor as dead load D in combinations (1a through 4a).
- Where lateral earth pressure loads H are present, they shall be included as follows:
    - Where the effect of H adds to the principal load effect, include H with a load factor of 1.6.

- Where the effect of *H* resists the principal load effect, include *H* with a load factor of 0.9 where load *H* is permanent or a load factor of 0 for all other conditions.

Load Combinations Worksheet

Owner Name:		**Preparer**	
Address:		**Date:**	
Property Details:			

Variables

Building Footprint = Floor Area (*A*) = _____ square feet (1-story residence)

Dead Load = _____ lbs (vertical) Use unit dead load of 150 psf for concrete residence

E = Earthquake Load = _____ lbs (horizontal)

Flood Zone: Non-Coastal Zone A

Flood Load = 1.0 F_a = _____ lbs (horizontal); 1.0 F_a = _____ lbs (vertical)

L = Live Load = _____ lbs (vertical) Use unit live load of 40 psf per ASCE 7-22

L_r = Roof Live Load = _____ lbs (vertical) Use unit roof live load of 20 psf per ASCE 7-22

R = Rain Load = _____ lbs (vertical)

S = Snow Load = _____ lbs (vertical)

W = Wind Load = _____ lbs (horizontal); *W* = _____ lbs (vertical)

Load Combinations - Strength Design (LRFD) (see ASCE 7-22, Chapter 2.3)

Number	Combination	Horizontal (lbs)	Vertical (lbs)
Combination 1a =	$1.4D$	_____ lbs	_____ lbs
Combination 2a =	$1.2D + 1.6L + (0.5L_r$ or $0.3S$ or $0.5R)$	_____ lbs	_____ lbs
Combination 3a =	$1.2D + (1.6L_r$ or $1.0S$ or $1.6R) + (L$ or $0.5W)$	_____ lbs	_____ lbs
Combination 4a =	$1.2D + 1.0(W$ or $W_T) + L + (0.5L_r$ or $0.3S$ or $0.5R)$	_____ lbs	_____ lbs
Combination 4b =	$1.2D + 0.5W + 1.0F_a + L + (0.5L_r$ or $0.3S$ or $0.5R)$	_____ lbs	_____ lbs
Combination 5a =	$0.9D + 1.0(W$ or $W_T)$	_____ lbs	_____ lbs
Combination 5b =	$0.9D + 0.5W + 1.0F_a$	_____ lbs	_____ lbs
Combination 6 =	$1.2D + E_v + E_h + L + 0.15S$	_____ lbs	_____ lbs
Combination 7 =	$0.9D - E_v + E_h$	_____ lbs	_____ lbs

Summary of Load Combinations

Combination Load that controls in the horizontal direction: _____ lbs

Combination Load(s) that control in the vertical direction: _____ lbs and _____ lbs

Page 1 of 2. See next page for Notes and References

Figure 4-10. Load and Resistance Factor Design Load Combinations Worksheet

Load Combinations Worksheet (continued)	
Notes:	1. Load combinations are based on the Strength Design (LRFD) method from ASCE 7-22. Gravity loads (D, L, L_r, R, S) act in the vertical direction; while most hazard loads (F_a, W) have components that can act in both the horizontal direction and the vertical (negative/uplift) direction. 2. Dead Load (D) can be determined using the four step process in FEMA P-259 Section 4.5.2 using the unit weights of various construction materials in Table 4-1 multiplied by the applicable surface areas and added together using the Building Weight Estimating Worksheet in Figure 4-6. 3. Live Load (L) can be assumed to be uniformly distributed at 40 lbs/ft^2 (psf) across all interior floor areas. 4. Roof Live Load (L_r) can be assumed to be uniformly distributed at 20 psf across the surface of the roof. 5. Rain Load (R) and Snow Load (S) can be estimated based on local requirements. Design snow loads (in psf) from ASCE 7-22 can be determined using the ASCE Hazard Tool website (https://ascehazardtool.org). 6. Wind Loads (W) can be determined in the two directions. Horizontal wind loads are based on positive wind pressures acting against the walls and roof of the building; vertical wind loads are based on positive and negative (uplift) wind pressures acting on the roof surface. Design wind speeds (in mph) for residential buildings (Risk Category II structures) from ASCE 7-22 can be determined using the ASCE Hazard Tool website (https://ascehazardtool.org). 7. Flood Loads (F_a) can be determined in the two directions. Horizontal flood loads are based on hydrostatic, hydrodynamic, debris impact and breaking wave forces acting against the foundations and walls of the building; vertical flood loads are based on negative (uplift) due to buoyancy and wave slam. 8. Earthquake Loads (E) can be determined in two directions (horizontal and vertical). Horizontal earthquake loads for the structure are tied to base shear. Spectral response accelerations from ASCE 7-22 can be determined using the ASCE Hazard Tool website (https://ascehazardtool.org).

Figure 4-11. Instructions for completing Load Combinations Worksheet (Figure 4-10)

4.5.7. DETERMINE LOADS ON FOUNDATION SYSTEMS

The foundation system of a house (footings and foundation walls) serves several purposes. It supports the house by transmitting the building loads to the ground and serves as an anchor against uplift and forces caused by wind, seismic, flooding, and other loads. Below-grade foundation walls restrain horizontal pressures from adjacent soil pressures. The foundation system anchors the house against horizontal, vertical, and shear loads from water, soil, debris, seismic, snow, and wind hazards. Retrofitting measures, such as elevation, change the dynamics of the forces acting on a building. More details regarding foundations and the loads experienced by them can be found in the Fourth Edition of FEMA P-55, *Coastal Construction Manual* (FEMA, 2011), in Chapters 8 through 10. FEMA P-550, *Recommended Residential Construction for Coastal Areas* (FEMA, 2009), also provides design plans for coastal foundations and construction guidance.

Note

Elevating a house exposes it to greater vertical loads from additional weight, and horizontal and shear loads from increased wind forces. Figure 4-12 illustrates the various loads that affect a foundation system.

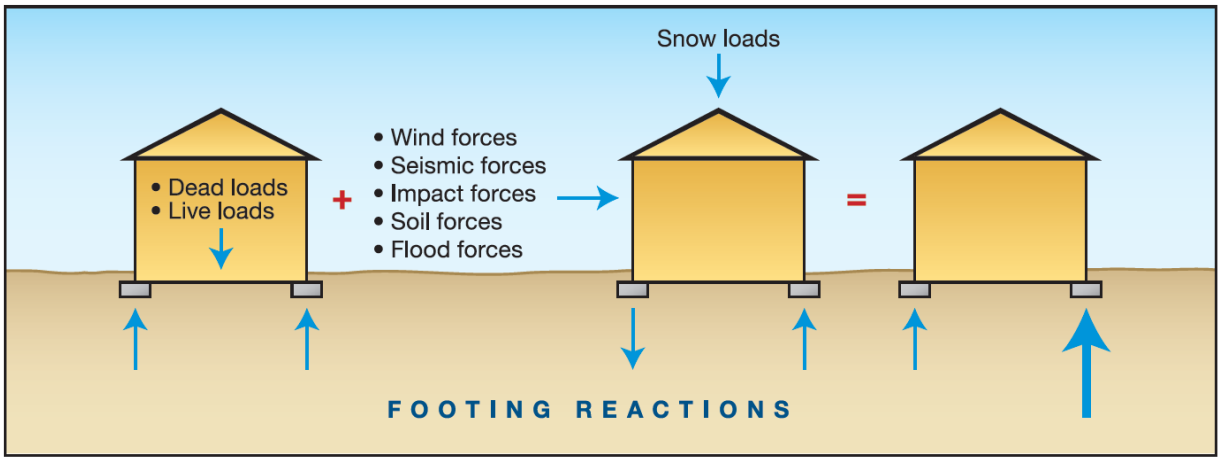


Figure 4-12. Foundation system loading

The vertical load on the foundation system can be determined by adding the load combination that controls in vertical direction to the self-weight of the foundation components. The load combination that controls in the vertical direction can be determined using the Load Combinations Worksheet (Figures 4-10 and 4-11) and then applied to the appropriate wall or column tributary area above the foundation (see Section 4.5.4). The self-weight of the foundation components can include the weight of the wall or column connected to the foundation, the overbearing soil weight, and the weight of the foundation. Calculate the self-weight of the wall or column. This information can be determined using Equation 4-5.

EQUATION 4-5: CALCULATION OF FOUNDATION COMPONENTS SELF-WEIGHT

$$W_{self} = (SA \times W_u) + OSW + FW$$

Where:

W_{self} = self-weight of the foundation components

SA = section weight area of the component (ft²)

W_u = unit weight of the component (lb/ft² of surface)

OSW = overbearing soil weight (lb)

FW = foundation weight (lb)

Add the above calculated loads to find the total load carried by the wall or column to the foundation or footing (Equation 4-6).

EQUATION 4-6: CALCULATION OF TOTAL LOAD CARRIED BY THE WALL OR COLUMN TO THE FOOTING OR FOUNDATION

$$TL = P + W_{self}$$

Where:

TL = total load carried by the wall or column to the footing or foundation (lb)

P = maximum vertical load acting on a specific wall or column (lb)

W_{self} = self-weight of the component (lb)

Note

Non-gravity flood loads from buoyancy and uplift forces from vertical wind pressures act in the opposite direction of gravity loads, but are not applied to Equation 4-6. However, they are included in the load combinations discussed in Section 4.5.6.

The lateral load on the foundation system can be determined by adding the load combination that controls in the lateral direction, which can be determined using the Load Combinations Worksheet (Figures 4-10 and 4-11). This load can then be multiplied by the average height above the building foundation where the load is applied to determine the total moment and then divided by the width of the building to resolve the lateral load into additional positive (compression) and negative (uplift) vertical forces on the foundation (Figure 4-12). These resolved forces can be added to the vertical forces on the foundation to determine the total load on the foundation system. As stated previously, retrofitting measures such as elevation change the dynamics of the forces acting on a building. More details regarding foundations and the loads experienced by them can be found in the Fourth Edition of FEMA P-55, *Coastal Construction Manual* (FEMA, 2011), in Chapters 8 through 10. FEMA P-550, *Recommended Residential Construction for Coastal Areas* (FEMA, 2009), also provides design plans for coastal foundations and construction guidance.

Bearing Capacity of Footings

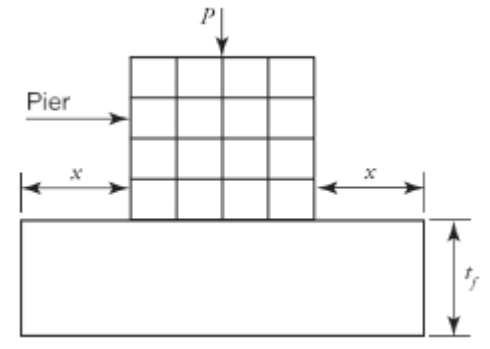
Footings are designed to transmit building loads to the ground and should be placed completely below the maximum frost penetration depth (see Note). Equation 4-7 can determine footing size.

Note

Frost penetration depths range between 0 and 8 feet within the contiguous United States, with the largest frost depths and incidents of frost heave occurring in the upper Midwest and Northeast.

Note

The load carrying capacities of residential footings, particularly strip footings, are usually limited by the bearing capacity of the soil. For spread footings (i.e., isolated footings that may be spread over a relatively large area), the footing may be controlled by the structural capacity of the footing itself. Thus, spread footings typically require reinforcing bars near the bottom of the footing. In general, when x exceeds 1.5 times t_f in the note figure, an analysis of shear and bending forces are required. Refer to ACI 318-19(22), *Building Code Requirements for Structural Concrete and Commentary* (2019, reapproved 2022), for investigations of such concrete footings.



EQUATION 4-7: DETERMINING FOOTING SIZE

$$A_f = \frac{P}{Q_u}$$

Where:

A_f = bearing area of the footing (ft²)

P = load (lb)

Q_u = Ultimate soil bearing capacity (lb/ft²); see Table 4-2

Table 4-2. Presumptive Ultimate Bearing Capacities for Different Materials

Material Class	Ultimate Bearing Capacity, Q_u, (lb/ft²)
1. Rock	8,000+
2. Sandy gravel, gravel	6,000
3. Sand, silty sand, clayey sand, silty gravel, clayey gravel	4,000
4. Clay, sandy clay, silty clay, clayey silt	3,000

SOURCE: DERIVED AND ADJUSTED FROM 2021 IBC TABLE 1806.2

Note

The presumptive ultimate bearing capacities shown in Table 4-2 are guidelines and are derived from allowable bearing capacities found in IBC 2021 Table 1806.2, which are increased by a safety factor of 2 to reflect Load and Resistance Factor Design factored loads.

In conducting this computation, it is important to confirm the size and depth of the footing and bearing capacity of the soil to ensure that the existing conditions meet current codes. In the absence of reliable information, excavation may be required to confirm the depth, size, and condition of the existing footing. Maximum loading of the existing footing can be calculated using Equation 4-9.

The designer should also check the existing footing to ensure that it has a perimeter drainage system to prevent saturation of the soil at the footing. If one does not exist, the designer should consider including this feature in the retrofit design.

Note

Perimeter drainage systems may be used if the bearing soil is adversely affected by saturation. Often, soils under bearing pressure will not become saturated due to low permeability. Each situation should be evaluated separately.

EQUATION 4-8: MAXIMUM LOADING OF EXISTING FOOTING

$$P_{max} = A_f Q_u$$

Where:

A_f = bearing area of the footing (ft^2)

P_{max} = max load (lb)

Q_u = ultimate soil bearing capacity (lb/ft^2); see Table 4-2

The bearing capacity of an existing strip footing is shown in Equation 4-9.

EQUATION 4-9: BEARING CAPACITY OF EXISTING STRIP FOOTING

$$W_f = b_f Q_u$$

Where:

W_f = total weight of footing wall support (lb/ft)

b_f = width of footing (ft)

Q_u = ultimate soil bearing capacity (lb/ft^2); see Table 4-2

Note

W_f acts downward.

Note

The approximate bearing capacity of concrete and reinforced concrete materials may vary due to regional differences in concrete mix, aggregate, reinforcing practices, and other factors. In general, the approximate bearing capacity of concrete/reinforced concrete is substantially greater than that of masonry block: a conservative estimate ranges from 500 to 1,000 pounds per square inch. Additional information on the capacity and strength of concrete mixtures can be obtained from ACI 318.

Retrofitted Foundation Loading Versus Bearing Capacity

The next step is to check the bearing capacity of the existing foundation system versus the expected loading from the loads associated with the proposed retrofit. This analysis will provide an initial estimate of the magnitude of foundation modifications necessary to accomplish an elevation or relocation project.

The International Building Code and International Residential Code require the analysis of a variety of loading conditions and then base the capacity determination on the loading condition that presents the most unfavorable effects on the foundational or structural member concerned.

Since buildings and structures are exposed to different loads simultaneously, the effects of those loads can be cumulative. As discussed in Section 4.5.6, Chapter 2 of ASCE 7 includes load combinations to model simultaneous loading of buildings and structures. Loads for all ASCE 7 load combinations are determined, and the controlling load(s) are considered in the analyses. If the total foundation load from Equation 4-6 exceeds the maximum load capacity of the existing footing from Equation 4-8 or 4-9, then the bearing area of that footing must be increased to accommodate the additional retrofit loads. If not, then the existing footing size is considered acceptable as-is.

4.5.8. BUILDING STABILITY ASSESSMENT

For flood mitigation to be effective, environmental loads to which the building or structure may be exposed must be considered. Not doing so can render a mitigated building or structure vulnerable to failure from uplift, sliding, overturning, or collapse. Some retrofit actions, like the installation of flood vents that equalize flood levels within and outside of a building, can significantly reduce loads, but others, like dry floodproofing, can significantly increase loads on a building or structure, which can negate the reduction in flood risk and can increase the risk of structural failures. Some retrofit actions, like elevation, may result in a slight increase in loads, but the effects of those loads can be pronounced since the points where those loads are applied to the building or structure will shift upward, which can increase the risk of overturning and may increase the risk of sliding and collapse. These failures, which are often referred to as stability failures, can be assessed by global load calculations, which consider how the building or structure reacts to the applied loads.

As discussed in Section 4.5.6, building codes and standards that reference ASCE 7 require buildings and structures to be designed to withstand the effects of various vertical and lateral loads. Vertical loads include dead loads (D) resulting from the self-weight of the building; live loads (L) resulting from the occupancy of the building or structure; and rain loads (R) and snow loads (S) resulting from precipitation that collects and accumulates on buildings. Lateral loads include wind loads (W) resulting from pressures created when an air mass moves over or around a building or structure; flood loads (F_a) resulting from events that expose buildings and structures to floodwater; and earthquake loads (E) resulting from ground motions during seismic events. Dead, live, snow, and rain loads result from the earth's gravity and can only act in a vertical downward direction, while flood and wind loads can act vertically upward as well as laterally. Additionally, since buildings and structures are exposed to different loads simultaneously, the effects of those loads can be cumulative. Chapter 2 of ASCE 7 includes load combinations to model simultaneous loading of buildings and structures. Loads for all ASCE 7 load combinations are determined, and the controlling load(s) are considered in the analyses as shown in the Load Combinations Worksheet (Figures 4-10 and 4-11).

As discussed in Section 4.5.6, buildings must resist loads they are exposed to and must transfer those loads to the foundations that support them. The foundations, in turn, must transfer the loads imposed on the buildings and the loads imposed on the foundations themselves to the supporting soils. If the building, the foundation, or the supporting soil cannot resist the applied loads, then one of three primary failure modes - uplift, sliding, and overturning - can occur. Any of the three primary failure modes can result in collapse, a secondary failure mode. Each of these failure modes will be discussed in the sections that follow.

Uplift Failure

Global load calculations that address uplift consider *vertical* loads. Mathematically, gravity loads are generally considered positive and uplift loads negative. Preventing uplift failures requires that buildings and other structures have sufficient weight or sufficient weight and anchorage to resist the external loads. Uplift loads include wind, earthquakes, and hydrostatic flood loads from buoyancy. In coastal flood areas, flood loads from wave slam can also create vertical flood forces.

Uplift failures occur when *vertical* uplift loads exceed the combined weight of the building, the foundation, its connections, and the capacity of the earth and foundation to resist tensile loads. Uplift loads can occur from high winds (particularly on buildings with flat or low sloped roofs), floods (particularly buoyancy), and earthquakes (in some areas). An example of uplift failure is shown in Figure 4-13. When gravity loads are insufficient to resist uplift, robust connections and additional dead loads must be included in the design, or foundations capable of providing anchorage by transferring uplift loads to the supporting soils must be used. Since building materials weigh less when submerged, their submerged weight must be used.

Generally, ASCE 7-22 load combinations 3a, 4a, and 5a, and, in flood-prone areas, 4b, and 5b, address uplift loads.

Sliding Failure

Global load calculations that address sliding consider *horizontal* loads. To prevent sliding failure, the building and its foundation must be able to provide sufficient horizontal loads to resist external horizontal loads. Wind, earthquakes, and moving floodwater create horizontal loads.

Sliding failures occur when *horizontal* loads exceed the friction forces between the foundation and the supporting soil. Horizontal loads can result from high winds, floods (particularly from lateral hydrostatic, hydrodynamic, flood-borne debris, and waves), and earthquakes. An example of sliding failure is shown in Figure 4-14.



Figure 4-13. Example of uplift failure from Hurricane Sandy (2012), showing a home in Fire Island, NY, detached from its pile foundation by uplift forces



Figure 4-14. Sliding failure example showing homes circled in red in West Beach, Alabama, being swept away by lateral flood and wind forces due to insufficient pile embedment

For shallow foundation, like concrete strip and pad footings, horizontal loads are resisted by friction forces between the bottom of the footers and the supporting soils and by the compressive strength of the soils that surround the sides of the footers. Deeper foundations, like piles and caissons, resist sliding forces through the compressive strength of the adjacent soil. Friction forces are proportional to the net normal force on the foundation, so they depend on gravity loads. The gravity loads should consider the reduced weight of submerged building components.

Overturning Failure

Unlike uplift and siding failures, which consider the net vertical and horizontal loads on a building or structure, overturning calculations must consider the vertical and horizontal loads and where those loads are applied. Preventing overturning failures requires that the resisting moments that result from dead loads, and when present, anchorage, exceed the overturning moments caused by lateral and uplift forces. An example of overturning forces is shown in Figure 4-15.

While overturning analyses are not inherently complicated, they are more involved than uplift and sliding calculations. For example, to determine the overturning amounts from wind pressures, each individual surface of the building, e.g., windward and leeward walls, windward and leeward roof surface areas, and windward and leeward eave overhangs must be considered individually. For each surface, the total wind force (in pounds or kips) multiplied by its perpendicular distance to the pivot point chosen for the analysis determines the resisting or overturning moment caused by the applied force. Any point can be used for the pivot point, but selecting an at grade pivot point on the leeward or downstream side of the building is common. Moments that resist overturning are considered positive moments, and those that contribute to overturning are considered negative. If the calculated overturning moments exceed the resisting moments, additional dead load or anchorage will be needed to prevent overturning failures.



Figure 4-15. Overturning failure example from Hurricane Fran (1996), showing a North Carolina home overturned by lateral and uplift forces from flood and wind that exceed the self-weight of the building and the capacity of the foundation

The ability of the building and its foundation to withstand imposed flood- and non-flood-related forces depends upon the building elements, the foundation elements, and the connections between those elements. Once the loads on the building and foundation are determined, the capacity of the building, foundation, and supporting soils to resist those loads is checked for failure from overturning, bending, and shear (horizontal, vertical, and diagonal). If the stresses from the combined effects of gravity, flood, wind, earthquake, and other environmental loads are less than the code-allowable stress or material strengths for the expected failure modes, then the building and foundation design is acceptable. Conversely, if the stresses caused by the combined loadings exceed the code-allowable stresses or materials strengths for the expected failure mode, then the proposed design is unacceptable, and reinforcing is required.

Secondary Mode – Collapse

Collapse occurs when a critical element of the building or foundation fails, leading to a loss of the entire structure. An example of a residential building collapse is shown in Figure 4-16. Collapse is considered a secondary failure mode since it is typically caused by the overstress or overload of a particular building or foundation element due to uplift, sliding, or overturning loads imposed on the structure.



Figure 4-16. Collapse example of a multi-family residential building in Orange Beach, Alabama, built on a shallow foundation that was subject to coastal flood forces and undermined by erosion and scour (Source: Figure 2-5, FEMA P-762)

4.6. Case Study Exercise 5 – Load Combinations and Building Assessment

Use the Load Combination Worksheet with instructions (Figures 4-10 and 4-11) to determine what load combinations control in the vertical and horizontal/lateral direction and the overall stability of the case study buildings using the Load and Resistance Factor Design Method, and assess any building stability concerns.



Case Study A – Exercise 5

Case Study A – Exercise 5: Residential Retrofit in Riverine Floodplain Using Relocation or Elevation

Load Combinations and Building Assessment

An evaluation of load combinations associated with Mr. and Mrs. Doe's house will help identify critical hazards that govern the building design. Figure CSA-16 shows the load combinations worksheet that generates the largest horizontal and vertical loads for Load and Resistance Factor Design in accordance with ASCE 7-22. Supplemental calculations that provide additional details beyond the worksheet for dead load, live load, snow load, and wind load are found in Appendix A.

Global design checks evaluate the three primary failure modes of uplift, sliding, and overturning to confirm that all the loads imposed on a building are properly resisted or transferred to the supporting soils. A detailed analysis of global design checks is outside the scope of this publication, but a brief discussion of them in relation to the Doe's retrofit options is warranted.

If Mr. and Mrs. Doe relocate their house, although the global design checks are unlikely to change significantly, it is still important to confirm the global design checks using the proper building code load combinations. It is expected that the new foundations of the relocated house would match the original with very limited differences. This should result in similar uplift, sliding, and overturning resistance.

If Mr. and Mrs. Doe elevates their house, it will increase in height by 5.6 feet. This additional height increases the maximum global uplift force, sliding force, and overturning moment for the house. The additional dead load of the taller perimeter walls can help resist the new uplift force. A cursory evaluation of the load combinations for the Doe's house confirms that the dead load of the house is sufficient to resist uplift. The footing depth, along with the additional dead load of the perimeter walls, will provide proper sliding resistance. With proper reinforcement of the perimeter walls into the footings, the walls and footings will be able to engage the passive soil resistance that comes with the top of the footings located 3 feet below grade. The overturning check will be governed by the largest horizontal load and the least vertical load, with the load positions evaluated in relationship to one edge of the building. For Mr. and Mrs. Doe's house, the horizontal load combination (5a) of 27,690 lbs will produce a lower absolute moment than the absolute resisting moment from the dead load of the house using the least vertical load combination (5a) of 247,388 lbs. The result will be a positive overturning moment that is acceptable.

Load Combinations Worksheet			
Owner Name:	**John and Jane Doe**	**Preparer**	**JJS-MH**
Address:	**55 Cedar River Road**	**Date:**	**7/6/2026**
Property Details:	**Case Study A**		

Variables

Building Footprint =	Floor Area (A) =	1,600	square feet (1-story residence)
	Dead Load =	302,794	lbs (vertical) Use unit dead load of 150 psf for concrete residence
E =	Earthquake Load =	0	lbs (horizontal)
Flood Zone:	Non-Coastal Zone A		Riverine
Flood Load =	1.0 F_a =	3,118	lbs (horizontal); 1.0 F_a = **0** lbs (vertical)
L =	Live Load =	64,000	lbs (vertical) Use unit live load of 40 psf per ASCE 7-22
L_r =	Roof Live Load =	35,840	lbs (vertical) Use unit roof live load of 20 psf per ASCE 7-22
R =	Rain Load =	0	lbs (vertical)
S =	Snow Load =	91,392	lbs (vertical)
W =	Wind Load =	27,690	lbs (horizontal); W = -25,127 lbs (vertical)

Load Combinations - Strength Design (LRFD) (see ASCE 7-22, Chapter 2.3)

Number	Combination	Horizontal (lbs)	Vertical (lbs)
Combination 1a =	$1.4D$	- lbs	423,912 lbs
Combination 2a =	$1.2D + 1.6L + (0.5L_r$ or $0.3S$ or $0.5R)$	- lbs	493,170 lbs
Combination 3a =	$1.2D + (1.6L_r$ or $1.0S$ or $1.6R) + (L$ or $0.5W)$	- lbs	518,745 lbs
Combination 4a =	$1.2D + 1.0(W$ or $W_T) + L + (0.5L_r$ or $0.3S$ or $0.5R)$	27,690 lbs	429,644 lbs
Combination 4b =	$1.2D + 0.5W + 1.0F_a + L + (0.5L_r$ or $0.3S$ or $0.5R)$	12,874 lbs	442,207 lbs
Combination 5a =	$0.9D + 1.0(W$ or $W_T)$	27,690 lbs	247,388 lbs
Combination 5b =	$0.9D + 0.5W + 1.0F_a$	12,874 lbs	259,951 lbs
Combination 6 =	$1.2D + E_v + E_h + L + 0.15S$	- lbs	- lbs
Combination 7 =	$0.9D - E_v + E_h$	- lbs	- lbs

Summary of Load Combinations

Combination Load that controls in the horizontal direction:	27,690 lbs	
Combination Load(s) that control in the vertical direction:	518,745 lbs and	247,388 lbs

Page 1 of 2. See next page for Notes and References

Figure CSA-16. Load and Resistance Factor Design Load Combinations Worksheet for the Doe house



Case Study B – Exercise 5

Case Study B – Exercise 5: Residential Retrofit Outside of the Floodplain Using Floodwalls or Dry Floodproofing

Load Combinations And Building Assessment

Figure CSB-14 shows the load combinations worksheet for The Valley Apartments that generates the largest horizontal and vertical loads for Load and Resistance Factor Design in accordance with ASCE 7-22. Supplemental calculations that provide additional details beyond the worksheet for dead load, live load, snow load, and wind load are found in Appendix B.

Global design checks for the dry floodproofing option will need to confirm that sliding, uplift (buoyancy), and overturning are not a problem. This document will not review detailed calculations associated with each of these checks. The dead load of the bearing walls, coupled with soil friction, will provide ample sliding resistance. The footings supporting the dead load of this two-story building are expected to be able to resist buoyancy and wind uplift, as shown in the vertical component of Load Combination 5b. The overturning check will be governed by the largest horizontal load and the least vertical load, with the load positions evaluated in relationship to one edge of the building. For The Valley Apartments, the horizontal load combination (5a) of 71,000 pounds will produce a lower absolute moment than the absolute resisting moment from the dead load of the building using the least vertical load combination (5b) of 390,744 lbs. The result will be a positive overturning moment that is acceptable.

A load combinations worksheet for the floodwall of The Valley Apartments is excluded. Requirements for floodwalls are prescriptive. FEMA P-936 provides a floodwall design flow chart that explains the iterative process to finalize the floodwall design. The process results in a structure that can resist the design checks for sliding, overturning, and bearing pressure.

Load Combinations Worksheet			
Owner Name:	**Atticus Finch**	**Preparer**	**JJS-MH**
Address:	**2908 Valley Drive**	**Date:**	**7/3/2025**
Property Details:	**Case Study B**		

Variables

Building Footprint =	Floor Area (*A*) =	5,000 square feet (2-story multi-family residence)		
	Dead Load (D) =	1,522,631 lbs (vertical)	Use unit dead load of 150 psf for concrete residence	
E =	Earthquake Load =	0 lbs (horizontal)		
Flood Zone:	Not a Special Flood Hazard Area		Riverine	
Flood Load =	1.0 F_a =	29,765 lbs (horizontal);	1.0 F_a =	-936,000 lbs (vertical)
L =	Live Load =	200,000 lbs (vertical)	Use unit live load of 40 psf per ASCE 7-22	
L_r =	Roof Live Load =	125,800 lbs (vertical)	Use unit roof live load of 20 psf per ASCE 7-22	
R =	Rain Load =	0 lbs (vertical)		
S =	Snow Load =	0 lbs (vertical)		
W =	Wind Load =	168,000 lbs (horizontal);	*W* =	-87,248 lbs (vertical)
W_T =	Tornado Load =	0 lbs (horizontal);	W_T =	0 lbs (vertical)
E_h =	Earthquake Load =	0 lbs (horizontal);	E_v =	0 lbs (vertical)

Load Combinations - Strength Design (LRFD) (see ASCE 7-22, Chapter 2.3)

Number	Combination	Horizontal (lbs)	Vertical (lbs)
Combination 1a =	$1.4D$	- lbs	2,131,684 lbs
Combination 2a =	$1.2D + 1.6L + (0.5L_r$ or $0.3S$ or $0.5R)$	- lbs	2,210,058 lbs
Combination 3a =	$1.2D + (1.6L_r$ or $1.0S$ or $1.6R) + (L$ or $0.5W)$	- lbs	2,228,438 lbs
Combination 4a =	$1.2D + 1.0(W$ or $W_T) + L + (0.5L_r$ or $0.3S$ or $0.5R)$	168,000 lbs	2,002,810 lbs
Combination 4b =	$1.2D + 0.5W + 1.0F_a + L + (0.5L_r$ or $0.3S$ or $0.5R)$	110,765 lbs	1,110,434 lbs
Combination 5a =	$0.9D + 1.0(W$ or $W_T)$	168,000 lbs	1,283,120 lbs
Combination 5b =	$0.9D + 0.5W + 1.0F_a$	110,765 lbs	390,744 lbs
Combination 6 =	$1.2D + E_v + E_h + L + 0.15S$	0 lbs	2,027,158 lbs
Combination 7 =	$0.9D - E_v + E_h$	0 lbs	1,370,368 lbs

Summary of Load Combinations

Combination Load that controls in the horizontal direction:	168,000 lbs		
Combination Load(s) that control in the vertical direction:	2,228,438 lbs	and	390,744 lbs

Page 1 of 2. See next page for Notes and References

Figure CSB-14. Load and Resistance Factor Design Load Combinations Worksheet for The Valley Apartments

Chapter 5. Elevation and Relocation Techniques

Chapter 5 addresses elevation and relocation techniques for retrofitting flood-prone residences. In general, the techniques discussed in this chapter are considered compliant with the National Flood Insurance Program for retrofitting existing buildings that are Substantially Improved/Substantially Damaged. For this reason, since regulatory compliance is assumed to be required, **the Floodproofing Design Depth (H) used in Chapter 5 will be determined by the Design Flood Elevation** in accordance with ASCE 7-22 (see Section 3.1.1). The techniques in this chapter are passive measures that do not require human intervention to be effective.



Note

For discussion purposes, this chapter makes the following distinctions regarding elevation techniques.

Structural Elevation (Section 5.1): Structural elevation involves raising the entire structure so that the lowest floor is at or above the Design Flood Elevation. All structural elevation techniques are National Flood Insurance Program-compliant for existing and new construction. Structural elevation can be accomplished using a wide range of foundation types. Structural elevation is usually limited to existing detached single-family homes with basic floor plans and sufficient site space to allow for placement of lifting beams.

Elevation Alternatives (Section 5.2): Elevation alternatives are typically used for buildings where structural elevation is not technically feasible, including existing multi-family homes, attached townhouses or row houses, or buildings with complex floor plans on limited site clearances. Elevation alternatives involve retrofitting techniques that effectively elevate the lowest floor at or above the Design Flood Elevation or flood protection level without raising the entire structure. All alternative elevation techniques are National Flood Insurance Program-compliant for existing buildings. However, some techniques may not achieve ordinance and code compliance for Substantially Improved/Substantially Damaged buildings or new construction; these techniques have the option to elevate to the flood protection level that may be lower than the Design Flood Elevation (see Section 3.1.2).

5.1. Structural Elevation

One of the most common retrofitting techniques is elevation of the existing lowest floor above the Design Flood Elevation. When properly done, elevation of a residence results in the lowest floor (living area) being raised above the base flood, at a minimum, and more severe floods, if elevated to a higher Design Flood Elevation or above.

Steps required for structurally elevating a building are similar for all foundation types. A cradle of steel beams is inserted under (or through) the structure; jacks are used to raise the beams and structure to the desired height; a new, elevated foundation for the house is constructed; utility

systems are extended and modified; and the structure is lowered back onto the new foundation and reconnected.

While the same basic elevation techniques are used in all situations, the final siting and appearance of the house will depend on the type of new foundation and its height. The elevation process includes planning, budgeting, permitting, construction, and site stabilization.

The most critical aspects of an elevation project are preparation of the house for lifting and construction of a new, adequately designed, and elevated foundation. The elevation process becomes more complex for homes with added weight, height, or complex design or shape of the house. Brick or stucco veneers may require removal prior to elevation. Building additions may need to be elevated independent of the main structure.

It should be noted, there are alternative elevation options that are typically more complex projects that can involve elevation over an abandoned or filled basement, elevation of a slab-on-grade home, elevation of brick or stone veneer homes, and elevations on driven piles in coastal areas. During the past two decades, elevation costs have risen significantly due to increased material and labor costs. In some instances, elevation may be more expensive than demolishing the existing home and replacing it with a building fully compliant with National Flood Insurance Program requirements. Because material and labor costs vary greatly geographically, it is best to estimate an elevation project cost using detailed construction cost estimation software after many of the retrofit options are eliminated and once an optimal elevation method has been selected.

5.1.1. RESIDENTIAL STRUCTURE ELEVATIONS BY FOUNDATION TYPE

Structural elevation of simple residential buildings by foundation type is listed in order of technical complexity, starting with the straightforward and ending with the most complex:

- Houses over a crawlspace
- Houses with basements
- Houses on piers or columns
- Houses on piles
- Houses on backfilled stem walls
- Houses on a slab-on-grade

Each foundation type is examined in the subsections that follow. Regardless of foundation type, the designer must account for multiple (non-flood-related) hazards, such as wind and seismic forces. The methods used to elevate different home types are illustrated.

Houses elevated using solid foundation walls as opposed to piers, columns, or piles to raise the lowest floor to or above the Design Flood Elevation must include openings to allow automatic entry and exit of floodwater. Guidance on design and installation of flood vents can be found later in this section.



Note

Figures 5-1 through 5-5 show the elevation of a home on extended solid foundation walls. Subsequent figures for various elevation techniques will include only those illustrations unique to that technique.

Crawlspace Foundations

Existing houses on crawlspace foundations can be the simplest and least expensive to elevate. They are usually detached one- or two-story houses built on a masonry crawlspace wall. This allows for placement of steel beams under the house for lifting. The added benefit is that, since most crawlspaces have low clearance, most utilities (heat pumps, water heaters, air conditioners, etc.) are not under the home; thus, limiting the need to relocate utilities. Houses over a crawlspace can be:

- Elevated on extended solid foundation walls (see Figures 5-1 through 5-5); or
- Elevated on an open foundation such as masonry piers (see Figures 5-6 through 5-8).



Note

When elevating a house on masonry piers, consider placing the piers on a continuous concrete grade beam to provide greater resistance to hydrodynamic loads and other lateral forces.

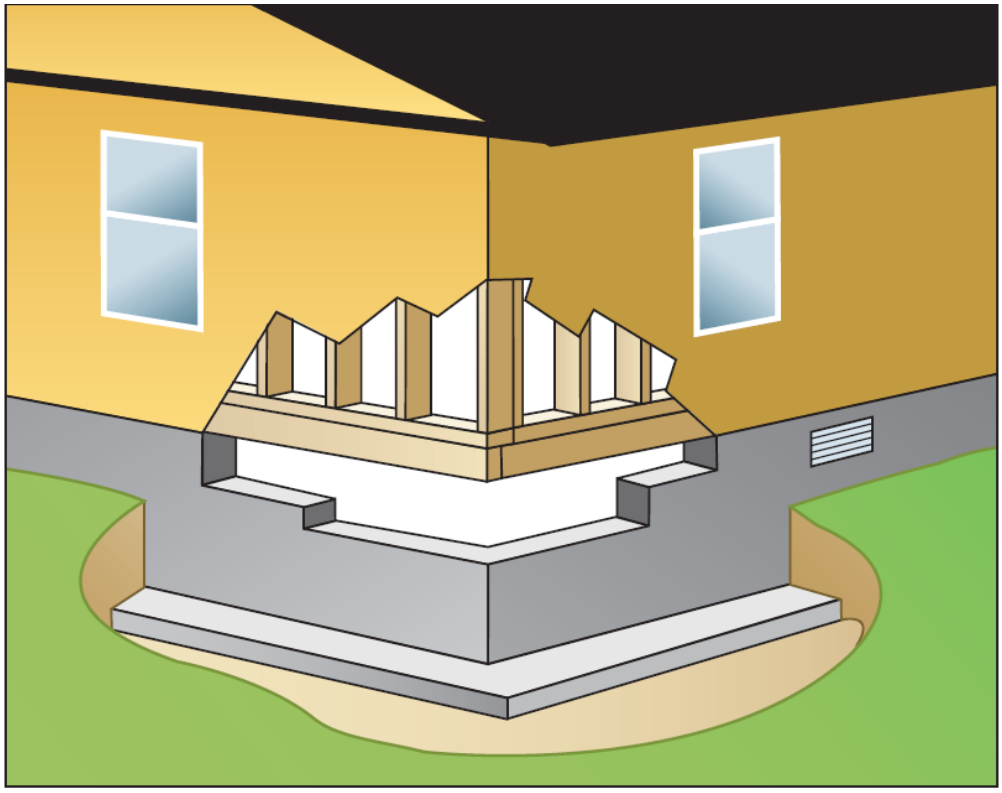


Figure 5-1. Existing wood-frame house on crawlspace foundation to be elevated with extended walls and piers

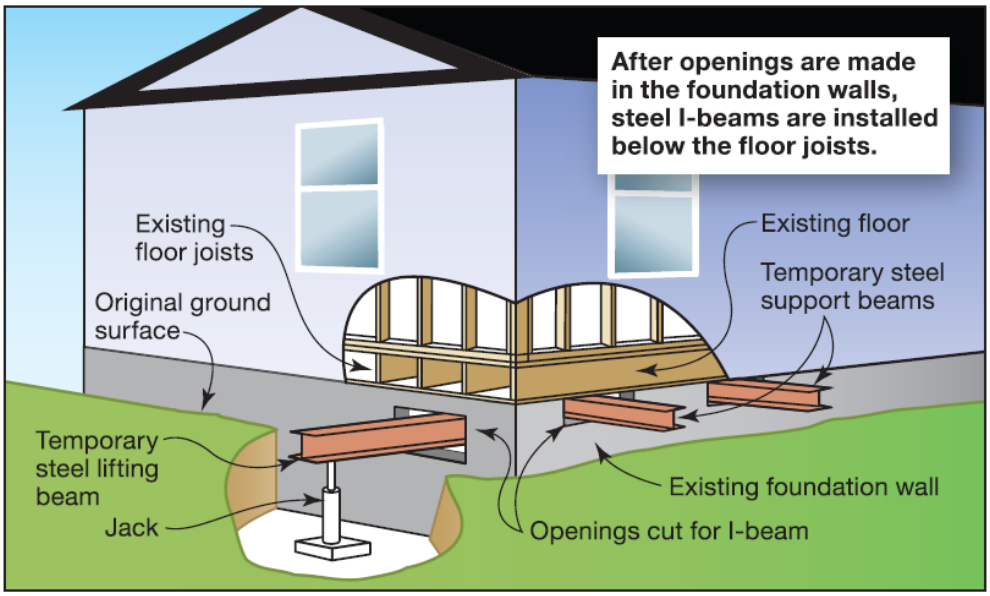


Figure 5-2. Step 1 of elevating an existing wood-frame house on extended foundation walls and piers: Install network of steel I-beams

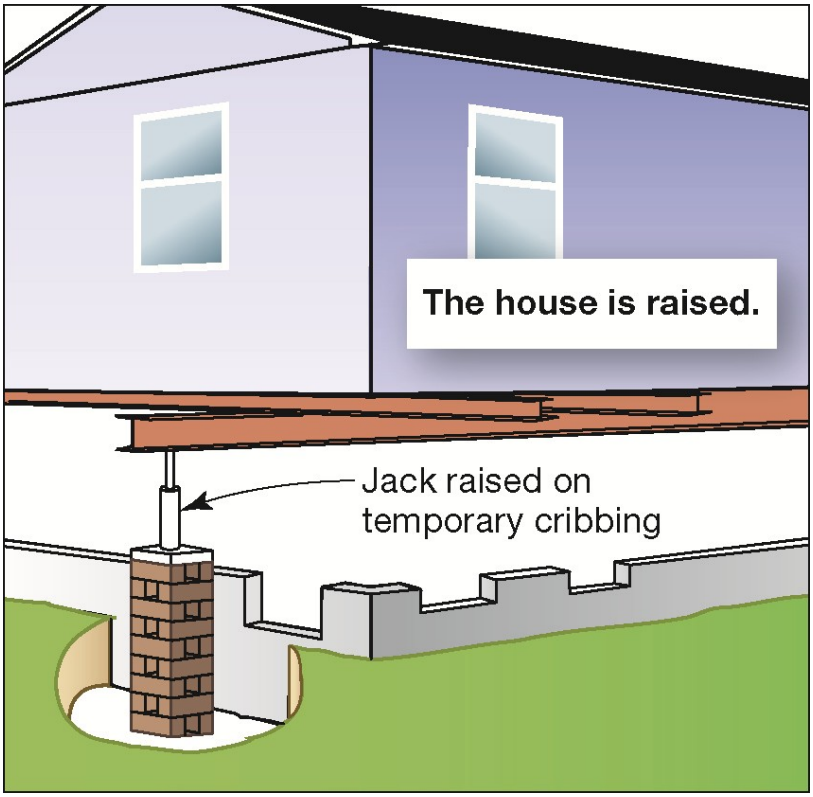


Figure 5-3. Step 2: Lift house and extend foundation walls and piers (reinforce as needed); relocate utility and mechanical equipment above flood level

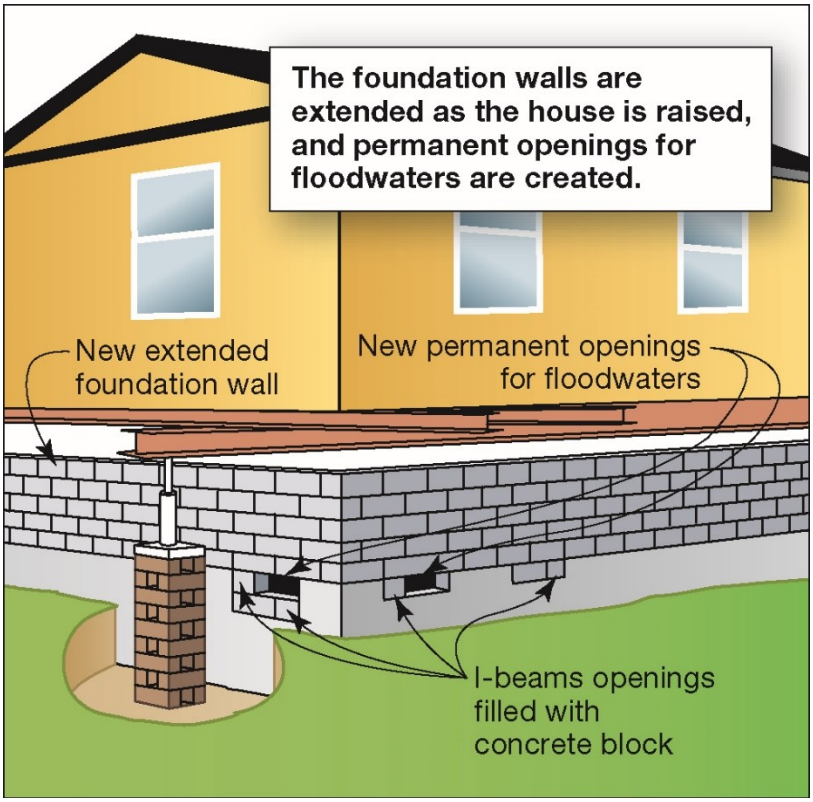


Figure 5-4. Step 3: Set house on new extended foundation and remove I-beams

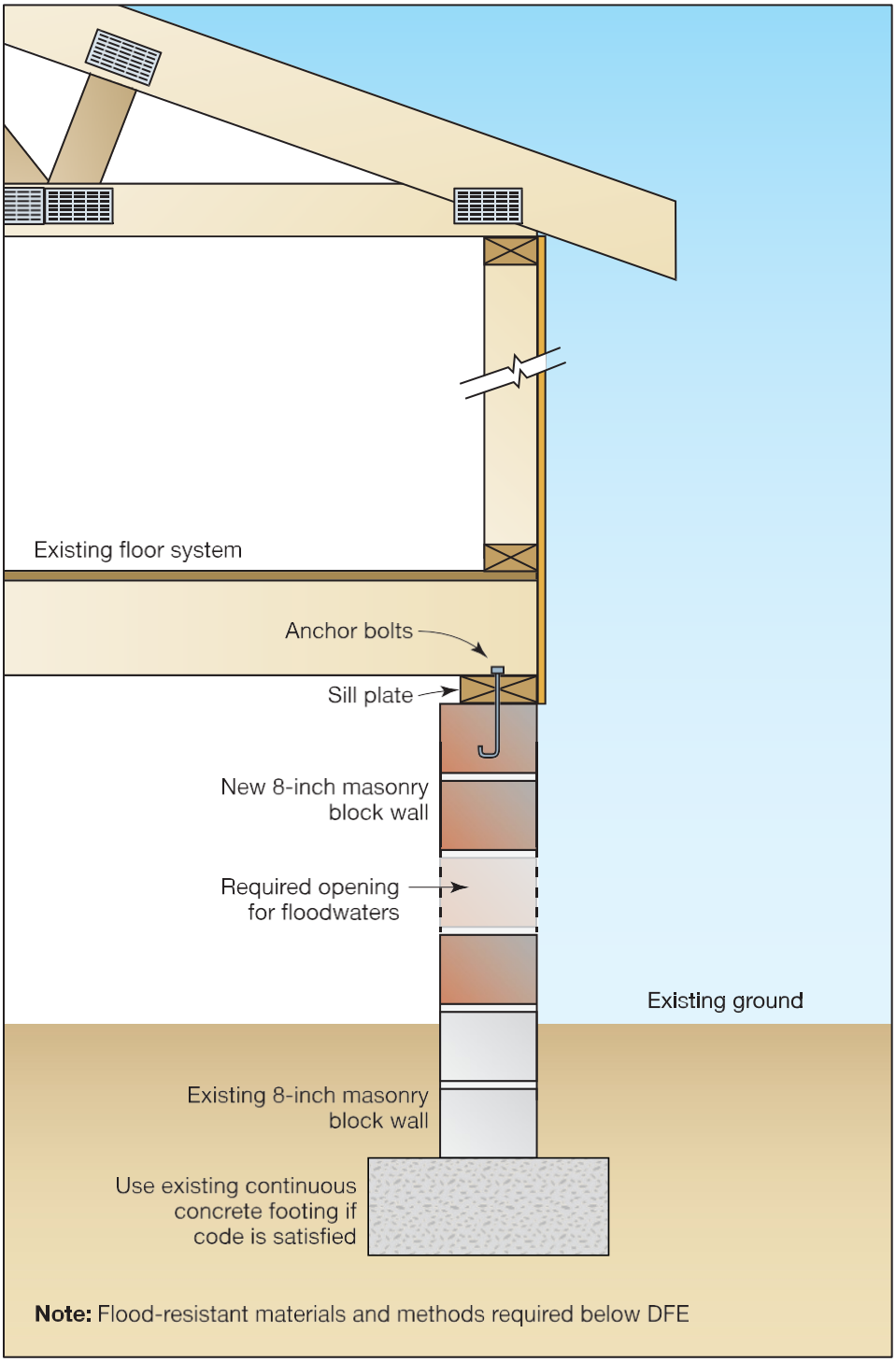


Figure 5-5. Cross-section of elevated wood-frame house on extended piers and crawlspace walls

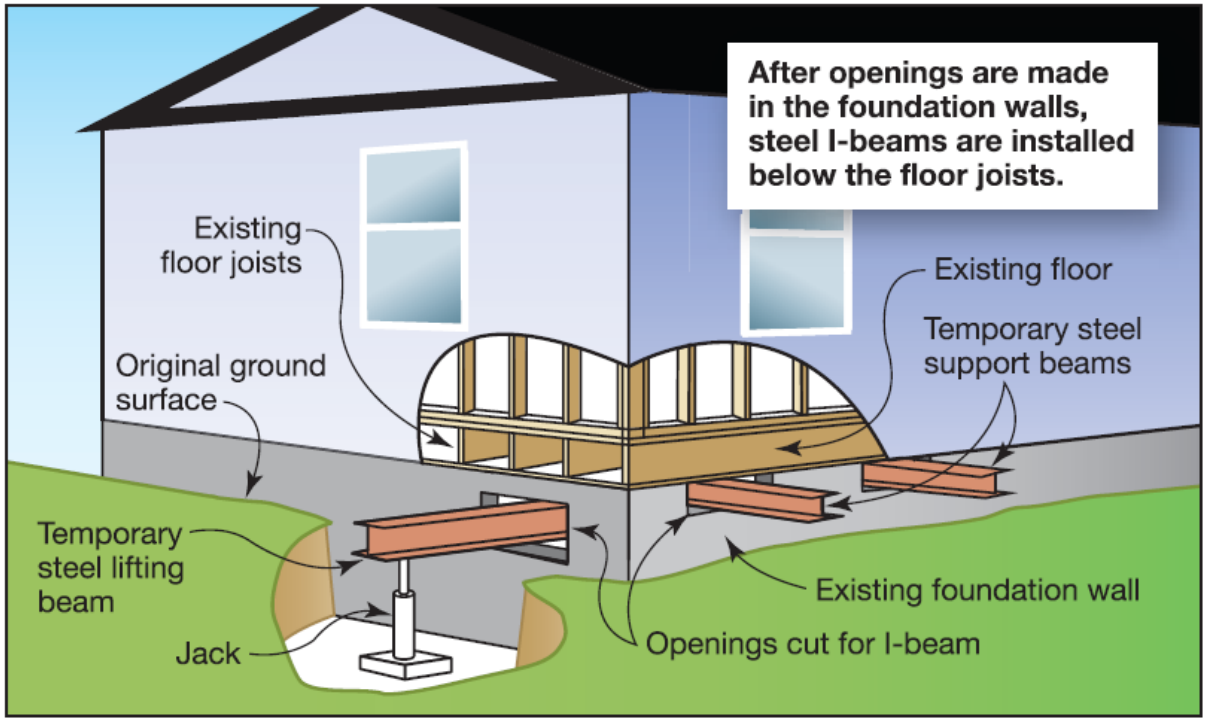


Figure 5-5. Step 1 of elevating an existing wood-frame house on new or extended pier foundations: Install network of steel I-beams. Step 2 (not shown): Lift house, rebuilding or extending (reinforce as needed) piers; relocate utility and mechanical equipment above flood level

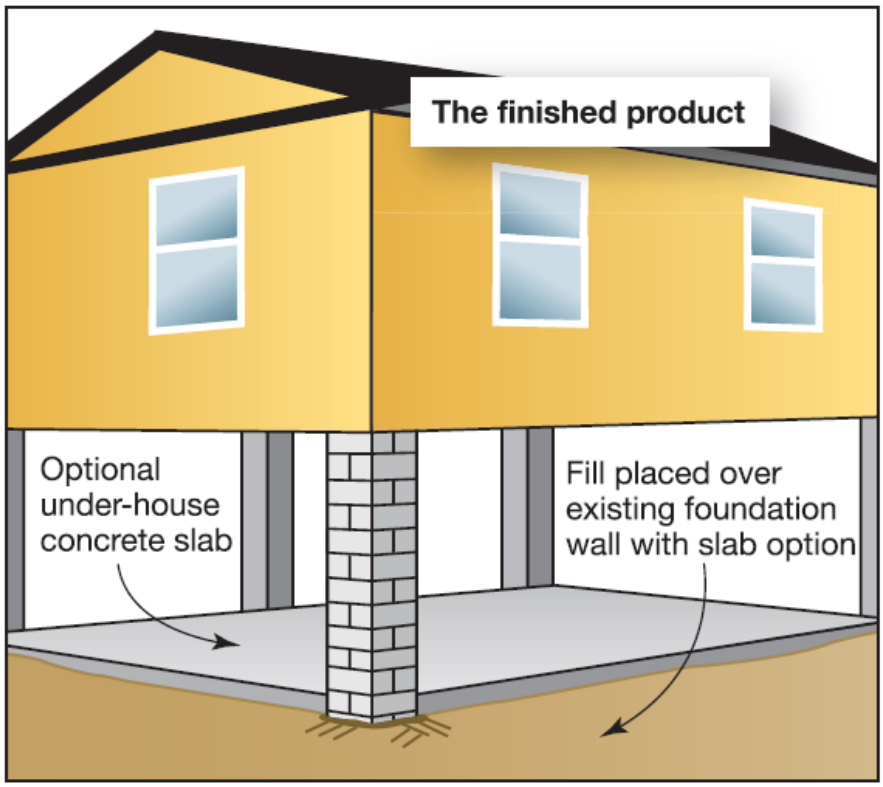


Figure 5-6. Step 3 of setting the house on new or extended piers

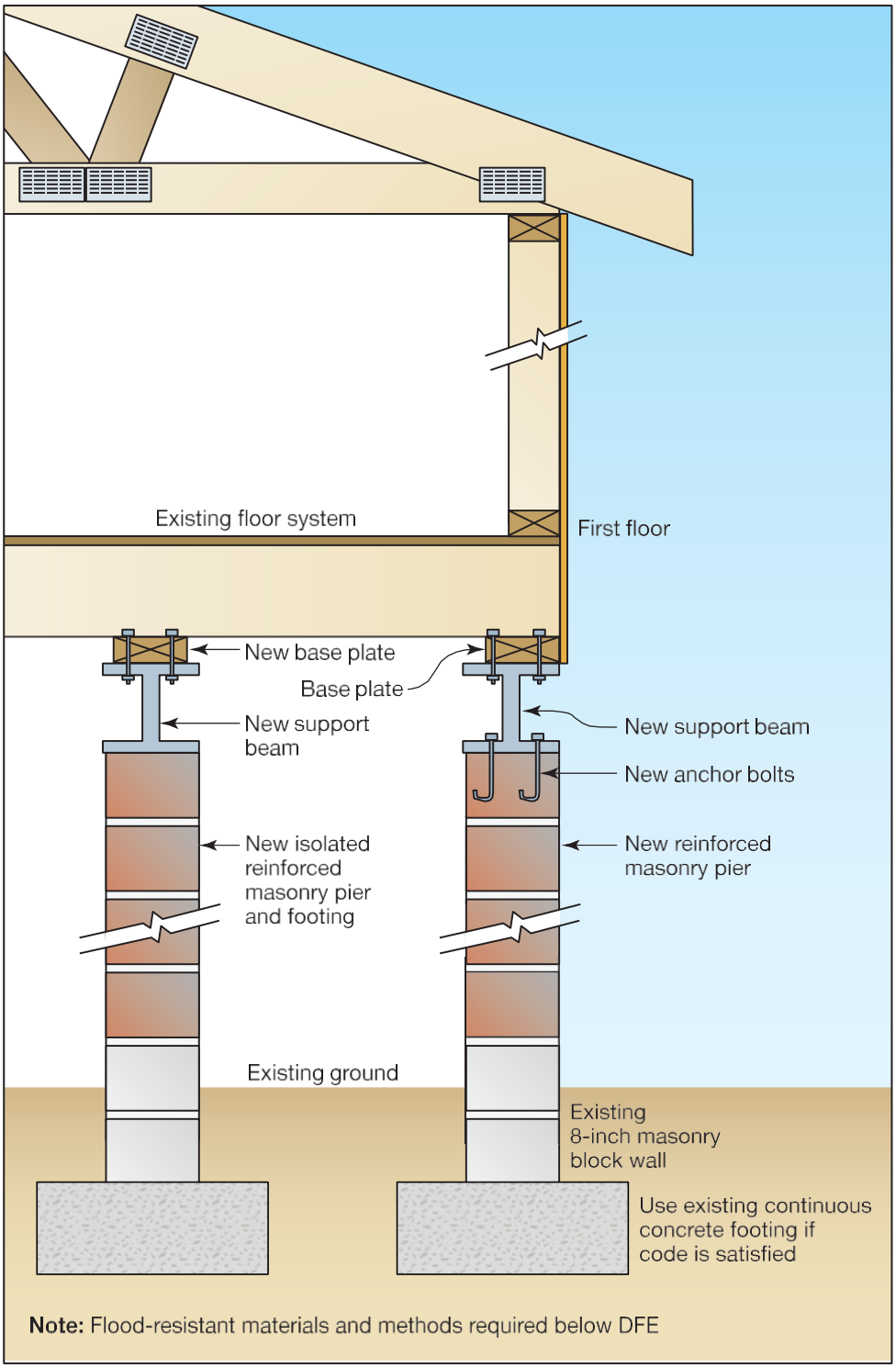


Figure 5-8. Cross-section of elevated wood-frame house on new or extended pier foundation

These issues must be addressed when elevating a home on extended crawlspace foundation walls:

- Add hydrostatic openings at the base of the foundation walls to equalize hydrostatic pressure.

- Adjust or relocate existing utilities within the crawlspace to protect them from flooding.
- Limit use of the lowest floor enclosure within the extended foundation walls to vehicle parking, building access, and storage.

Cross Reference

Additional information on foundation wall opening design and adjustment of existing utility systems can be found in Section 6.1, Wet Floodproofing.

The designer must check additional bending stress on the extended foundation walls (see Figures 5-9 and 5-10). If the existing foundation walls are constructed of unreinforced masonry block, it is likely that the existing walls will not be able to withstand additional lateral and bending stresses unless steel reinforcing bars grouted into the voids of the masonry blocks are added.

For example, a simplified analysis of a one-story house elevated on an 8-inch-thick unreinforced cement masonry unit crawlspace wall extended to a height of eight feet, exposed to a design flood depth of six feet with a design wind speed of 120 mph, resulted in a bending moment on the wall of 2,224 foot-pound per linear foot (lbs./LF) of wall. However, the allowable bending stress of the 8-inch-thick unreinforced concrete masonry unit wall is only 773 lbs./LF. The existing wall cannot withstand the bending moment stresses from design flood and wind forces. This challenge can be addressed by reinforcing the 8-inch-thick unreinforced concrete masonry unit walls with #5 steel reinforcing bars placed at 12 inches on center vertically, while grouting both the reinforced and unreinforced concrete masonry unit cells.

Note

Although elevating a house increases exposure to wind loads, it will not result in a significant wind load increase since wind loads do not typically increase significantly with heights less than 30 feet above the ground.

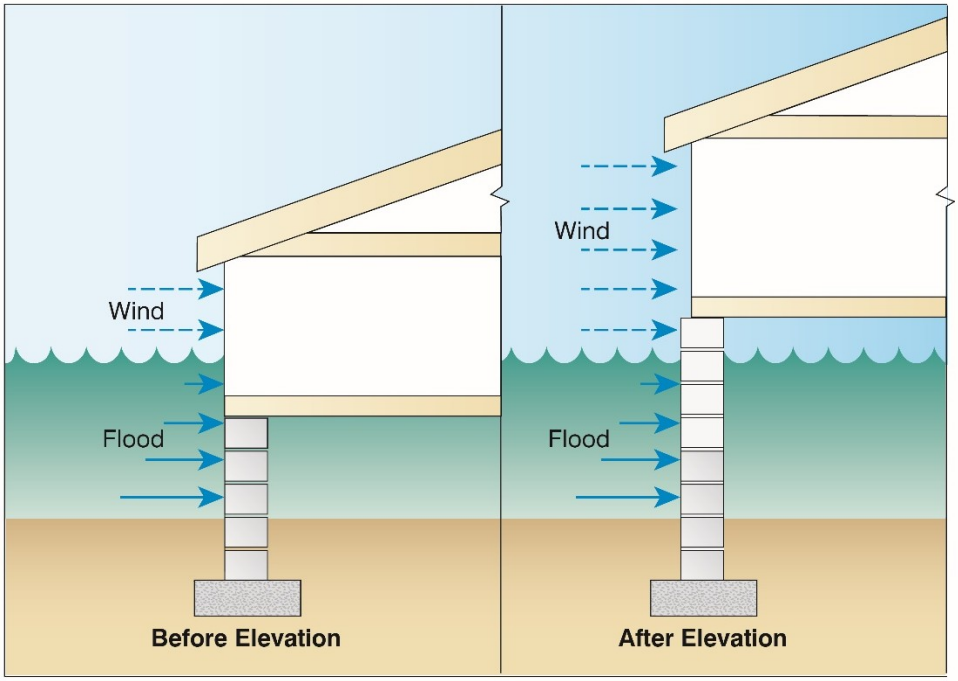


Figure 5-7. Increased wind exposure on a wood-frame house elevated on extended foundation walls

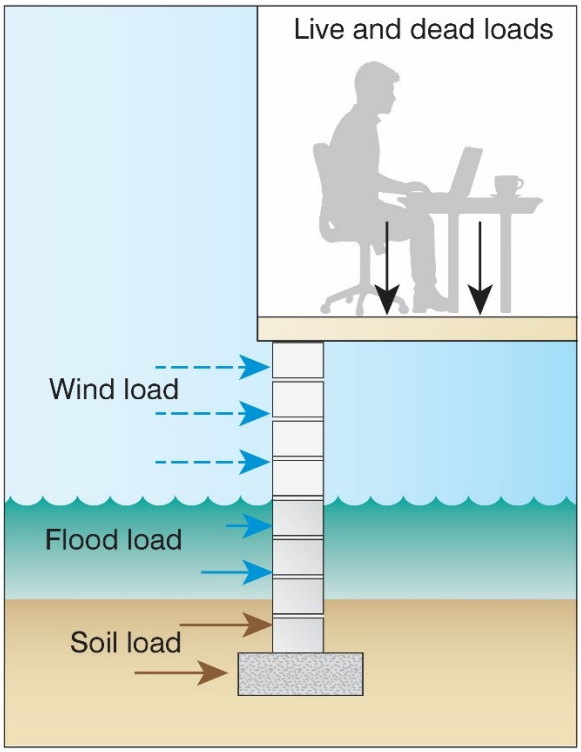


Figure 5-8. Combined effects of lateral, axial, and bending stresses on extended foundation walls

Basement Foundations

Houses on basement foundations are more difficult to elevate because mechanical and HVAC equipment is usually located in the basement. In addition, basement walls may already be extended to the point where they cannot structurally withstand flood forces. Houses over basements can be:

- Filled to grade, with hydrostatic openings added to the portions of the walls extending above grade.
- Elevated on solid foundation walls by creating a new masonry-enclosed area on top of an abandoned and filled-in basement (see Figures 5-11 and 5-12).
- Elevated on an open foundation, such as masonry piers, after filling the basement to grade (see Figures 5-13 and 5-14).

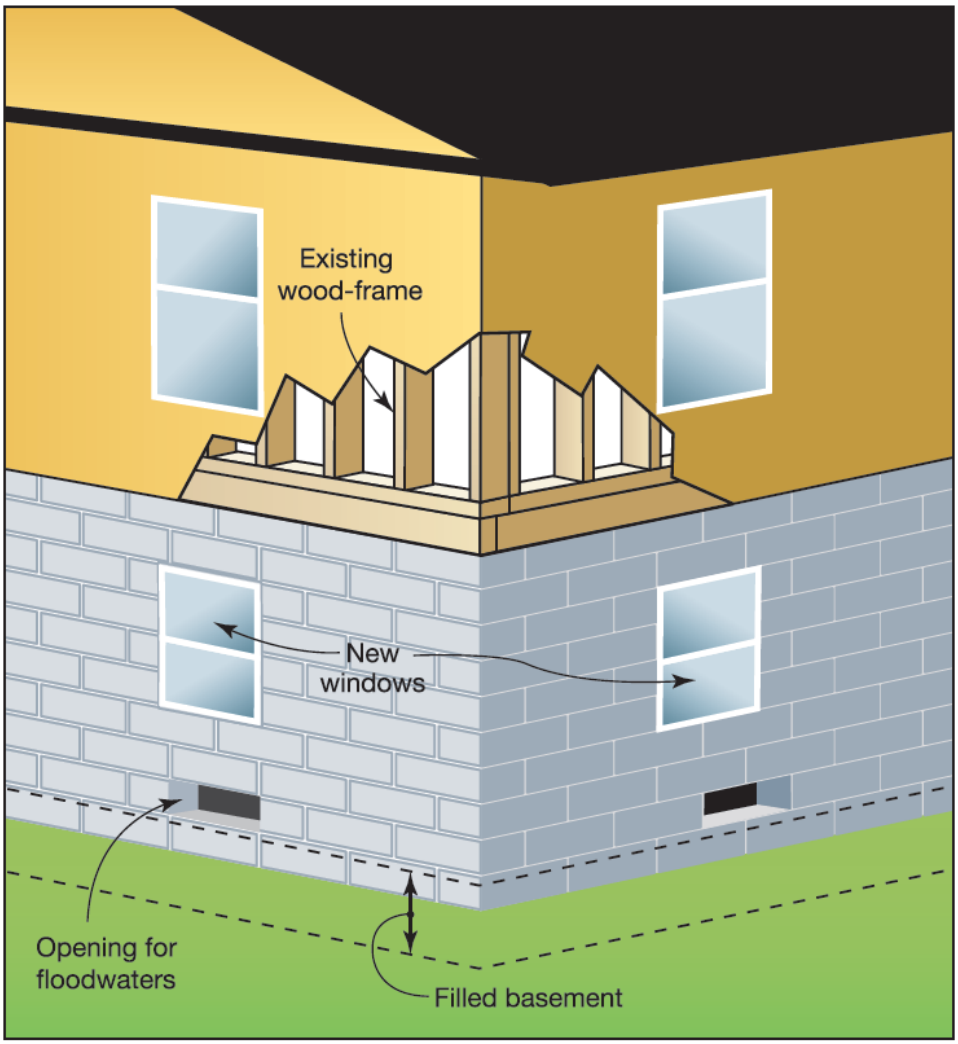


Figure 5-9. Elevated wood-frame house with a new masonry-enclosed area on top of an abandoned and filled-in basement. Utility and mechanical equipment must be relocated above the base/design flood level

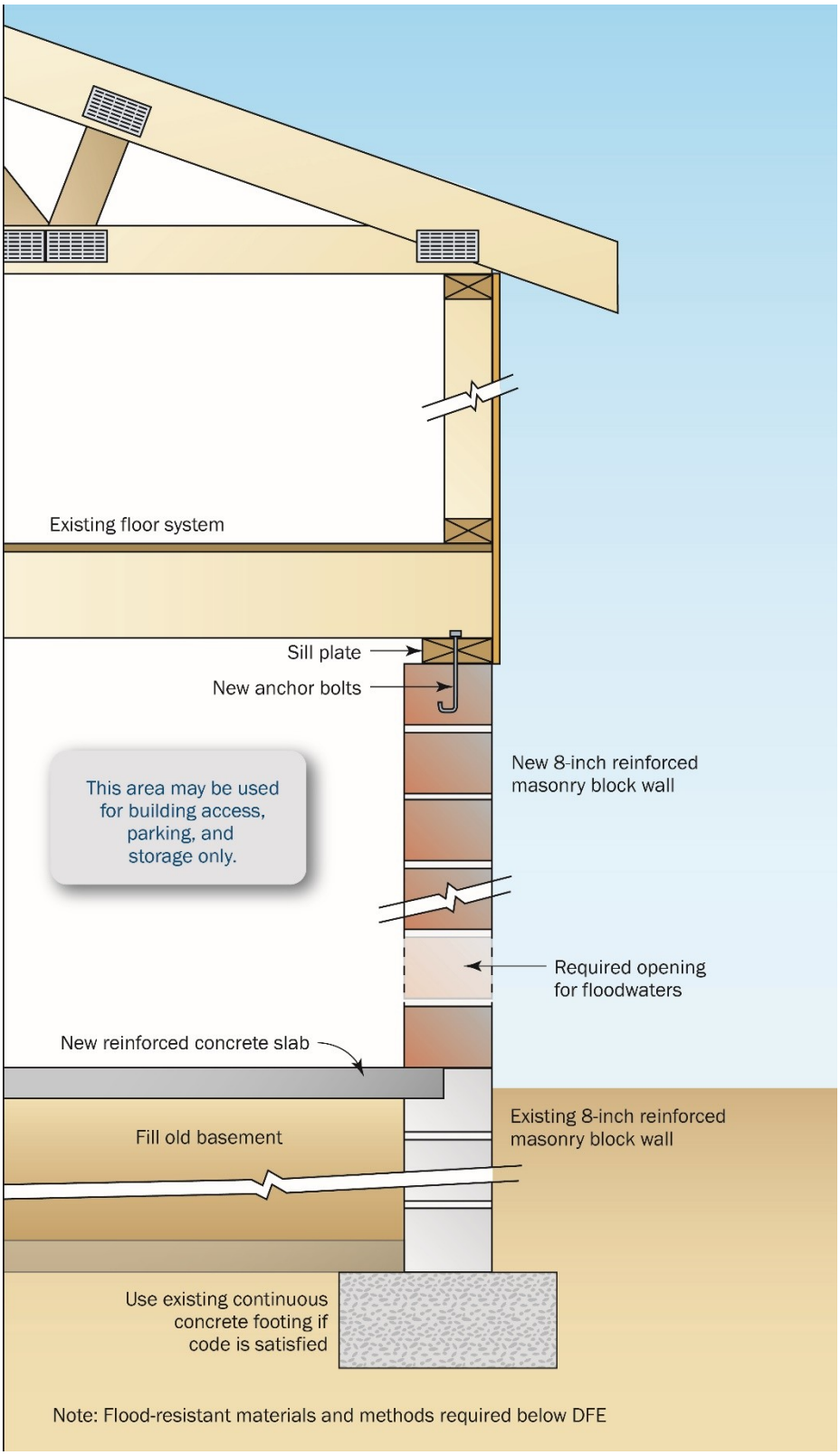


Figure 5-10. Cross-section of elevated wood-frame house with extended masonry-enclosed area on top of an abandoned and filled basement

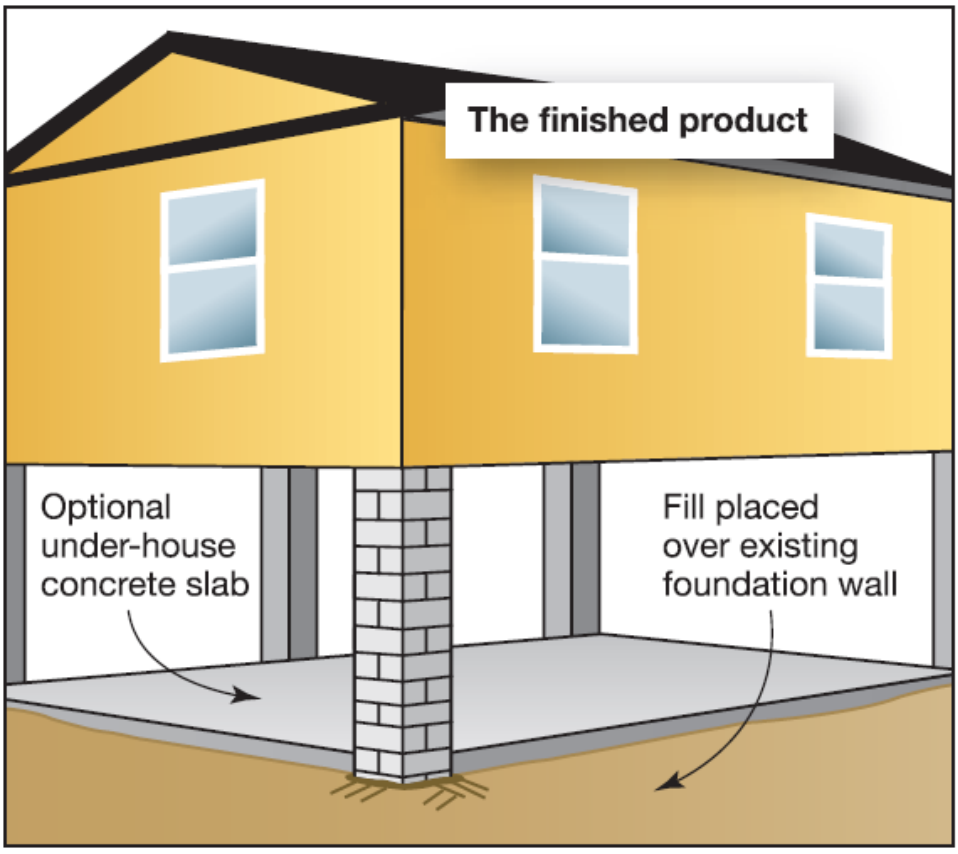


Figure 5-11. Elevated wood-frame house set on new reinforced piers on top of the existing filled-in basement

Note

Section 5.1.1 addresses the traditional structural elevation of a house with a basement foundation by backfilling in the basement and raising the structure's first floor on walls or piers. An alternative to this approach that also accomplishes elevation is to simply backfill the basement to grade but leave the first floor elevation unchanged. This alternative basement infill approach is discussed in Section 5.2.1.

Cross Reference

Elevation of an existing house over a basement will require filling the basement. Basement fill is considered an "elevation alternative" and is covered in Section 5.2.1.

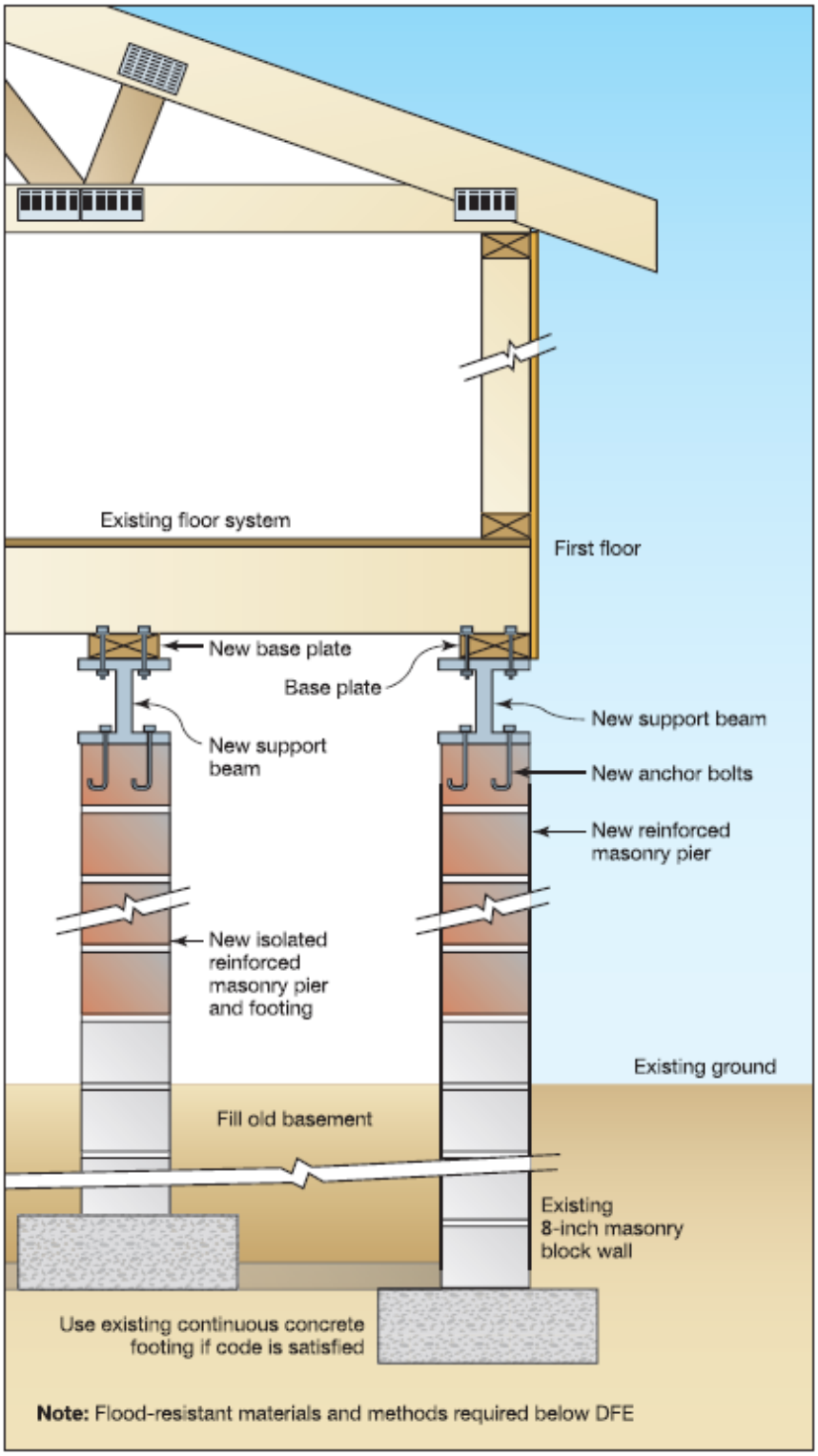


Figure 5-12. Cross-section of elevated wood-frame house on new reinforced piers on top of the existing filled-in basement

Design of Openings in Foundation Walls for Intentional Flooding of Enclosed Areas Below the Design Flood Elevation

It is important that foundation walls contain openings that allow automatic entry and exit of floodwater for buildings constructed on extended solid foundation walls or that have other enclosures below the Design Flood Elevation (see Figure 5-15).

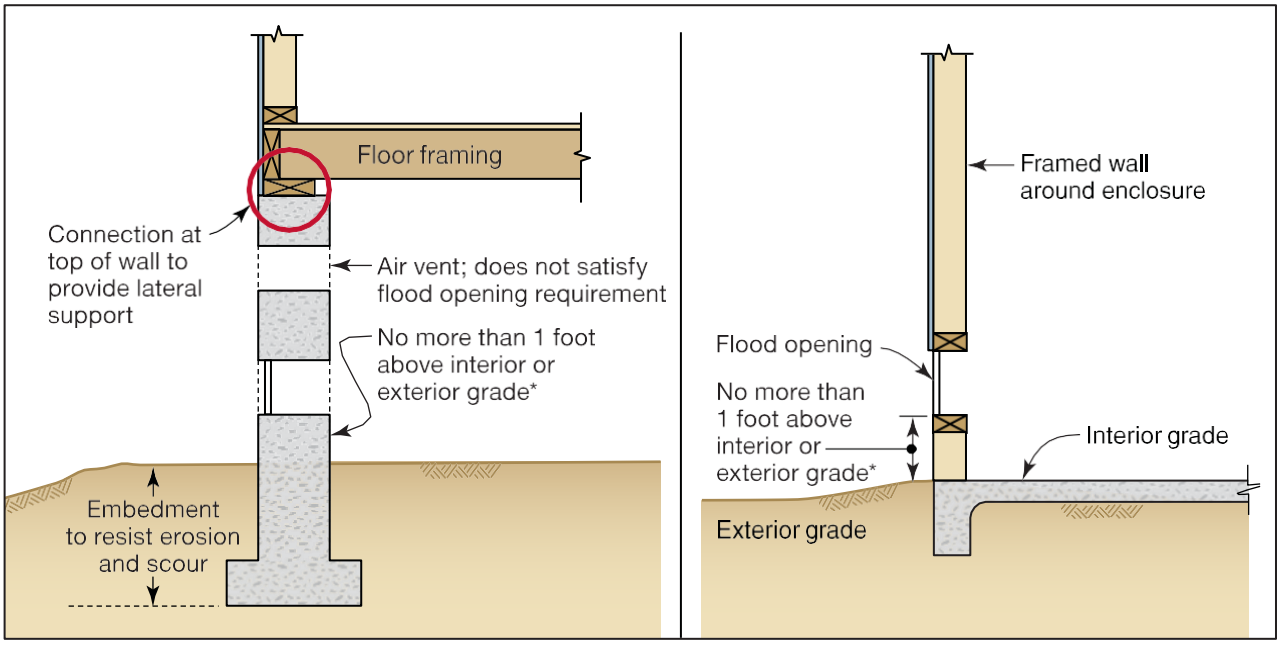


Figure 5-13. Typical opening for solid foundation wall

Openings allow floodwater to equalize on both sides of the walls, lessening potential damage from hydrostatic pressure. While there is no requirement for existing buildings built prior to the community's participation in the National Flood Insurance Program or if initially constructed outside of a Special Flood Hazard Area, floodplain management regulations and building codes require flood openings for all new construction and substantial improvements of existing buildings in Special Flood Hazard Areas.

The minimum design criteria for openings are:

- A minimum of two openings must be provided on at least two sides of each enclosed area, having a total net area of not less than one square inch for every square foot of enclosed area subject to flooding; fewer openings are necessary for engineered and certified flood vents.
- The bottom of all openings shall be no higher than one foot above grade.
- Openings may be equipped with screens, louvers, or other coverings or devices if automatic entry and exit of floodwater is allowed and the net open area below Base Flood Elevation/Design Flood Elevation is not reduced to less than the required area of the opening.

It is important to make sure that flood openings will not be obstructed during a flood. In wet floodproofed buildings, openings can be obstructed by drywall or other wall coverings (Figure 5-16), resulting in significant foundation damage if the opening does not operate as intended. Figure 5-17 shows an National Flood Insurance Program-compliant house with attached garage with flood openings that prevent the build-up of hydrostatic loads on the foundation walls.

Cross Reference

For additional information on regulations and design guidelines for foundation openings, refer to FEMA's National Flood Insurance Program Technical Bulletin 1, Requirements for Openings in Foundation Walls and Walls of Enclosures Below Elevated Buildings Located in Special Flood Hazard Areas in Accordance with the National Flood Insurance Program (FEMA, 2020).



Figure 5-16. A house with flood openings covered by insulation and drywall, which is a National flood Insurance Program violation

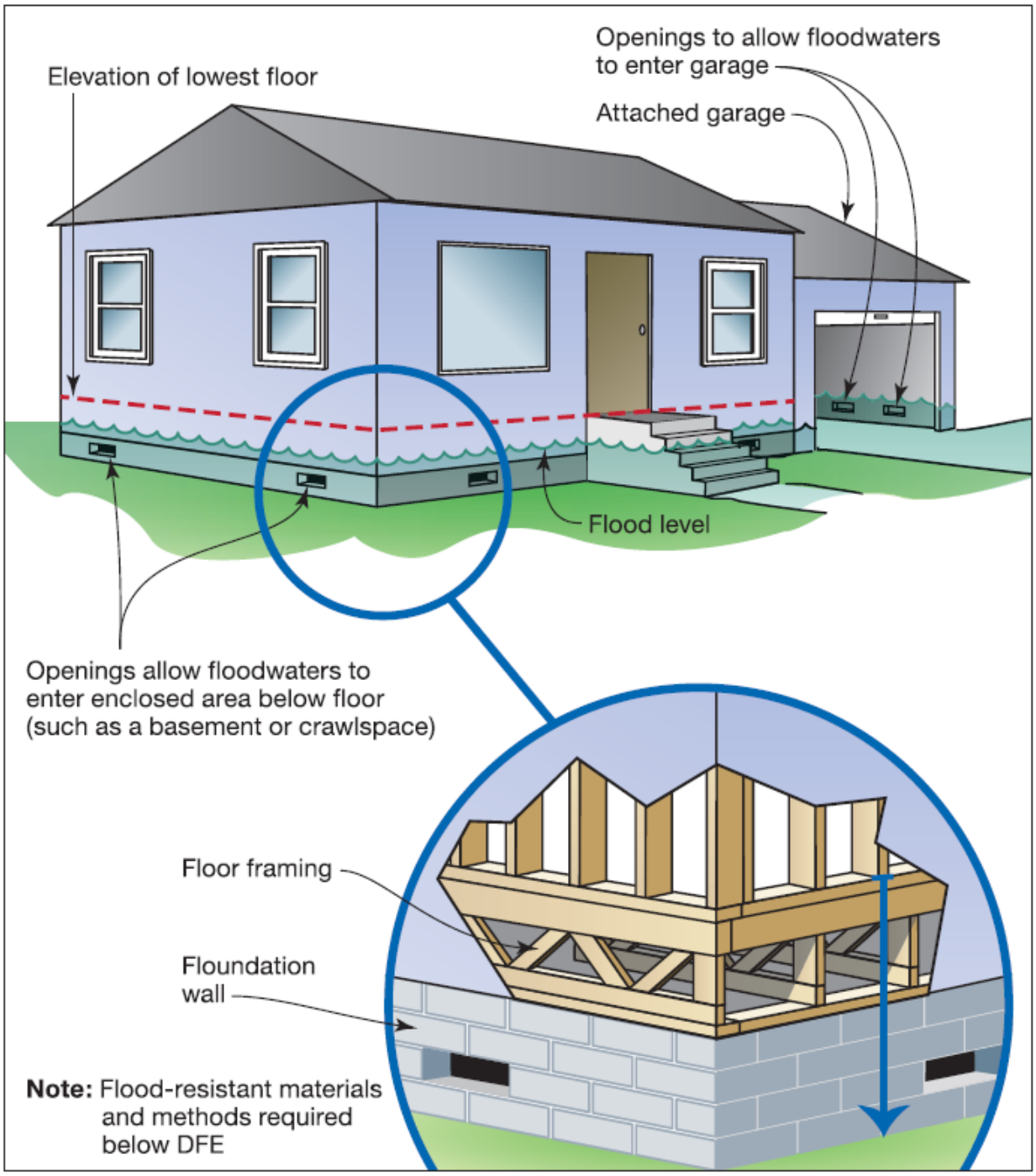


Figure 5-14. National Flood Insurance Program-compliant house built on solid foundation walls with attached garage

Piers or Column Foundations

Elevating an **existing house on piers or columns** is slightly more complex because the house may need to be relocated adjacent to the new foundation rather than lifted in place. With pier foundations, the house may need to be lifted off the existing foundation and temporarily placed

elsewhere on the building site. The existing foundation is then removed, piers or columns are built, and the house is placed on the new foundation. In some instances, raising the home above the new foundation construction area (instead of relocating off to the side) may provide sufficient room to install new piers or columns or extend existing piers or columns.

When elevating a home on piers or columns, the following issues must be addressed:

- Sufficient pier/column strength to resist lateral loads and connections to resist lateral and vertical loads (see Figure 5-18).
- Piers/columns may need to be braced to reduce lateral movement of the building.
- Concrete Masonry Unit or concrete piers/columns will have little lateral flexibility.
- Piers/columns are subject to collapse if struck by wind or flood-borne debris (see Figure 5-19).



Figure 5-15. House failed due to inadequate connections between pier foundation and structure during Hurricane Katrina in Harrison County, MS. The combination of buoyancy forces and storm surge displaced this home after separating it from the foundation piers.



Figure 5-16. Collapsed masonry piers with shallow footings in Mississippi from Hurricane Katrina Mitigation Assessment Team report

Pile Foundations

Elevating an **existing house on piles** is more complex because piles are deep foundation members that require significant equipment to drive them into the ground. The major advantage of elevating a house on a pile foundation is increased protection from significant damage from riverine floods and coastal floods. Pile foundations perform better than piers against hydrostatic, hydrodynamic, and coastal wave forces and flood-borne debris (see Figure 5-20).

When elevating a home on piles, the following issues must be addressed:

- Piles can be driven into the ground with a hydraulic pile driver, placed in holes pre-drilled by an auger, or jetted into place using pressurized air or water. Driven piles take the most effort and cost more to install than jetting or augering, but driven pile capacities will be higher than with jetting or augering installation methods. Additionally, while jetting piles may be done under an existing structure, there is a risk that the piles can kick back upwards and damage the structure.

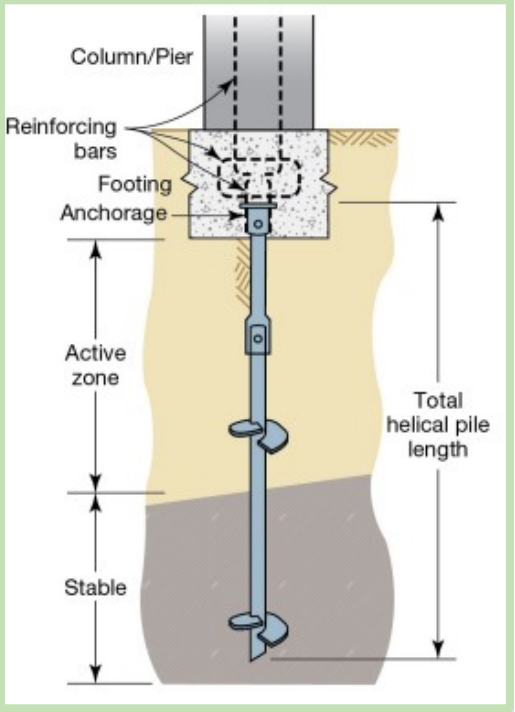
- The existing house must be typically moved off its existing footprint to allow for pile-driving equipment to install driven piles. As an alternative to driven piles, designers may want to consider helical piles, especially where site access and vertical and horizontal clearances are limited (see Note below for details).

- Regardless of type or installation method, piles must be sufficiently sized and embedded to resist lateral and vertical (uplift) loads from flood and wind.

- Piles that extend above grade may require cross braces, knee braces, or grade beams to reduce lateral movement of the building.

Note

Helical piles are manufactured steel, deep foundation elements consisting of one or more auger helixes connected to a slender central shaft, which is drilled into the ground (see Note Figure). The auger helixes act as the bearing surface to resist compressive forces from the elevated structure. Increased bearing capacities can be provided by using larger diameter helixes or by attaching more piles to the foundation. Lateral resistance must be provided by a strong moment-resisting connection to the foundation; since the helical piles themselves provide little lateral resistance. Helical piles can be a cost-effective solution to deep foundation requirements with limited available access and/or clearances.



For additional information regarding helical piles, refer to FEMA's Hurricane Sandy Recovery Fact Sheet, *Foundation Requirements and Recommendations for Elevated Homes* (FEMA, May 2013).

Note

Although more commonly associated with coastal areas, elevation on piles can be effective at retrofitting in riverine areas subject to deep, high-velocity flooding, erosion and scour, and other high risk flood hazard areas discussed in ASCE 24 Chapter 3.



Figure 5-17. House elevated on piles

Stem Wall (Fill) Foundation

A backfilled stem wall foundation (also called raised-slab-on-grade, and slab-on-stem wall-with-fill) resembles a solid perimeter foundation wall exterior, but is backfilled with compacted structural fill, concrete, or gravel to support the first floor slab and raise the floor above the surrounding grade (Figure 5-21). Backfilled stem wall foundations on fill provide a high degree of flood protection by enhancing the foundation wall strength against hydrostatic forces and raising the first floor to the Design Flood Elevation. Backfilled stem wall foundations should only be used in areas prone to shallow flooding with low erosion potential and where breaking waves do not occur during the Base Flood.

When stem wall foundations are backfilled, flood openings should not be installed (see Figure 5-21).

Note

Elevation Certificates: When the National Flood Insurance Program Elevation Certificate for a building elevated on a backfilled stem wall is completed, the foundation should be described in the form's comment section to clarify that the foundation is not a crawlspace and therefore flood openings are not appropriate. Failure to perform this important documentation may result in future compliance questions by local authorities, state or federal personnel, given visual appearances alone, might conclude the foundation system is in violation of the National Flood Insurance Program.

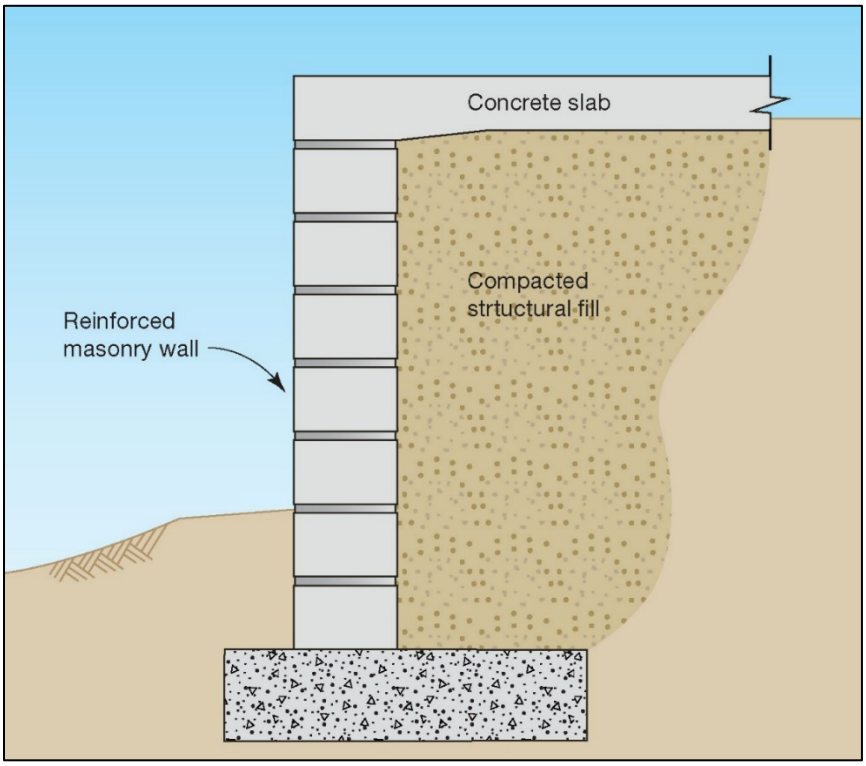


Figure 5-18. Stem wall foundation with backfill; flood openings are not required

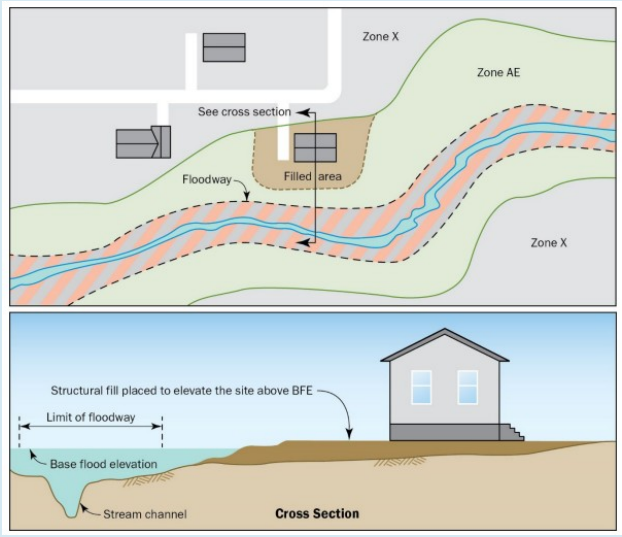
Proper design and placement of fill requires an understanding of local site conditions, soil mechanics, the specific characteristics of the earthen materials used for fill, methods to place and compact the fill to achieve the desired characteristics, and soil testing procedures. When retrofitting an existing building by placing fill inside the stem wall foundation, compacted structural fill considerations include:

- Licensed professionals may be required to design fill placement in Special Flood Hazard Areas intended to support buildings. Communities may require submission of the signed and sealed certification form. Property owners should collaborate with a licensed professional engineer, geotechnical engineer, engineering geologist, or other qualified professional licensed in the state where the building is located, to design the fill.
- The I-Codes and ASCE 24 specifications for site grading, fill compaction, protection from erosion during flooding, and design and performance of structural fill.
- Site preparation before fill placement (e.g., grading and compacting, moisture control).
- Limited clearance for compaction equipment, which can challenge fill placement inside the foundation.
- Heavy compaction equipment close to the wall can exert excessive lateral pressure, potentially causing the wall to bulge, crack, or even collapse. Use of thinner fill lifts and smaller compaction equipment can mitigate potential damage to the wall.
- Fill material may consolidate over time, resulting in settlement. Use of sand and gravel materials may reduce consolidation and facilitate compaction.
- Fill material and underlying soil permeability affect fill infiltration and drainage, which may affect the structure.
- Flowable backfill, also known as Controlled Low Strength Material, is a self-compacting, cementitious material used for backfill or void-fill, and can be used as an alternative to traditional compacted soil.

Warning

This publication recommends avoiding elevation on structural fill in the floodplain as a retrofit option for the following reasons:

1) As illustrated, elevation on structural fill invariably requires demolition of the existing structure, which is not considered new construction.



2) Elevation on structural fill requires compacted soils placed at stable slopes requiring grading ranging from 1:2.5 (vertical to horizontal) and 1:5, depending on soil type. Any significant elevation requires access to suitable fill soil for placement on a large lot extending far beyond the structure.

3) National Flood Insurance Program regulations prohibit the placement of encroachments in floodways including fill that would result in an increase in flood levels [Title 44 CFR Section 60.3(d)(3)]. The Letter of Map Revision Based on Fill (LOMR-F) process cannot be used for properties or structures that have been elevated by fill placed within the regulatory floodway [Title 44 CFR Section 65.5(a)]. All Letter of Map Change requests involving the placement of fill in floodways must go through the Conditional Letter or Map Revisions (CLOMR) and Letter of Map Revision (LOMR) processes [Title 44 CFR Section 65.7]. See National Flood Insurance Program Technical Bulletin 10, *Reasonably Safe from Flooding Requirement for Building on Filled Land* for more information on the placement of fill.

Slab-on-Grade Foundations

Slab-on-grade houses can be the most challenging to elevate because just two complex options are available to raise the structure.

Slab Separation (Recommended): The first option is to raise the house without the slab and construct a new elevated wood or concrete first floor. Figures 5-22 through 5-26 show the process of elevating a wood-frame house without the slab, using a new first floor constructed of wood trusses. Elevation by slab separation involves intrusive placement of beams through the structural walls (see Figure 5-27). Additionally, since the existing slab remains in place, the house must be detached from the slab, the structure is raised separately from the slab, and a new floor system is built above the new, elevated foundation. Despite the complexity of the process, elevation of slab-on-grade homes by slab separation is successful. This option is considered best practice for slab-on-grade elevations.

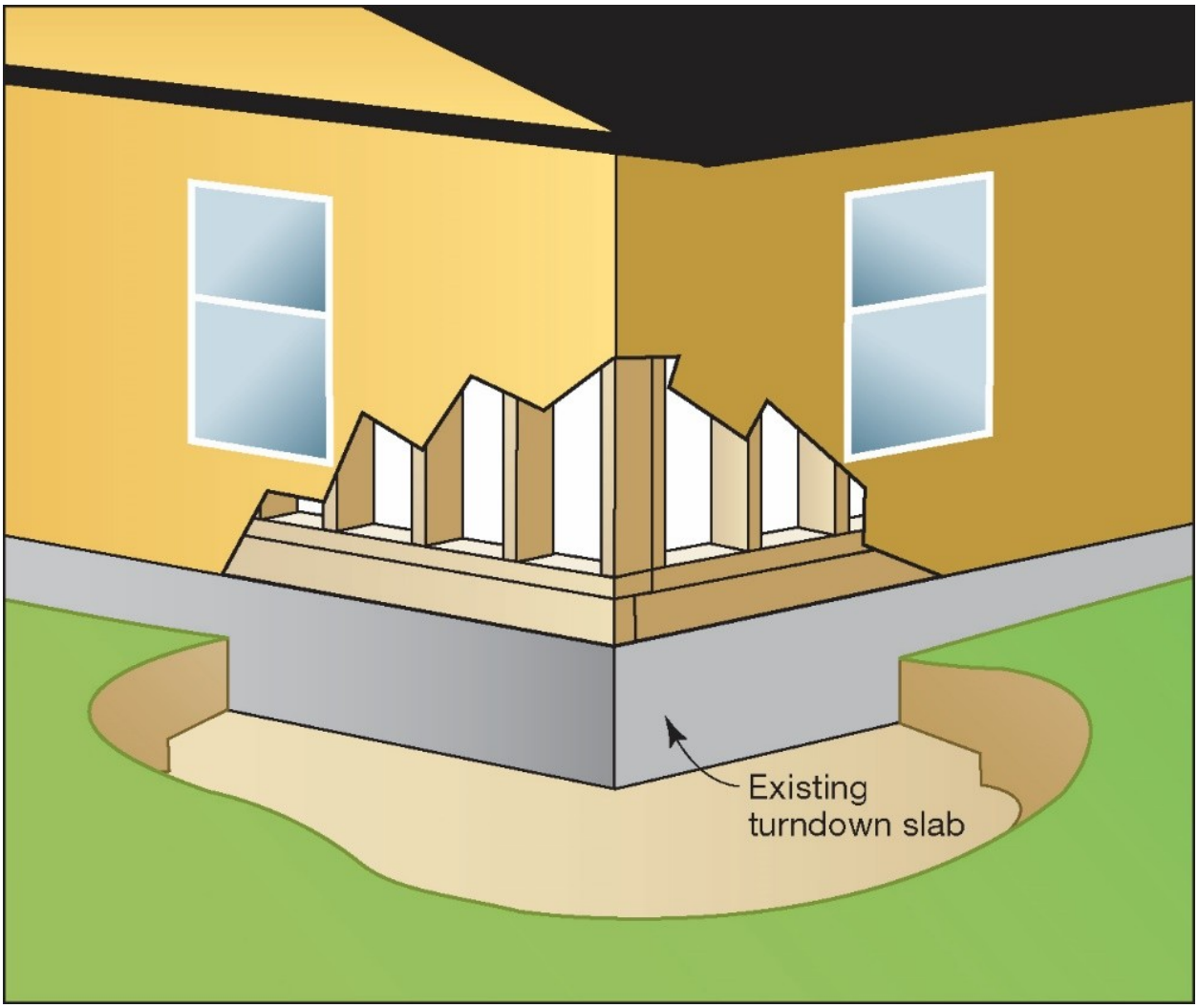


Figure 5-19. Existing wood-frame house with slab-on-grade foundation, shown just below grade

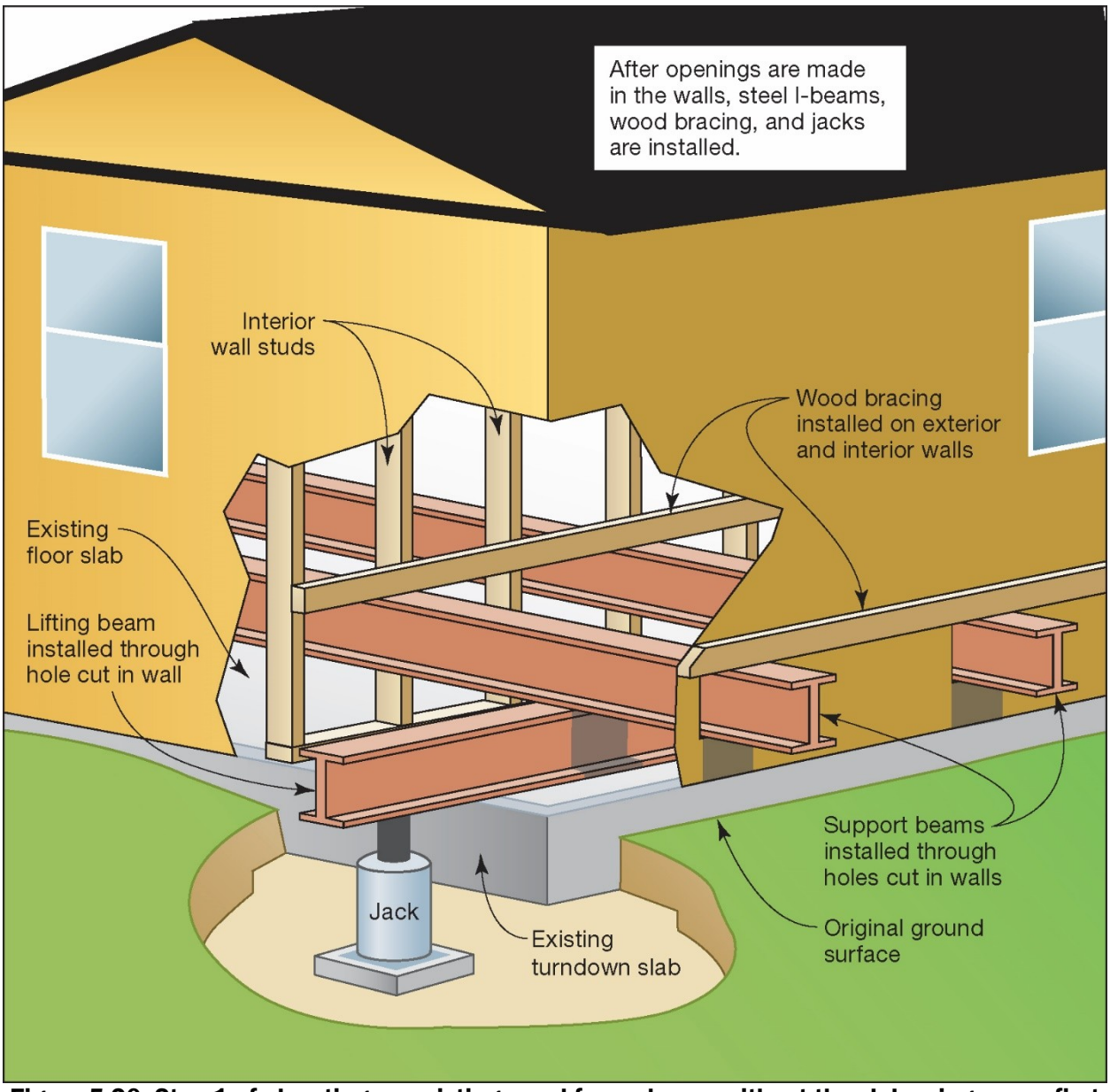


Figure 5-20. Step 1 of elevating an existing wood-frame house without the slab using a new first floor constructed of wood trusses: Install steel I-beam network and prepare to lift walls

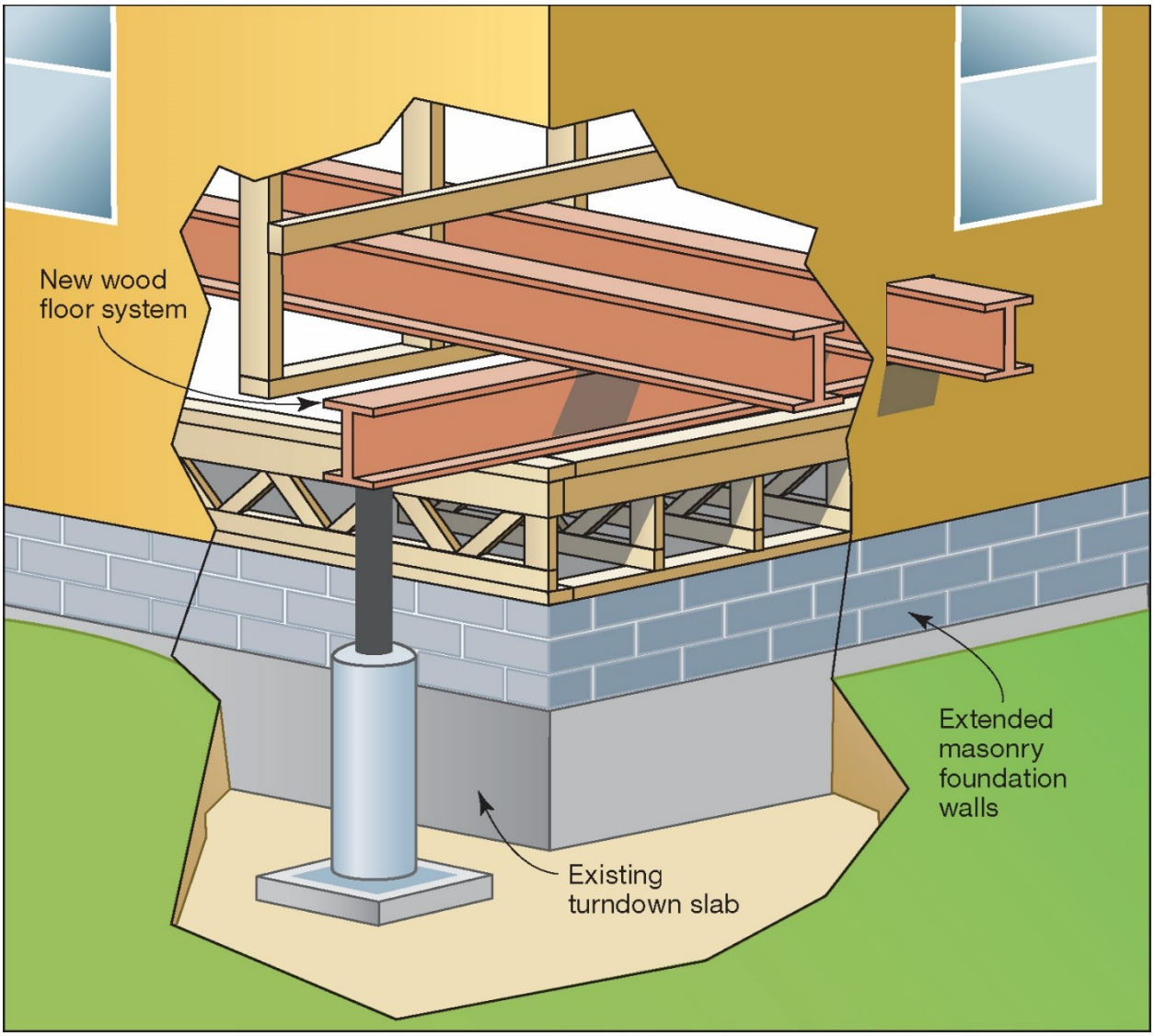


Figure 5-21. Step 2: Lift house, extend masonry foundation wall, and install wood floor trusses; relocate utility and mechanical equipment above flood level

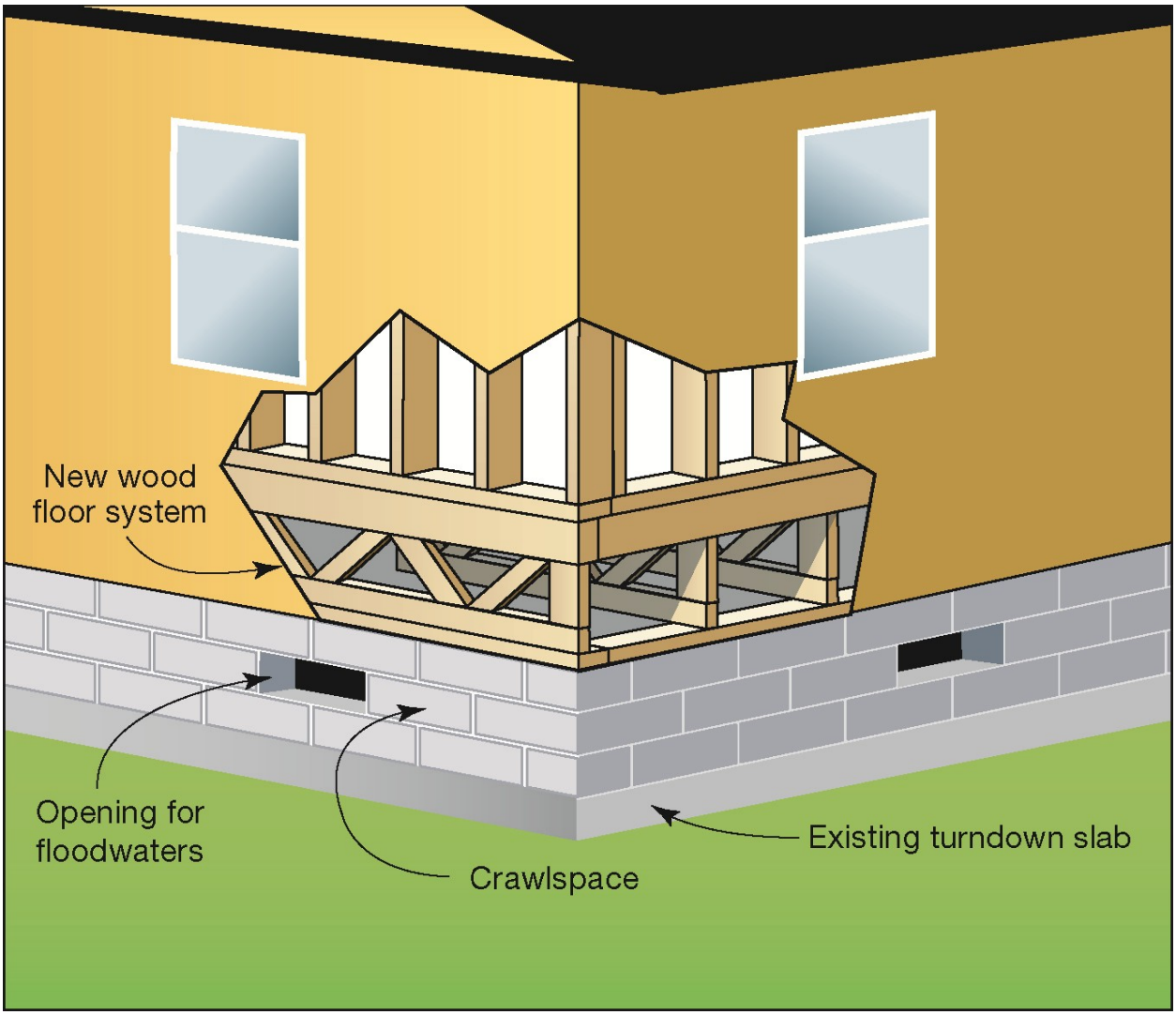


Figure 5-22. Step 3: Set house on new foundation and remove I-beams

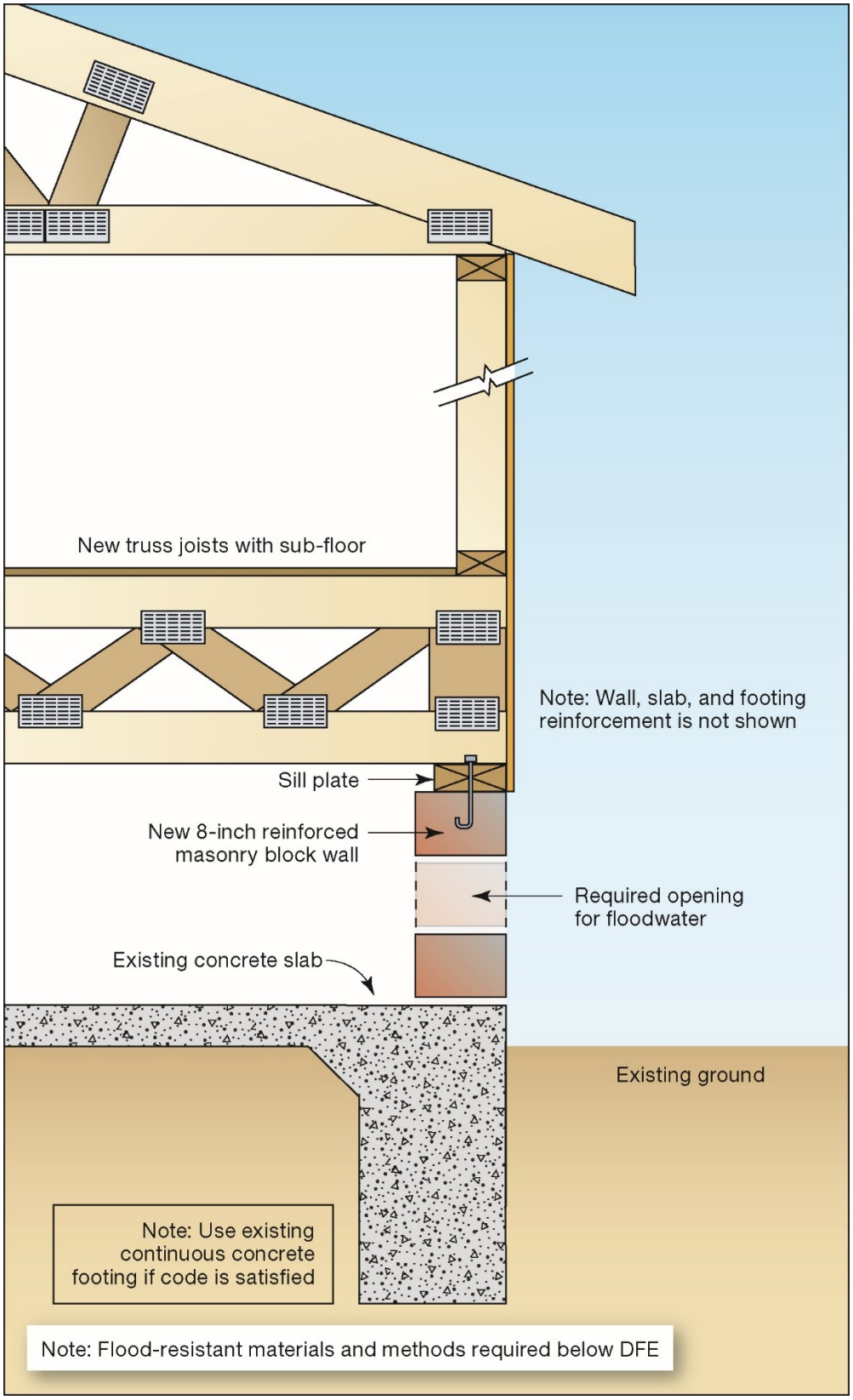


Figure 5-23. Cross-section of elevated wood-frame house (slab not raised) with extended crawlspace wall foundation and newly installed wood truss floor



Figure 5-24. Structural elevation using slab separation approach in Mandeville, Louisiana

Slab-In-Place (Not Recommended): The second option is to raise the slab with the house by digging a trench under the house to provide space for lifting beams. This requires highly specialized skills and equipment. Additionally, site visits of slab-on-grade homes elevated using the slab-in-place approach have revealed several issues:

- Elevated grade slabs are heavy, requiring support from a series of steel beams and piers. Most slab-in-place operations do not have permanent beams or in-place framing once the slab elevation on piers is completed.
- The underside of elevated slabs is uneven and requires shimming to connect the steel beam supports (Figure 5-28).
- Connections between the elevated slab and the supporting piers are often inadequate.
- The elevated grade slab may be thin in places and could crack when lifted, damaging the structure (Figure 5-29).
- The elevated grade slab may lack sufficient reinforcing steel (Figure 5-28).
- The reinforcing steel's location within the concrete is probably not optimally located to address live or other loads during its elevated lifetime, which are different than it being on the ground.
- Reinforcing steel may have inadequate concrete cover to protect it from the elements when in a raised condition.
- Many older concrete slab on grade residential foundations were built in areas with no building codes, poorly enforced building codes, or older building codes that may have poor quality control, unknown construction, since most residential homes are not required by building codes to be designed by an engineer, including their foundation systems.
- Slab on grade foundations were never intended to be elevated and perform their function as a floor without the support of the ground below it. As such, the various live, point, and other

loads it will be subjected to under its raised life include inherent residual risk with many unknowns, such as all of the above, among others.

Due to these important issues, many with significant unknowns, in-place slab-on-grade elevations are not recommended unless design professionals have determined otherwise (see Cross Reference).

Cross Reference

The 2024 edition of ASCE 24, Flood Resistant Design and Construction includes the following requirements for using an existing grade slab as the lowest floor of an elevated building:

1. The existing slab must be assessed in accordance with American Concrete Institute (ACI) Standard 562, *Assessment, Repair, and Rehabilitation of Existing Concrete Structures*.
2. If required by the ACI 562 assessment, the existing slab must be strengthened in accordance with ACI 562 and ACI 318, *Building Code Requirements for Reinforced Concrete*, to meet the load requirements of ASCE 7 and ASCE 24.

Although the ASCE 24-24 Standard has not yet been adopted into the current International Code Council Codes, this publication recommends designers follow the above requirements before pursuing a slab-in-place elevation retrofit.

For additional information regarding issues encountered with residential slab-in-place elevation, refer to FEMA P-938, Mitigation Assessment Team Report: Hurricane Isaac in Louisiana (FEMA, March 2013).



Figure 5-25. Elevated slab on grade in Slidell, Louisiana, with insufficient reinforcing steel cover



Figure 5-29. Slab-in-place elevation in Slidell, Louisiana, with structural crack in wall, shown by red arrow

Additional Alternatives for Masonry Houses

In addition to slab-in-place and slab separations, the following alternatives may be necessary for elevating masonry homes with slab-on-grade foundations:

- Install an elevated concrete slab or an elevated wood-frame floor system within an existing masonry structure. Note this is similar to elevating the lowest interior floor discussed in Section 5.2.3.
- Create a new masonry or wood-frame livable area on top of an existing one-story masonry structure.

5.1.2. STRUCTURAL ELEVATION DESIGN PROCESS

The elevation design process is illustrated in Figure 5-30 based on a detailed example of the design for a crawlspace house.

Note

The elevation process becomes more complex with added weight, height, or complex design of the house. Brick or stucco veneers may require removal prior to elevation. Combination foundations (i.e., slab-on-grade and basement) should be evaluated jointly, as well as separately, using the most conservative scenario to inform the design. Building additions may require elevation independent from the main structure. Due to the extreme variability of structural conditions, a structural engineer should evaluate the suitability of elevating masonry homes.

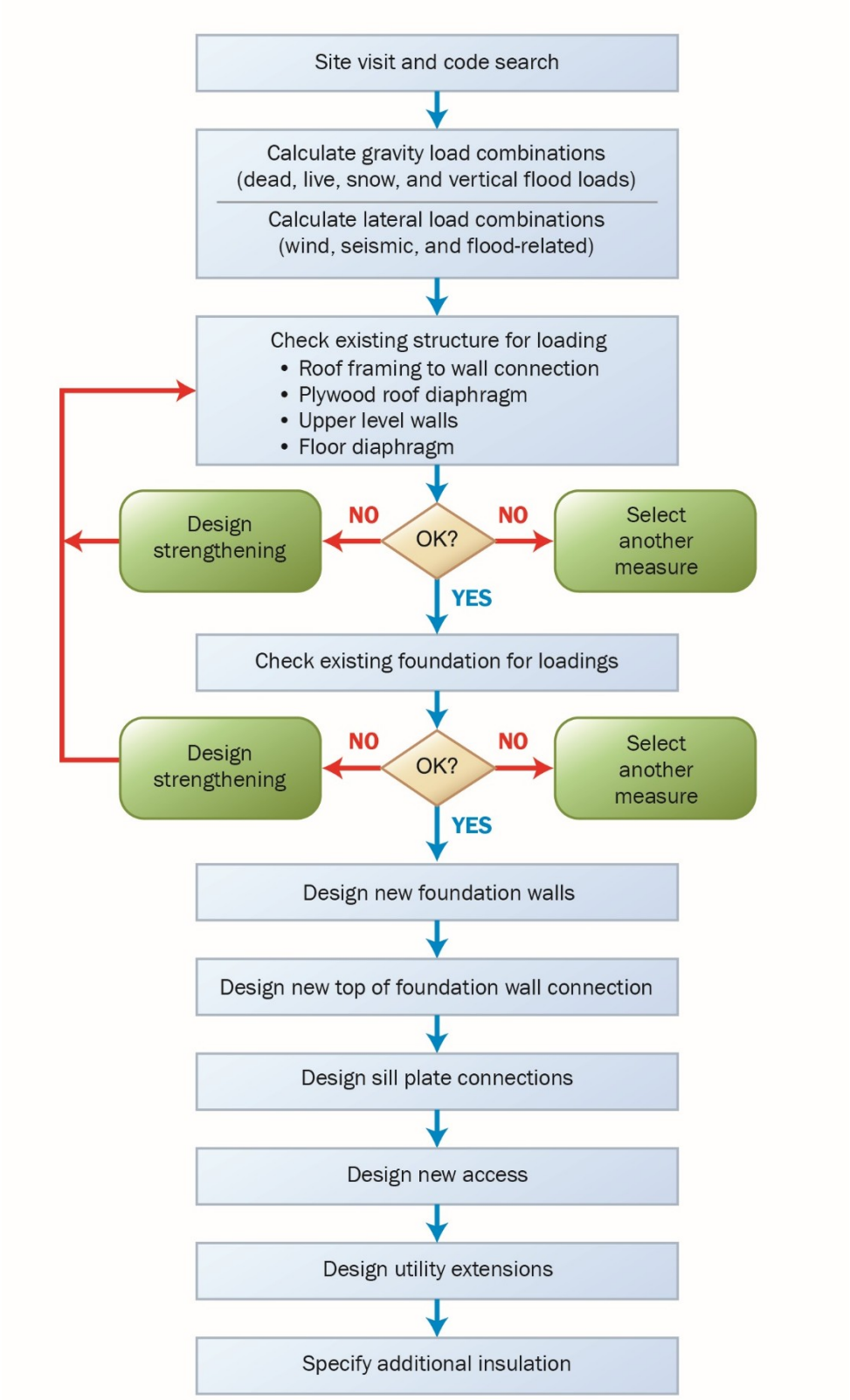


Figure 5-26. Structural elevation design process

Site Visit and Building Code Search

A site visit is necessary to determine whether elevation is appropriate for the building. In addition to the site visit and inspection, a data review and building code compliance review are required.

During the site visit, the designer should inspect the property and review existing data to confirm appropriateness of the selected alternative and validate specific design guidance including elevation height and foundation type. The designer should refer to guidance in Chapter 4 and relevant information in Chapters 2 and 3. Use of the Elevation Site Visit Worksheet (Figure 5-31) is recommended.

During the site visit, the designer should verify local floodplain ordinance, local and state building code requirements, any deed restrictions, along with subdivision and zoning regulations. In addition, consultation with the local building official will determine unique community requirements. During the code search, the following should be determined:

- Elevation and foundation requirements per the community floodplain ordinance and flood hazard map
- Building code compliance requirements
- Design wind speed
- Design seismic zone
- Ground snow loads
- Frost depth
- Height restrictions (total building, and allowable height/thickness ratios)
- Foundation restrictions
- Soil bearing capacity

Elevation Site Visit Worksheet

Owner Name:_____ Prepared By:_____

Address: _____ Date: _____

Property Location: _____

Does site topography data cover required area? ☐ Yes ☐ No

Additional data required:

Any construction access issues?

Site and building utilities identified? ☐ Yes ☐ No

Potential utility conflicts identified? ☐ Yes ☐ No

Describe conflicts: _____

Review homeowner preferences: _____

Can aesthetics reconcile with site and building constraints? ☐ Yes ☐ No

How?

Confirm type and condition of existing framing:

☐ member sizes ☐ spans ☐ connections ☐ supports

Confirm type and condition of foundation:

☐ type ☐ depth ☐ size

Confirm types and condition of existing construction materials:

☐ roof ☐ floor ☐ walls ☐ foundation

Confirm soil information:

☐ type ☐ depth of rock ☐ bearing capacity ☐ susceptibility to erosion and scour

Confirm characteristics of flood-related hazards:

☐ base flood elevation (BFE) ☐ velocity ☐ design flood elevation (DFE) ☐ frequency

☐ duration ☐ potential for debris flow

Confirm characteristics of non-flood-related hazards:

☐ wind ☐ seismic ☐ snow ☐ other

Review accessibility considerations:

☐ access/egress ☐ special resources for elderly, disabled, children

Architectural constraints noted: _____

Is clearance available to install lifting beams and jacking equipment? ☐ Yes ☐ No

Check local codes/covenants for height or appearance restrictions:

☐ deed/subdivision rules ☐ local building codes

Restrictions: _____

Figure 5-27. Elevation Site Visit Worksheet

Load Combinations and Structure Assessment

The next steps in the design process for an elevated structure, shown in Figure 5-30, address load combinations and existing structure assessment using the following steps:

Step 1: Calculate Vertical Loads. The computation of vertical loads, which includes building dead and live loads (gravity loads), and non-gravity loads from buoyancy and wind uplift forces, was presented in Sections 4.5.2 and 4.5.3.

Step 2: Calculate Lateral Loads. Calculation of building lateral loads includes flood, high wind, and seismic loads. One objective of the wind and seismic analysis is to determine which loading condition controls the design of specific structural components. Computation of lateral flood loads was presented in Section 3.2, and the basic concepts for determining high wind and seismic loads were presented in Section 3.5.

Step 3: Check ability of elevated structure to withstand elevated loading. Chapter 4 presented information on determining the ability of the existing structure to withstand additional loads and load combinations imposed by retrofitting. The process details that follow are similar for each common building type. The expected loads are tabulated and compared against allowable load amounts specific to the site soil conditions, local building code requirements, or building material standards. The following list of existing building components and connections should be validated:

Roofs: The plywood roof diaphragm, trusses, connections, and uplift on roof sheathing should be capable of resisting increased wind and seismic loads. The Engineered Wood Association (also known as APA) has published several references that are useful in this calculation, including APA SR-1013, *Design for Combined Shear and Uplift from Wind* (APA, 2016) and APA Form T325, *Roof Sheathing Fastening Schedules for Wind Uplift* (APA, 2019).

These references or the local building code will provide the necessary plywood thicknesses and connection specifications to resist the expected loads and will provide load ratings for specific material types and sizes.

If the roof diaphragm and sheathing are not sufficient to resist increased loads, the design can enable component strengthening by:

- Increasing the thickness of the materials
- Strengthening connections with additional plates and additional fasteners

Roof Framing-to-Wall Connections: Roof framing connections to walls should be checked to ensure resistance to increased wind loads. Gable ends, where many wind failures occur, are critically important. The Engineered Wood Association has references that detail this calculation, including APA SR-1013, *Design for Combined Shear and Uplift from Wind* (APA, 2016) and APA Form L350, *Diaphragms and Shear Walls* (APA, 2024).

These references or local building codes will provide the necessary truss size, configuration, and connection specifications to resist the expected loadings, and provide load ratings for specific truss and connection types and sizes.

Cross Reference

For additional information on the performance of various building system products, refer to product evaluation reports prepared by the model code groups or the National Evaluation Service.

If the roof trusses and wall connections are not sufficient to resist increased loads, the design can strengthen these components by:

- Increasing the amount of bracing between the trusses
- Strengthening the connections with additional plates and additional fasteners

Upper-Level Walls: The upper-level walls are subject to increased wind pressure and shear due to increased roof loads. Both short and long walls should be checked against shear, torsion, tension, and deflection using the governing loading condition (wind or seismic).

The Engineered Wood Association has published several references useful to this calculation, including APA SR-1013, *Design for Combined Shear and Uplift from Wind* (APA, 2016) and APA Form L350, *Diaphragms and Shear Walls* (APA, 2024).

These references or the community building codes will dictate the necessary wall size and configuration, and connection specifications, which will resist the expected loads. They will also inform load ratings for specific wall types, sizes, and connection schemes.

If upper-level walls are unable to withstand increased loads, the entire structure must be strengthened. This may be cost-prohibitive, and the homeowner should consider an alternative flood retrofitting approach, such as relocation. Measures to strengthen upper-level walls include:

- Adding steel strapping (cross bracing) to interior or exterior wall faces
- Adding a new wall adjacent to the exterior or interior of the existing wall
- Bolstering the interior walls in a similar fashion
- Increasing the number and sizes of connections

Floor Diaphragm: The floor diaphragm and connections are subject to increased loading due to wind, seismic forces, and flood. The existing floor diaphragm and connections should be checked to ensure their ability to withstand the increased forces that might result from the elevation.

The Engineered Wood Association has published several useful references in this calculation, including APA Form Y250. *Shear Transfer at Engineered Wood Floors* (APA, 2015) and APA Form L350, *Diaphragms and Shear Walls* (APA, 2019).

These references or the community building codes will prescribe the necessary floor size and configuration and connection specifications to resist expected loads, or will provide load ratings for specific floor types, sizes, and connection schemes.

If the floor diaphragm or connections are unable to withstand the increased loads, the designer could strengthen these components by:

- Adding a new plywood layer on the bottom of the existing floor diaphragm
- Increasing the number and size of bracing within the floor diaphragm
- Increasing the number and size of connections

Elevated Foundation Assessment

Check Elevated Foundation Capacity

The existing foundation should be checked to determine its ability to withstand increased gravity loads from elevation, increased lateral loads due to soil pressures from potential backfilling, and increased overturning moment loads due to seismic and wind loads. All gravity loads (dead and live loads) plus the weight of the new foundation walls should be tabulated to determine a soil bearing pressure, which is then compared with the allowable bearing pressure of the soil at the site. Not including expected buoyancy forces in this computation will yield a conservative value.

If the existing footing is insufficient to withstand the additional loads created by the elevated structure, foundation improvements should be undertaken. Foundation improvements may be as straightforward as increasing the size of the footing and/or more substantial reinforcement. The designer may refer to the ACI manual for footing design, recent guidance for walls and footing design, and applicable codes and standards.



Cross Reference

For wet floodproofing applications where openings in foundation walls are necessary, refer to Section 6.1.

Design of Other Elevated Foundation Elements

Design of a new foundation, whether solid (closed) or open, is governed by community building codes which have minimum requirements for foundation wall sizes and reinforcing schemes, including seismic zone considerations. Appropriate code document tables for minimum requirements for vertical wall or open foundation reinforcement should be consulted.

For new slab applications where the lower level is allowed to flood and the slab is not subject to buoyancy pressures, the Portland Cement Association's *Concrete Floors on Ground* (2008) is an

appropriate source for designing correct thickness and reinforcing schemes based upon expected loads. Slab loads will vary based on overall foundation design and the use of the home's lower level.

Top-of-wall connections are critical to avoid pullout of the sill plate or floor diaphragm from the masonry foundation. A preliminary size and spacing of anchor bolts is assumed, and uplift, shear, and tension forces are computed and compared against the allowable loads for the selected bolts. Where necessary, adjustments are made to the size and spacing of the anchor bolts to keep the calculated forces below the allowable forces.

Existing sill plate connections will be subject to increased lateral loads and increased uplift forces due to increased wind and buoyancy loading conditions. The sill plate is designed to span between the anchor bolts and resist bending and horizontal shear forces. The designer should refer to the appropriate wood design manual that provides recommended compression, bending, shear, and elasticity values for various sill plate materials. If the sill plate connection is insufficient to withstand expected loadings, the size of the sill plate can be increased (or doubled), and/or the spacing of the anchor bolts can be reduced.

5.1.3. ADDITIONAL DESIGN CONSIDERATIONS

Accessibility

Selection and design of new access to an elevated structure is done in compliance with local regulations. Special household requirements, such as for aesthetics, accessibility, and requirements for children and seniors, should be included using references in Chapter 2.

Incorporating the new access to multiple entries may present a unique challenge, as a greater area is required on the existing site to accommodate the increase in elevation from the adjacent grade to egress. A particular obstacle occurs with attached garages where the main home's living space is elevated, and the garage slab remains at the original grade as allowed for enclosed areas below Base Flood Elevation/Design Flood Elevation only for building access, parking, and storage. Additional accessibility considerations that must be addressed may include area and height constraints required for the additional stairs or ramps to the elevated entry, aesthetic issues, increased drainage requirements, and potential changes to roof systems to allow for covered building access.

Connection of new access to the house must be building code compliant. Either the foundation for stairs or ramps must be free-standing and subject to its own lateral stability requirements, or it must be an integral part of the new elevated structure. In either case, analysis of the structure to ensure adequate foundation strength and lateral stability should be completed to assure building code compliance.

Cross Reference

Any access below the Base Flood Elevation should use flood damage-resistant materials referenced in FEMA's National Flood Insurance Program Technical Bulletin 2, *Flood Damage-Resistant Materials Requirements for Buildings Located in Special Flood Hazard Areas in Accordance with the National Flood Insurance Program* (FEMA, 2025).

Building Utility Systems

The site visit will reveal the specific utility systems that will require relocation, extension, or modification. Whenever possible, utility systems should be relocated above the Design Flood Elevation. Utility providers should be contacted about specific requirements for the extension of utility services. In some instances, the utility provider will install the extension. Critical issues to extend utilities include:

- Handling of utilities encased in the existing slab or walls
- Coordination of disconnection and reconnection
- Any local codes that require upgrades to the utility systems as part of new construction, substantial damage repair, or improvement
- Introduction of flexible connections on gas, water, sewer, and oil lines to minimize potential for seismic damage
- Potential for relocation or elevation of electrical system components from existing crawlspace and/or basement areas
- Design of separate GFCI-type electrical circuits and use of flood-damage resistant materials in areas below the Base Flood Elevation

Cross Reference

Refer to Wet Floodproofing Section 6.1.4 and FEMA P-348, *Protecting Building Utility Systems From Flood Damage*, Edition 2 (FEMA, 2017) for additional information on protection of building utility systems.

Insulation

Elevated floors and extended utility system components may increase the potential for heat loss through increased exposure and airflow and necessitate additional insulation. The energy efficiency of each aspect of the project, as well as the potential need for increased fire separation for living spaces elevated above garages, should be evaluated. This includes existing insulation (R-values)

compared to building code specifications, so additional insulation (greater R-value) can be added where required.

Cross Reference

Guidance on the selection of an elevation contractor follows the same principles as selecting a relocation contractor; provided in Section 5.3, Relocation.

5.1.4. CONSTRUCTION CONSIDERATIONS

Prior to structurally elevating any house, the following general considerations should be addressed:

- Obtain all permits and approvals required.
- Ensure that all utility hookups are disconnected (plumbing (potable, sewage (sewer / septic tank), phone, electrical, cable, mechanical or other).
- Estimate the lifting load of the house.
- Identify the best location for principle lift beams, lateral support beams, framing lumber, and evaluate their adequacy (generally performed by a structural engineer or the elevation contractor).

Additional elevation considerations:

- **Elevation of garage walls:** Since this area is not living space, some contractors propose separating the garage from the house rather than elevating the garage walls with the house. While this may seem like a minor issue, it can result in significant framing challenges compared to the less costly option of elevating the garage walls. Additionally, not elevating the garage creates an access issue. Even if the garage walls are elevated, maintaining an access door into the garage can be a challenge if stair placement is difficult.
- **Foundation reuse:** In locations where site soils lack load capacity, removing the existing foundation may worsen soil conditions due to soil disturbance. In these situations, it may be necessary to use as much of the existing foundation as possible, adding additional footings or piers to address the load increase.
- **Ductwork under the house:** Additional elevation may be necessary if ductwork is installed under the home. Although the National Flood Insurance Program allows flood damage-resistant ductwork to be located below the Base Flood Elevation, elevating ductwork above the Base Flood Elevation may be more cost-effective than trying to prevent water intrusion damage. Adding more than one foot of freeboard in Zone A may be necessary so that damage resilient ductwork can be installed under floor joists.
- **Brick veneer:** Because of the condition of most brick ties, brick veneer must be removed and either reinstalled or replaced with new brick veneer following elevation. Although replacing brick

veneer seems more costly, it may be simpler and less expensive to eliminate concern for damage to existing brick and match old veneer to new brick foundation walls.

- **Chimneys:** Since exterior chimneys are typically heavy and poorly reinforced, they are often removed and reconstructed rather than elevated with the house. Interior chimneys may be lifted with the house, with additional beams to support chimney load. A new chimney foundation is necessary to support the new chimney.
- **Building access:** Depending on elevation height, construction of ramps or stairs can become expensive and require significant space, especially if ramps are required for accessibility.
- **Framing discrepancies:** Existing houses may not be built on a level foundation, and differential settlement can happen over time. By contrast, the new elevated foundation will be level. Once the existing house is set down on the new elevated foundation, significant cracks may occur throughout the house. In many parts of the existing house, these cracks will require repair. Often, interior corners around windows and doors, where joints are stressed, will require repair.
- **Bonding of contractors for large projects:** Elevation projects that include several houses may have total dollar values that exceed the bonding capacity of most general contractors. Many communities require construction and/or material bonds before a contract is executed. These requirements may be difficult to meet, so creative methods like letters of credit in lieu of a bond may be necessary to ensure community compliance. This flexibility may also encourage more contractors to submit project proposals.

Crawlspace or Basement Foundation Houses

Procedures for elevating a house over a crawlspace or basement:

- Masonry is removed to allow placement of support beams
- Main lifting beams are installed
- Lateral beams are installed
- Jacks are placed and the structure is prepared for lifting
- All foundation connections are removed
- The house is lifted and cribbing installed
- Existing foundation walls are raised or demolished, depending on whether the existing foundation walls can manage the new loads
- New footings and foundation walls are constructed if the existing foundation walls/footings cannot withstand the additional loads
- Basement is backfilled where appropriate
- House is lowered and attached to the new foundation

- Support beams are removed
- Access holes are patched
- All utilities are reconnected
- New stairways and access are constructed
- All utilities below the Design Flood Elevation are floodproofed

Pier, Column, or Pile Foundation Houses

If the house remains in the same location, it will most likely need to be temporarily relocated to allow space for footing and foundation construction. If the house is relocated within the same parcel, footings should be constructed prior to moving the house. Procedures for elevating a house on piers, columns, or piles:

- Main support beams are installed
- Lateral beams are installed
- Jacks are moved into place and the structure is prepared for lifting
- House is elevated and cribbing is installed
- If the house is being relocated, see section 5.3
- Existing foundation is demolished and removed, and new pier and column foundation is installed, or existing foundation elements are extended upward and reinforced as needed
- House is attached to new foundation
- Support beams are removed
- All utilities are reconnected
- New stairways and access are constructed
- All utilities below the Design Flood Elevation are floodproofed

Slab-on-Grade Foundation Houses

Slab Separation

Procedures for elevating a slab-on-grade house without raising the slab:

- Holes are cut for lift beams in the exterior and interior walls
- Main lifting beams are inserted
- Holes are cut for the lateral beams

- Lateral beams are inserted
- Bracing is installed to transfer the loads across the support walls and lift remaining walls
- Jacks are moved into place and structure is prepared for lifting
- Straps and anchors used to attach house to slab-on-grade are released
- The house is elevated, and cribbing installed
- Slab around edges is removed to allow for new foundation
- The new foundation is constructed
- New support headers and floor system are installed
- Any required wind and seismic retrofit is completed
- House is attached to new foundation
- All temporary framing is removed; holes are patched
- All utilities are reconnected
- New stairways and access are constructed
- All utilities below the Design Flood Elevation are floodproofed



Warning

As indicated in Section 5.1.1, elevation of slab-on-grade homes using the slab-in-place approach is not recommended.

5.2. Elevation Alternatives

This section describes alternative ways to reduce flood risk for existing residential buildings that cannot be elevated due to their structural characteristics. The methods described in this section typically apply to larger residences that are not Substantially Damaged or Substantially Improved, meaning that the buildings have not sustained damage or undergone improvement (i.e., reconstruction, rehabilitation, addition) where the cost of the damage or improvement exceeds 50% of the market value of the building before the damage occurred or improvement began. In some cases, these methods may not bring the structure into compliance with the National Flood Insurance Program, so flood insurance premiums may not be lowered. The alternative elevation methods include:

- Infilling the basement (Section 5.2.1)
- Abandoning/repurposing the lowest floor (Section 5.2.2)
- Elevating the lowest interior floor (Section 5.2.3)

Rather than physically elevating the entire structure, each of the elevation alternatives in this section seeks to either achieve National Flood Insurance Program elevation compliance by adjusting the National Flood Insurance Program rated "lowest floor" of the structure above Base Flood Elevation or simply increase resilience to above grade. The height of this adjustment will directly impact the flood hazard risk reduction and potential National Flood Insurance Program compliance (see Note).

Note

As stated above, the Floodproofing Design Depth (H) used for elevation alternatives may be determined by the Design Flood Elevation based on the regulatory and community requirements described in Section 3.1.1, but may also be based on the flood protection level established by the owner as described in Section 3.1.2, where regulatory compliance is not required.

Cross Reference

The elevation alternatives in this section were developed in response to Section 26 of the Homeowner Flood Insurance Affordability Act of 2014, which requires FEMA to "provide alternative methods of mitigation, other than building elevation, to reduce flood risk to residential buildings that cannot be elevated due to their structural characteristics." This led to FEMA developing guidance for various elevation alternatives for residential buildings, including basement infill, abandoning or repurposing the lowest floor, and elevating the lowest interior floor. The results of this guidance are summarized in FEMA P-1037, *Reducing Flood Risk to Residential Buildings That Cannot Be Elevated*, September 2015.

5.2.1. BASEMENT INFILL

Houses with basements can be more difficult to elevate because their mechanical and HVAC equipment is usually in the basement, and part of the basement may be used as habitable space. Sometimes, basement walls may have been extended to the point where they cannot be extended to structurally withstand the additional flood forces that would be imposed on a structurally elevated floor. In these situations, infilling the basements can be used to provide some additional protection from flooding. If the next highest floor above the basement floor is at or above the Base Flood Elevation and the basement is infilled to grade, then the next highest floor may be designated the lowest floor. Existing buildings with basements can be retrofitted using the following basement infill techniques to provide additional flood protection:

- Removing all habitable space and any mechanical and HVAC equipment from the basement and relocating it at grade or to the next highest floor of the residence.

- Placing compacted lifts of soil or flowable concrete in basements filled to grade, and adding hydrostatic flood openings to the portions of walls extending above grade (Figure 5-32).

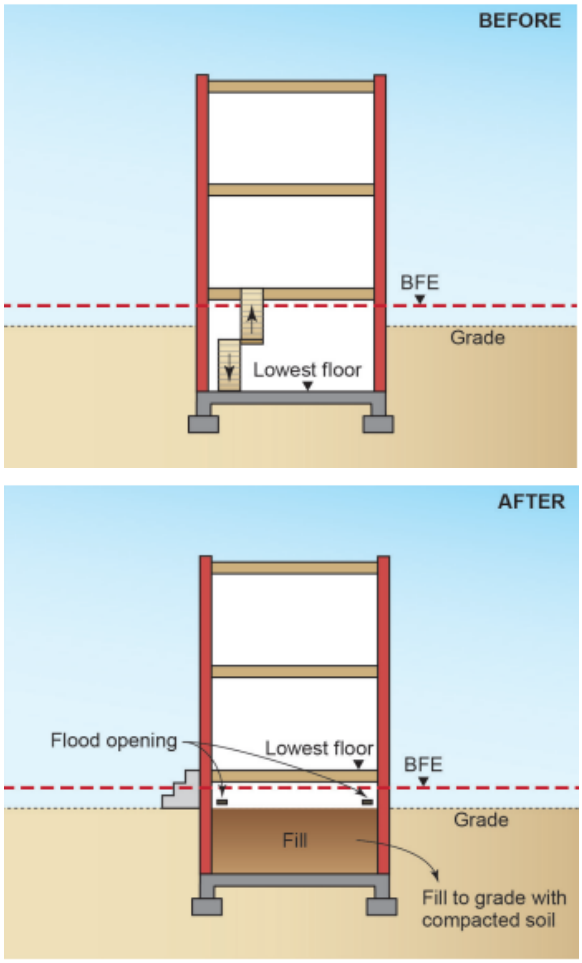


Figure 5-28. Basement Infill on Solid Foundation Walls (Source: FEMA P-1037, Figure 1)

Note

Section 5.2.1 addresses simply backfilling the basement to grade but leaving the first floor elevation unchanged. Once this is done, additional elevation can be accompanied by the traditional structural elevation of a house with a basement foundation by raising the structure's first floor on walls or piers. This structural elevation approach is discussed in Section 5.1.1.

Considerations for basement infill include:

- Monitoring of compacted fill or flowable concrete placement within the basement.
- Loss of basement square footage and livable space within the existing building.

- Potential structural renovations to enable the addition of another story on upper floors or construction of an elevated lateral addition to replace lost residential space, which could trigger a substantial improvement declaration.

Note

Flood openings are discussed in detail in Wet Floodproofing Section 6.1.1

Cross Reference

FEMA's requirements for pre- and post-FIRM structures do not allow basements below the Base Flood Elevation in a Special Flood Hazard Area for Substantially Improved/Substantially Damaged and post-FIRM structures. To be National Flood Insurance Program compliant, when triggered, existing below grade areas must be backfilled to or above the adjacent ground surface. For more information on what retrofitting measures are allowable under FEMA guidelines, refer to Chapter 2, Regulatory Requirements.

5.2.2. ABANDON/REPURPOSE LOWEST FLOOR

The lowest level of a two- or more story residence can be abandoned entirely or repurposed (converted) to parking, storage, or building access using wet floodproofing measures (Figure 5-33) including adding flood openings, using flood damage-resistant materials, and relocating flood-prone utilities. This approach should be limited to structures in floodplains with low velocity floodwater (less than five feet per second) and short duration flood events (less than three days). Since utility service lines often enter urban buildings through the basement, utility connections must be retrofitted to allow maintenance on utility lines while reducing exposure of the building to flood damage.

Considerations for abandoning or repurposing the lowest floor include:

- Moving all living space and necessary utility equipment (electrical, heating, ventilation and air conditioning, plumbing) above. Limit conversion of enclosed areas below elevated buildings to using only for parking, building access, and storage.
- Loss of lowest floor square footage and livable space within the existing building.
- Replacement of wood-framed walls on the lowest floor with concrete or masonry walls equipped with hydrostatic flood openings placed within 1 foot of grade (Figure 5-34). Finish materials on the lowest floor that are vulnerable to flood damage need to be replaced with flood damage-resistant materials.

- Potential structural renovations to enable the addition of another story on upper floors, finishing an unfinished attic space, or construction of an elevated lateral addition to replace lost residential space, which could trigger a substantial improvement declaration.
- Abandoning or limiting the use of the lowest floor may not be acceptable to property owners due to loss of living space.

Note

Flood openings, flood damage-resistant materials, and protecting utilities from flood damage are discussed in detail in Wet Floodproofing Section 6.1.1.

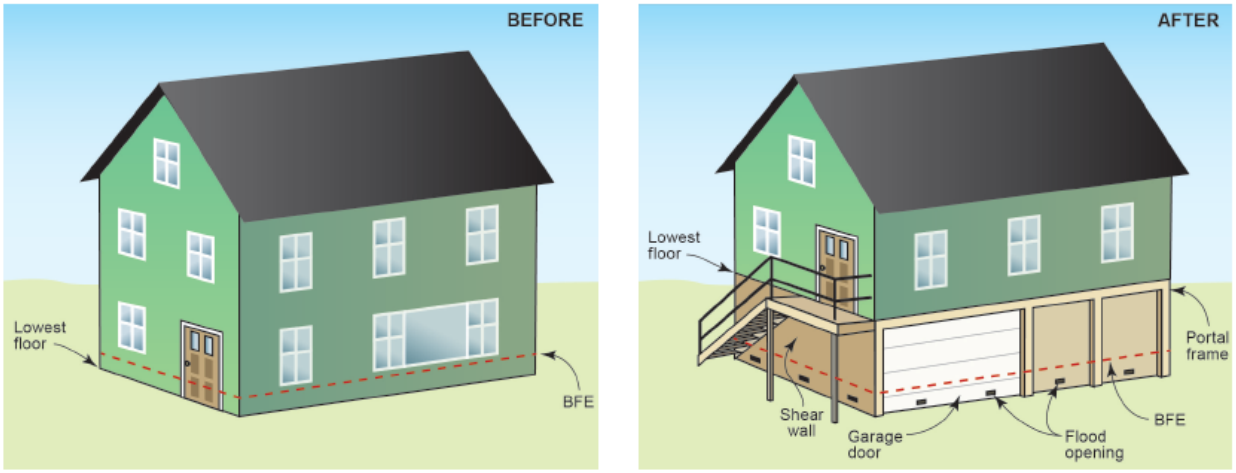


Figure 5-29. Abandoning the Lowest Floor (Source: FEMA P-1037, Figure 2)

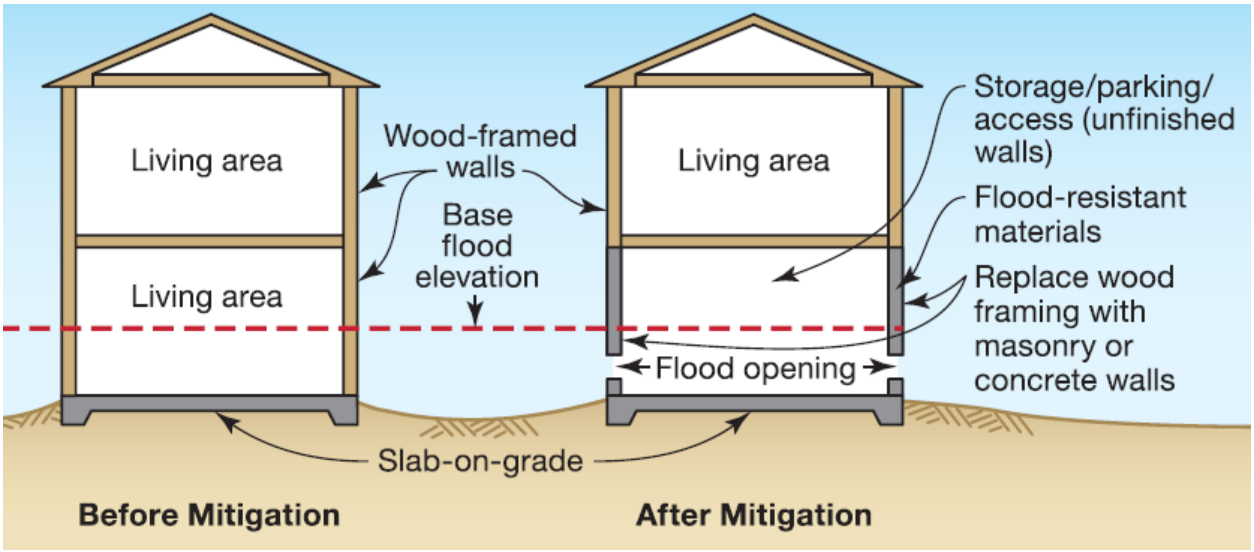


Figure 5-30. Recommended Modifications to the Lowest Floor for National Flood Insurance Program Compliance (Source: Hurricane Sandy RA7, Figure 2)

5.2.3. ELEVATE LOWEST INTERIOR FLOOR

Elevating the lowest interior floor to the design flood level can be feasible for homes with high first level ceilings (Figure 5-35). The space below the lowest elevated interior floor walls must be either backfilled with compacted soil or flowable concrete to create a filled stem wall or retrofitted with flood openings that allow automatic entry or exit of floodwaters. Additionally, any utility systems and associated utility equipment located below the lowest interior floor must be elevated to protect from flood damage or loss of function. To minimize flood damage and reduce flood insurance premiums, the lowest floor and building utilities should be elevated above the Base Flood Elevation.

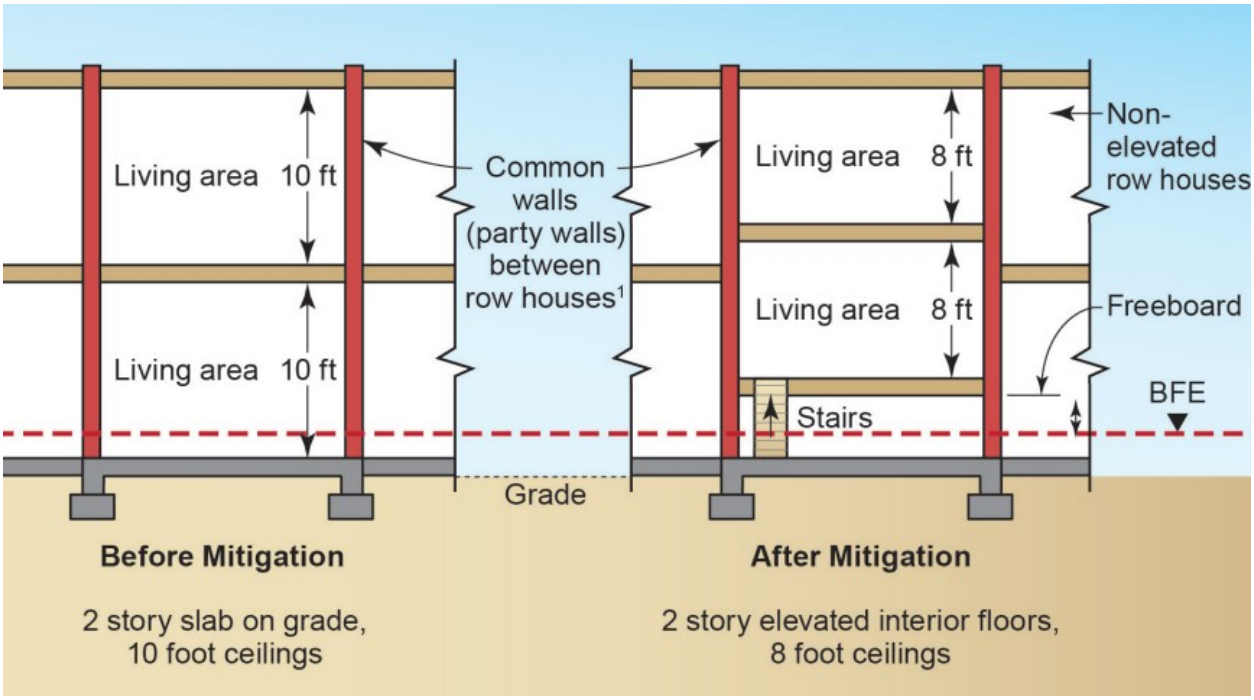


Figure 5-31. Elevating the Lowest Interior Floor (Source: FEMA P-1037, Figure 3)

If the floor above the lowest floor is also below the Base Flood Elevation, it will need to be raised and reconstructed to an elevation above Base Flood Elevation. For row houses with higher ceilings typical of older construction, it may be possible to raise the interior floor while retaining the original floor space of the upper levels (see Figure 5-35). In these instances, front and rear walls can often be modified to raise windows as needed.

Elevating the lowest interior floor and, if required, elevating or floodproofing utilities can result in reduced square footage and the possible loss of livable space within the existing building. This may not be acceptable and feasible for some homeowners. Furthermore, this flood protection measure could trigger Substantial Improvement floodplain management and building code compliance requirements.

Additional considerations for elevating the lowest interior floor include:

- Assessing the heights of the existing stories to determine the available space to accommodate elevation (assuming a minimum story height of 8 feet).
- Monitoring compacted fill or flowable concrete placement below the lowest elevated interior floor.
- Potential structural renovations to raise the interior story heights, which could trigger a substantial improvement declaration.

5.2.4. ELEVATION ALTERNATIVES SUMMARY

The key advantages and disadvantages of the three elevation alternatives are summarized in Figure 5-36. The relative costs of elevation alternatives are summarized in Table 5-1.

Note

Some of the specific advantages and disadvantages of elevation alternatives shown in Figure 5-36 will depend on the determination of the lowest rated floor once the retrofit is complete. If the lowest floor is determined to be at or above the Design Flood Elevation, then the elevation alternative may be considered compliant with the National Flood Insurance Program and the latest building codes and standards when other requirements are also met (e.g., flood openings). However, if the lowest floor is determined to be below the Design Flood Elevation or Base Flood Elevation, then an elevation can provide flood protection to lower flood levels but cannot achieve National Flood Insurance Program compliance when the structure is substantially damaged or substantially improved.

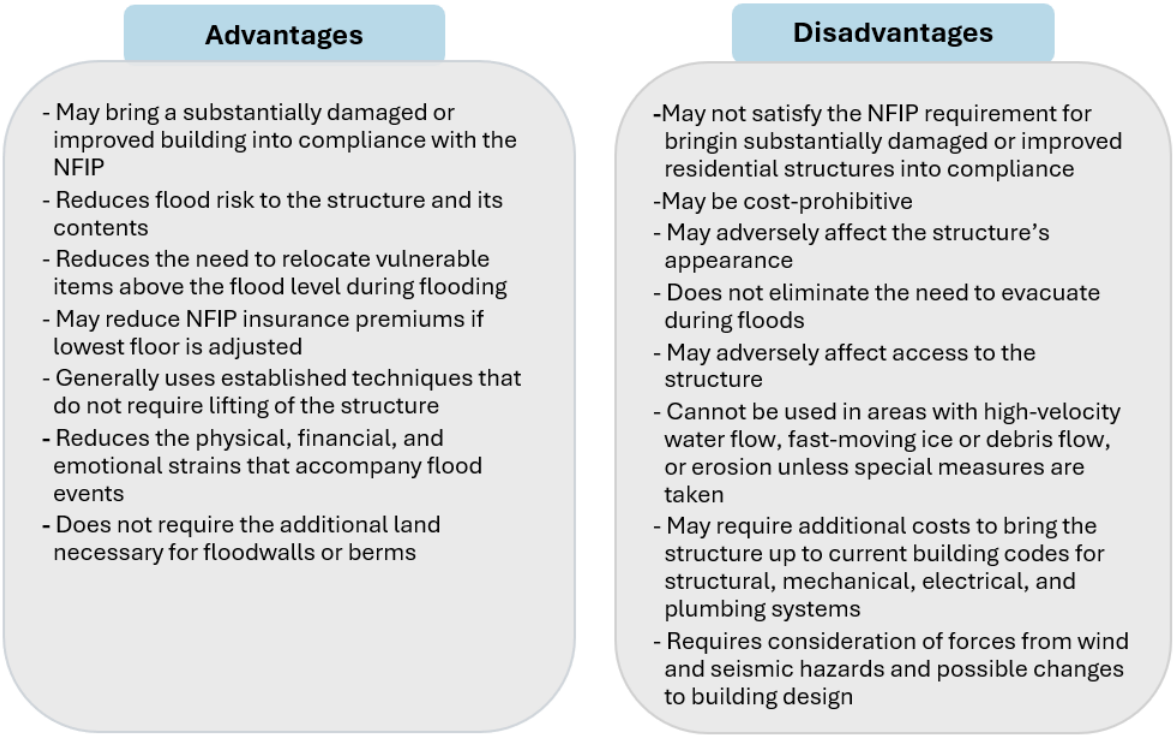


Figure 5-32. Advantages and Disadvantages of Elevation Alternatives

Table 5-1. Relative Costs of Elevation Alternatives

Construction Type*	Existing Foundation	Retrofit	Relative Cost
Frame or frame with masonry veneer	Slab-on-grade	Elevate lowest interior floor	Lowest
Load-bearing masonry or concrete	Basement	Basement infill	Lower range
Load-bearing masonry	Slab-on-grade	Elevate lowest interior floor	Mid-range
Frame with masonry veneer	Slab-on-grade	Abandon or repurpose lowest floor	Higher range
Load-bearing masonry	Slab-on-grade	Abandon or repurpose lowest floor	Highest

**NOTE: Wood-frame foundation walls and/or basements are rare and not recommended for flood-resistant design.*

5.3. Relocation

Relocation is the retrofitting measure that can offer the greatest security from future flooding (see Figure 5-37). It involves moving an entire structure to another location, usually outside the floodplain. The property owner usually selects the new site unless a community supports the relocation of a neighborhood of flood-prone homes to a new location. Consultation with the designer is recommended to ensure that critical site selection factors such as floodplain location, accessibility, utility service, cost, and property owner preferences meet engineering standards and comply with local regulations and requirements. Relocation typically reduces flood risk and owner concern about future flooding. If the building is moved outside of the Special Flood Hazard Area flood insurance premiums will be minimized.



Figure 5-33. House Relocation

The relocation process, as illustrated in Figure 5-38, is straightforward. There are, however, design considerations to address prior to initiating a building relocation. Nine structure relocation steps are detailed throughout this section.

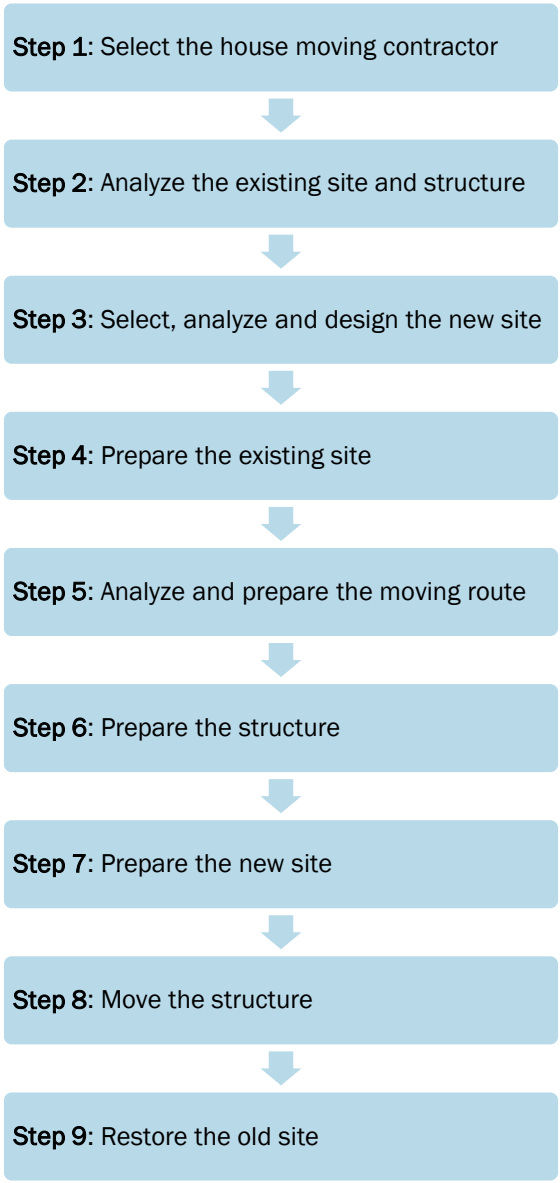


Figure 5-34. Relocation Process

Step 1: Select the House Moving Contractor. The selection of a moving contractor may have the greatest impact on a successful relocation. The designer can assist the property owner in contractor selection. Some of the key elements of this selection (outlined in Figure 5-39) include:

- **Experience:** The homeowner and designer should visit recent contractor-completed projects and talk to owners to evaluate the quality of the work.
- **Financial Stability:** The homeowner or designer should verify contractor licensing, insurance, and bonding. A prudent homeowner will consider the potential risk of a failed project before enlisting the assistance of a contractor.

- **Professionalism and Reputation:** The designer/homeowner may wish to check the contractor's reputation with the state licensing board, the local Better Business Bureau, local officials, and the International Association of Structural Movers (IASM). It is critical that the selected contractor hold appropriate local licenses.

Relocation Contractor Selection Checklist

1. **Experience of the Contractor:**
   - Recent, successful house re-elevation projects? Yes _____ No _____
   - Satisfied clients providing good references? Yes _____ No _____
   - Met time schedules? Yes _____ No _____
   - Cleaned up and restored old site? Yes _____ No _____
   - Quality product through your visual inspection of recent projects? Yes _____ No _____
2. **Financial Stability of Contractor:**
   - Bonded? Yes _____ No _____ Amounts _____
   - Licensed? Yes _____ No _____ Amounts _____
   - Insured? Yes _____ No _____ Amounts _____
3. **Professionalism and Reputation of Contractor:**
   - State Licensing Agency: _____
   - Better Business Bureau: _____
   - Local Officials: _____
   - International Association of Structural Movers: _____
   - Results of the Interview: _____
4. **Cost of Services:** _____
5. **Summary of References:** _____

Figure 5-35. Relocation contractor selection checklist



Note

The International Association of Structural Movers may be contacted at: P.O. Box 1213, Elbridge, NY 13060, (315) 689-9498, or http://www.iasm.org to obtain information on house relocation companies for a retrofitting project.

The designer and homeowner should also interview several contractors to determine:

- How well they may be able to collaborate with this contractor
- The extent of the contractor's knowledge
- Confidence that the contractor has the resources and ability to complete the relocation project

Cost of Services: While this should not be the sole determinant of contractor selection, project cost is an important factor in contractor selection. To ensure a comparison of similar levels of effort, the

designer should develop a detailed project scope of comprehensive services and have each contractor prepare a bid and proposal (including schedule) from the same scope of services. The most qualified contractor may not always have the highest cost, and conversely, the least qualified contractor may not have the lowest cost.

Step 2: Analyze the Existing Site and Structure. The designer should help the owner ensure that the contractor conducts a complete evaluation of the existing site and structure to determine critical criteria for the relocation of the structure. These criteria will include:

- Is there sufficient space around the structure for the installation of lifting beams and truck wheels?
- Can the structure be lifted in one piece, or must it be separated into sections?
- Depending on the final assessment of the structure's condition, how much bracing will be required to successfully move the structure?
- Will this structure survive the lift and travel distance to the proposed new site?
- Comprehensive assessment of all utilities requiring disconnection and associated safety or hazard concerns with utility disconnection.
- Complete list of local ordinances, regulation compliance, community requirements, and required permitting for removal of the structure from its present site, site preparation, foundation construction at the new site, and building transport. This should include utility disconnection and connection, and all other building code compliance inspection and certificate of occupancy procedures.
- Requirements and regulations for original foundation demolition and site stabilization (including pavement removal, erosion control, etc.) Specifications for size and placement of lifting beams, jacks, and lateral or cross beams.

The final project workplan detailing specifics of these issues may require finalization of the proposed building moving route, as the moving route can present other factors the contractor must consider (see Step 5).



Warning

Analysis of the existing site and structure is conducted by the moving contractor and not by the project designer. It is important that the designer and owner coordinate and communicate with the contractor on issues related to the existing and proposed site, new foundation construction, utility connections, and structure relocation.

Lifting Beam Placement: Each of the following factors for placement of lifting beams must be considered:

- Size and shape of the house
- Existing framing and parameters
- Deflection limitations
- Distribution of the house's weight

The priority concern for lifting beam placement is limiting cracking due to excessive deflections during preparation, moving, and setting on the new foundation. The lifting beams, in tandem with cross or lateral beams, must sufficiently support the structure. When the house is removed from the foundation, the lifting and lateral beams should provide support as stable as the original foundation.



Warning

If the selected contractor is not familiar with factors regarding lifting beam placement, the owner and designer might reconsider their contractor selection.

Deflection of any portion of the structure is normally a result of how the weight of the house is distributed, the location of the jacks under the lifting beams, and the rigidity of the lifting beam. Proper placement of lifting beams, jacks, and lateral beams will protect against cracking of the interior and exterior finishes, as well as ensure the integrity of the entire structure.

A second concern when installing lifting beams is to place the beams so the house can be attached to truck wheel sets, which form a trailer.

The relocation route dictates the size and weight limit of the structure due to horizontal and vertical clearances from obstructions. The house may have to be cut into sections and moved separately to negotiate the moving route. In this case, lifting beams are placed under each building section. The entire elevation framing must also be rigid enough to accommodate forces associated with movement of the house.

Heavier construction materials such as brick veneer, chimneys, and fireplaces cause additional deflection and require special attention when designing the lifting beam system. Even with minimal deflection, brick walls, veneer, chimneys, and fireplaces are vulnerable to cracking. Extra precautions, like providing additional beam support or removal of the brick for later replacement, will be necessary.

The size and shape of the building also affect the placement and number of lifting beams. A simple rectangular floor plan allows for the easiest and most straightforward elevation project. Placement of longitudinal lifting beams, with lateral beams located as required, is used for building relocation. Larger or more complex shaped buildings, like L-shaped or multi-level houses, necessitate additional lifting beams and jacks for a stable lifting support system. Consideration of all bearing loads based

upon the size and shape of the house should be incorporated into the design and layout of the lifting beam system.

Step 3: Select, Analyze, and Design New Site. The selection of a new site for relocation requires verification of:

- Regulated floodplain status, flood zone (if any), and proximity to potential flood sources
- Utility extension feasibility
- Construction accessibility
- Permitting requirements

The process mirrors new construction lot selection. Compliance with local zoning ordinances and building codes, along with approval processes, is required. In some instances, mechanical, electrical, and plumbing systems must be upgraded or replaced to meet current code requirements.

Site Access: Accessibility of the site for both the house movers and the new site construction crews is critical. Severe site access constraints can increase the cost of the relocation. Tree and vegetation removal, along with grading, may be required, which can alter or diminish the site characteristics initially desired by the homeowner.

Permits: The designer and contractor should ensure that the house will conform to zoning ordinances and building code requirements in effect at the time of relocation. The designer should contact the local regulatory officials to determine the design standards and submission process requirements that govern development of the new site. All construction permits required for demolition at the original site, foundation construction and utility connection at the new site, and building transportation should be obtained prior to initiating the relocation process. Site stabilization plans for the old site may also be required at project onset.

Step 4: Preparing the Existing Site. Initial site preparation includes clearing all vegetation, landscaping, and attachments like decks and porches from the area proximate to the building footprint (Figure 5-40). This creates a path beneath the house to allow insertion of beams for lifting supports. These pathways should be deep enough to allow for the movement of contractors and equipment.



Figure 5-36. Clearing pathways beneath the structure for lifting supports

Step 5: Analyze and Prepare the Moving Route. Once the new site has been selected, building transport must be analyzed, staged, and finalized. The route should be carefully chosen, and transportation logistics planned and finalized prior to demolition at the existing site and development of the new site.

Identify Route Hazards: Consultation with local police or public safety officials is recommended to ensure that the house can navigate the following obstacles during transportation:

- Narrow passages, such as road cuts and widths
- Bridge weight limits and widths
- Utility poles and electric, telephone, and fiberoptic lines
- Fire hydrants
- Road signage
- Steep grades
- Traffic signals
- Tight turns around buildings, bridges, and overpasses

Warning

Timing may be critical in areas with heavy morning and evening rush hour traffic. Houses are often moved during late evening and early morning hours.

Care should be taken to ensure that the structure will clear all overhead utility lines. Many of these can be lifted during the move, but utility companies often require onsite utility staff, which requires advance coordination and possible charges.

Obtain Approvals: It may be necessary to obtain moving permits, not only for the area from which the structure is being moved, but also in communities through which the structure is moving. Approvals for transport in a public right-of-way may be required from local governments, state transportation agencies, and utilities. Approvals may also be necessary from landowners if private property is crossed or affected by the move.

The time required to obtain approvals and the complexity of required information for approvals will be dependent on the local community. The designer or contractor and homeowner should investigate the approval process early to better understand overall project / moving costs, decision making, and to minimize potential delays in permitting and approval.

Coordinate Route Preparation: The moving contractor is responsible for moving route coordination including:

- Raising or relocation of utilities by utility companies; potential road and highway obstructions like traffic lights, signage, temporary bridges, etc.
- Clearing overland areas, where necessary

The moving contractor is responsible for making sure that these facilities are returned to normal operating condition immediately after the move is completed.

Step 6: Prepare the Structure. The steps involved to prepare a structure for relocation include:

Disconnect Utilities: The first step in preparing the structure is to disconnect all utilities connected to the structure. Specific requirements governing the capping, abandoning, and removal of specific utilities will be available from utility companies and local regulatory officials.

Cut Holes in Foundation Wall for Beams: From beneath the structure, the pathways for lifting beams are cut into the existing foundation (Figure 5-41).



Figure 5-37. Pathways for lifting beams

Install Beams: Lifting and lateral beams are placed beneath the structure at all critical lift points and support cribbing is added as the structure is separated from its old foundation (Figure 5-42).



Figure 5-38. Beams supported by cribbing are placed at critical lift points and lifting jacks are placed

Jacks are used to lift the structure from the foundation (Figure 5-43). Various types of jacking systems may be used to ensure gradual and uniform lifting pressures as the building is lifted.



Figure 5-39. Hydraulic jacks installed to lift structure from foundation

Install Bracing as Required: Bracing may be required to maintain structural integrity.

Structure from Foundation: The structure now stands free from its former foundation (Figure 5-44).



Figure 5-40. Structure is separated from its foundation

Step 7: Prepare the New Site. The new site is prepared for the arrival of the structure.

Design Foundation: The steps needed to design the new foundation are listed in Section 5.1.

Design Utilities: Utilities must be available for connection at the new site. Construction should follow approved design documents prepared for the new site and all building permit conditions specified by local officials (Step 3).

Excavation and Preparation of New Foundation: At the new site, excavation and preparation of the foundation begin (Figure 5-45).

Construction of Support Cribbing: Support cribbing is put in place so the building can be lifted, then the truck wheel sets are removed. With support cribbing in place, materials for completion of the foundation are prepared.



Figure 5-41. Preparation at new site

Construction of Foundation Walls: Foundation wall construction begins (Figure 5-46).



Figure 5-42. New foundation wall construction

Step 8: Move the Structure. Once the structure has been lifted, it is transported to the new site.

Excavate/Grade Temporary Roadway: Excavation and grading of a temporary roadway is done at one end of the structure. The truck wheels, which will form the trailer that will be used to move the house, are brought to the site and placed beneath the lifting and lateral beams (Figure 5-47).



Figure 5-43. Trailer wheel sets are placed beneath the lifting beams

Attach Structure to Trailer: The structure is attached to the truck wheels and then the tractor to prepare for the move from the original site (Figure 5-48). The tractor pulls the house to the street while workers continually block the wheels to prevent sudden movement. At the street, the house is stabilized and connected to a truck for transportation to the new site.

Transport Structure to New Site: With connections to the truck completed, the transport of the structure to the new site begins.

Lower Structure onto Foundation: Once the new foundation is complete, the house is lowered, cribbing is removed, and foundation connection is completed (Figure 5-49).



Figure 5-44. Trailer is used to pull the house to the street



Figure 5-45. House is lowered and connected to the foundation after foundation walls are completed

Landscaping: Finishing touches, like preparing the foundation for backfilling and landscaping, are done to blend the house into its new setting.

Step 9: Restore the Old Site. Once the structure is removed from the site, the site is stabilized in accordance with state and local requirements. Property owners sometimes sell or deed abandoned parcels to communities for parks or open spaces. Permits for demolition of the old site, remaining

foundation, and remaining utility system connections, as well as grading and site vegetative stabilization, are normally required.

Demolish and Remove Foundation and Pavement: If there was a basement, backfilling will likely be required to eliminate safety hazards. Local regulations will direct foundation and utility connection removal.

Disconnect and Remove All Utilities: The property owner may be required to remove all existing utility systems from the site. Septic tanks and oil/gas storage tanks remediation will be directed by local environmental requirements to prevent groundwater contamination. The owner may be required to drain and remove fuel and septic tanks or drain and stabilize the underground tanks to prevent flotation.

The owner may also be required to evaluate soils proximate to underground tanks to determine if leakage has occurred. If leakage is confirmed, the owner is usually responsible for contaminated soil remediation. A consultation with a qualified geotechnical or environmental engineer is recommended. Specific requirements for capping, abandoning, or removal of utilities should be determined from the local utility companies or local government officials.

Grading and Site Stabilization: The old site may require grading following excavation and heavy equipment use. The parcel lot will require vegetative stabilization as required by the local community.

Material from drained septic, oil, and gas storage tanks must be disposed of safely in compliance with local requirements.

5.4. Summary: Elevation and Relocation Techniques

An Elevation and Relocation Assessment Worksheet, shown in Figure 5-50, can be used to select the best structural elevation, alternative elevation, and/or relocation measures for the project.

Elevation and Relocation Assessment Worksheet								
Owner Name:						Preparer		
Address:						Date:		
Property Details:								
Elevation and Relocation Measures								
Structural Elevation			Elevation Alternatives			Relocation		
Stem Wall (Fill)	Perimeter Wall/ Piers	Piles	Basement Infill	Abandon/ Repurpose Lowest Floor	Elevate Lowest Interior Floor			
Discussion Questions			**Responses to Discussion Questions**					
1. After reviewing the project information and retrofitting matrices, which elevation or relocation option is best suited for the homeowner?								
2. Is the home's First Floor Elevation (FFE) currently below the Base Flood Elevation (BFE) on the current Flood Insurance Rate Map (FIRM)? If so, by how much?								
3. If the home is elevated to 2 ft above BFE, how high would the structure need to be raised?								
4. Does the elevation or relocation address future conditions such as more severe riverine flooding from increased precipitation or more severe coastal flooding from sea level rise?								
5. What elevated foundation option is most feasible to elevate the existing structure?								
6. Does a basic set of stairs seem adequate for homeowner access? If not, what is an alternative?								
7. Will FEMA Hazard Mitigation Assistance grant funds support elevation of building accessories (i.e., decks, porches)?								
8. What building utility systems and equipment must be elevated or relocated?								
9. Does the proposed elevation height surpass the flood of record at the site?								
10. Are there any other issues that need to be considered prior to selecting elevation or relocation as a final option?								
FINAL OPTION DETERMINATION			Structural Elevation			Elevation Alternatives		Relocation
Purpose:	The purpose of the Elevation and Relocation Assessment Worksheet is to develop a final technical assessment of structural elevation, elevation alternatives and relocation measures to determine what option(s) are the most feasible and recommended for final analysis.							

Figure 5-46. Elevation and Relocation Assessment Worksheet

5.5. Case Study Exercise 6 – Elevation and Relocation Assessment

Use new Elevation and Relocation Assessment Worksheet to assess elevation and relocation techniques for one of the two case study buildings (see Note).

Note

Case Study B was not considered for Exercise 6 because the assessment of flood retrofits for The Valley Apartments in previous exercises did not indicate any options for elevation or relocation. Therefore, the Elevation and Relocation Assessment Worksheet is not applicable to Case Study B.

Case Study A – Exercise 6

Case Study A – Exercise 6: Residential Retrofit in Riverine Floodplain Using Relocation or Elevation

As Mr. and Mrs. Doe evaluated the flood retrofit options of elevation, elevation alternatives, and relocation, the Elevation and Assessment Worksheet shown in Figure CSA-17 helped determine the most feasible option of the three. Mr. and Mrs. Doe answered ten questions for a final technical assessment, which resulted in two options: elevating the house using perimeter walls or relocating it.

Elevation and Relocation Assessment Worksheet			
Owner Name:	John and Jane Doe	Preparer	JJS-MH
Address:	55 Cedar River Road	Date:	7/6/2026
Property Details:	Case Study A		

Elevation and Relocation Measures						
Structural Elevation			Elevation Alternatives			
Stem Wall (Fill)	Perimeter Wall/ Piers	Piles	Basement Infill	Abandon/ Repurpose Lowest Floor	Elevate Lowest Interior Floor	Relocation

Discussion Questions	Responses to Discussion Questions
1. After reviewing the project information and retrofitting matrices, which elevation or relocation option is best suited for the homeowner?	Elevation on Perimeter Foundation Walls/Piers
2. Is the home's First Floor Elevation (FFE) currently below the Base Flood Elevation (BFE) on the current Flood Insurance Rate Map (FIRM)? If so, by how much?	Yes. FFE is below BFE by (697.8 - 694.2) = 3.6 feet
3. If the home is elevated to 2 ft above BFE, how high would the structure need to be raised?	(BFE + 2 ft) = (3.6 ft + 2 ft) = 5.6 ft
4. Does the elevation or relocation address future conditions such as more severe riverine flooding from increased precipitation or more severe coastal flooding from sea level rise?	Unknown
5. What elevated foundation option is most feasible to elevate the existing structure?	Structural Elevation on Perimeter Foundation Walls with Interior Piers
6. Does a basic set of stairs seem adequate for homeowner access? If not, what is an alternative?	Yes
7. Will FEMA Hazard Mitigation Assistance grant funds support elevation of building accessories (i.e., decks, porches)?	Not Applicable
8. What building utility systems and equipment must be elevated or relocated?	HVAC compressor
9. Does the proposed elevation height surpass the flood of record at the site?	No
10. Are there any other issues that need to be considered prior to selecting elevation or relocation as a final option?	Feasibility of bringing in elevation equipment. Lack of affordable property outside the floodplain for relocation.

FINAL OPTION DETERMINATION	Structural Elevation	Elevation Alternatives	Relocation
	Perimeter Walls		Relocation

Purpose:	The purpose of the Elevation and Relocation Assessment Worksheet is to develop a final technical assessment of structural elevation, elevation alternatives and relocation measures to determine what option(s) are the most feasible and recommended for final analysis.

Figure CSA-17. Elevation and Relocation Assessment Worksheet for the Doe house

Chapter 6. Floodproofing and Flood Barrier Techniques

Chapter 5 addressed elevation and relocation techniques for retrofitting flood-prone residences. Chapter 6 addresses floodproofing options, including wet and dry floodproofing and barriers like floodwalls and berms. National Flood Insurance Program regulations define floodproofing as:

> "any combination of structural and nonstructural additions, changes, or adjustments to structures which reduce or eliminate flood damage to real estate or improved real property, water and sanitary facilities, structures and their contents" (Title 44 Code of Federal Regulations Section 59.1).



Note

The work necessary to implement floodproofing measures is categorized as "alterations." An alteration is "any construction or renovation to an existing structure other than a repair or addition." When local officials determine that a proposed alteration will be a substantial improvement, the building must be brought into National Flood Insurance Program compliance with Special Flood Hazard Area new construction requirements. Floodplain management ordinance prohibits use of residential dry floodproofing when National Flood Insurance Program compliance is required, while wet floodproofing is allowed in residential buildings in non-living spaces used for parking, access, and limited storage below the elevated lowest floor.

In general, the techniques discussed in Chapter 2 for retrofitting flood-prone residences, including wet floodproofing, dry floodproofing, flood walls and flood berms may be appropriate for retrofitting existing buildings that have not been Substantially Improved/Substantially Damaged (see Note above); however they are not acceptable for retrofitting Substantially Improved/Substantially Damaged existing buildings or for new construction in the Special Flood Hazard Area in order to achieve compliance under the National Flood Insurance Program. For this reason, since regulatory compliance is not assumed to be required, **the Floodproofing Design Depth (H) used in Chapter 6 will be determined by the flood protection level (see Note below) and is intended as option to reduce flood damage.** Additionally, most of the floodproofing options presented in Chapter 6 are active measures that rely on human intervention (see Warning on the next page).

Note

As stated above, the Floodproofing Design Depth (H) used in Chapter 6 will be determined by the flood protection level. As used in this manual, the flood protection level is the elevation of flood protection selected by the owner and used by the designer to evaluate and design retrofitting measures when compliance with requirements for new construction or substantial improvement/damage is not required. Owners and designers have the option to set the flood protection level to the Design Flood Elevation (DFE) to further reduce flood risk, but the higher level of protection afforded by the Design Flood Elevation will not allow the floodproofing or flood barriers to achieve regulatory compliance with the National Flood Insurance Program for substantial improvement/damage.

Warning

Active mitigation measures rely on human intervention to be effective, while passive mitigation measures do not rely on human intervention. Chapter 5 elevation and relocation techniques are passive measures effective at reducing or eliminating flood damage without human intervention. However, most of the floodproofing and flood barrier techniques presented in Chapter 6, specifically dry floodproofing (Section 6.2), require adequate warning to enable installation of flood shields and pumps (with back-up power), valve closures, and safe evacuation.

Finally, Chapter 5 elevation and relocation techniques rely on simple measures that reduce residual risk; thus, the measures can still be effective at reducing damage even if a flood exceeds the designed flood depth. However, the floodproofing and flood barrier techniques in Chapter 6 are complex measures with substantial residual risk, meaning the measures are likely to fail and provide little protection if the design flood depth is exceeded or even if one mitigation element fails.

6.1. Wet Floodproofing

Wet floodproofing can be defined as the use of flood damage-resistant materials and construction techniques to minimize flood damage, intentionally allowing floodwaters to enter and exit structures, while protecting utility equipment and key contents. Wet floodproofing measures are intended to let floodwaters flow through a structure without causing damage that requires more than cleanup and cosmetic repairs. “Wet floodproofing” is sometimes used to refer to the requirements for enclosures below elevated buildings in Zone A, where the enclosures are used only for parking of vehicles, storage, and building access. Permanent or contingent wet floodproofing measures applied to a structure and/or its contents are intended to be automatic (passive), but some measures may require human intervention to maximize resistance to flood damage (active).

Wet floodproofing can be defined as the use of flood damage-resistant materials and construction techniques to minimize flood damage, intentionally allowing floodwaters to enter and exit structures,

while protecting utility equipment and key contents. Wet floodproofing measures are intended to let floodwaters flow through a structure without causing damage that requires more than cleanup and cosmetic repairs. “Wet floodproofing” is sometimes used to refer to the requirements for enclosures below elevated buildings in Zone A, where the enclosures are used only for parking of vehicles, storage, and building access. Permanent or contingent wet floodproofing measures applied to a structure and/or its contents are intended to be automatic (passive), but some measures may require human intervention to maximize resistance to flood damage (active).



Note

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

Allowing flooding of a building’s interior is intended to counteract hydrostatic pressure on the walls, floors, and supports of the structure by equalizing interior and exterior water levels. 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 relocation, modification of equipment and contents, operations and maintenance procedures, and emergency preparedness for actions that require human intervention. This section examines the following key components of wet floodproofing:

- Structure protection (Section 6.1.1)
- Hydrostatic openings (Section 6.1.2)
- Flood damage-resistant materials (Section 6.1.3)
- Utility equipment and key content protection (Section 6.1.4)
- Enhanced preparations and procedures (6.1.5)



Warning

The National Flood Insurance Program allows wet floodproofing of residential buildings in limited situations. The most common application is with existing structures within the Special Flood Hazard Area not subject to National Flood Insurance Program requirements, nor its associated Substantially Improved/Substantially Damaged triggering criteria. However, they may be subject to an Authority Having Jurisdiction’s building code or floodplain management requirements that are more restrictive than the National Flood Insurance Program. Existing structures can be retrofitted using any retrofitting method, but for existing structures that are Substantially Improved/Substantially Damaged or new structures, application of wet floodproofing techniques is limited to the following:

Enclosed areas below the Base Flood Elevation are used solely for building access, vehicle parking, or storage. These areas must be designed to allow automatic entry and exit of floodwater through openings. Flood damage-resistant materials are used in these areas.

Accessory structures constructed with the structure floor slab below the Base Flood Elevation must be designed to allow for the automatic entry and exit of floodwater. Openings are required in the structure's exterior walls or the structure's doors. Areas below the Base Flood Elevation must be constructed with flood-damage resistant materials.

FEMA has advised communities that variances to allow wet floodproofing may be issued for certain categories of structures (see Cross Reference).

Cross Reference

- FEMA National Flood Insurance Program Technical Bulletin 7, *Wet Floodproofing Requirements and Limitations for Buildings Located in Special Flood Hazard Areas in Accordance with the National Flood Insurance Program*, May 2025.
- FEMA P-936, *Floodproofing Non-Residential Buildings*, Section 4,2, July 2013.
- FEMA P-2140, Floodplain Management Bulletin: Floodplain Management Requirements for Agricultural Structures and Accessory Structures, July 2020.

6.1.1. STRUCTURE PROTECTION

Developing a wet floodproofing strategy requires site-specific evaluation by a design professional. Failure of various structural components (foundations, cavity walls, and solid walls) subjected to flood inundation is a major cause of structural damage. Some of the reasons a homeowner may want to consider wet floodproofing include:

- It is an existing house located in an area below the Base Flood Elevation
- It is a historic structure, and elevation is not an option
- It has an attached garage
- It is in an area outside the Special Flood Hazard Area where there is significant nuisance flooding potential
- It has accessory structures (e.g., detached garage or storage shed)

The following is a description of various building structural elements that can be wet floodproofed. Each section explains the typical wet floodproofing building materials and precautions for each method.

In some locations, ASCE 24 requirements may be incorporated into the local building code. This standard includes minimum requirements for wet floodproofing (Section 6.3), specifically limitations of use for the space and design load minimums. It also presents requirements for utilities located below the minimum elevation requirements. Other sections of the standard discuss flood damage-resistant materials (Section 5.0) and minimum design elevations below which more stringent design requirements are required (Chapter 1 of ASCE 24).

While wet floodproofing offers an improved level of protection for a structure, extended floodwater inundation can still damage building components. Additionally, areas of the home above the wet floodproofed surfaces are still at risk of damage from higher-than-expected floodwater, contamination, toxic materials near the house, or growth of mold from extended inundation or high humidity. The damage risk is referred to as the residual risk for the structure. While residual risk can be financially reduced with the purchase of flood insurance, homeowners living in a flood-prone area should be aware that risk cannot be eliminated by either physical risk reduction measures, floodproofing, or financial risk reduction measures, such as insurance. The selected level of flood protection should be consistent with the owner's ability to absorb the residual risks. Many design guidance documents and design standards, such as ASCE 24, incorporate additional elevation above the Base Flood Elevation to reduce risk. However, the designer and homeowner should be aware that the floodwater can exceed this additional elevation, requiring methods to address the inherent residual risk.

Foundations

Floodwaters can adversely affect the integrity of the structure's foundation by eroding supporting soils, scouring foundation materials, and undermining footings. This requires careful review of foundation designs and construction. Footings should be located deep enough below grade so that flood-related erosion and scour do not reach the top of the footing. It is vital that the structure is adequately anchored to the foundation. A continuous load path is necessary to withstand uplift forces during a flood, which are often large 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 flooding can be resisted. Areas where cripple walls are used should be checked to verify proper earthquake bracing.

Cavity Walls

Wet floodproofing equalizes hydrostatic pressure throughout the structure by allowing floodwater to enter the structure and equalize internal and external hydrostatic pressures. Any attempt to seal internal air spaces within the wall system is not only technically difficult but 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 rate of rise and fall of floodwater. Insulation within cavity walls subject to flooding should also be resistant to flood damage. The design of foundation openings to equalize hydrostatic pressure is covered later in this section. Following a flood, it may be necessary to remove one side of a cavity wall to allow the interior to properly dry. It is important to verify that drainage or weep holes remain clear of debris. Although not always an indicator of trapped water within a cavity wall system, the presence of dried white salt crystals called efflorescence on a wall system may indicate improper drainage or a lack of sufficient drainage (weep) holes. This type of crystallization may be present in cavity or solid walls, indicating significant moisture infiltration.

Solid Walls

Solid walls are designed without internal spaces that can retain floodwater. Since these walls are somewhat porous, they can absorb moisture and associated contaminants. Such intrusion can cause internal damage, especially in cold (freeze-thaw) weather conditions. Where solid walls are built of porous material, retrofitting measures should include exterior and interior protective cladding to guard against absorption. Some liquid products may be applied to both sides of porous wall systems. It is possible for voids or cavities within solid wall systems to be open and not grouted, retaining additional moisture. These are difficult to grout during retrofitting and may require draining following flooding.

As discussed in Chapter 5, it is important that the base of elevated foundation walls or enclosures below the Design Flood Elevation contain openings that permit automatic entry and exit of floodwaters. These openings, known as hydrostatic openings, allow floodwater to reach equal levels on both sides of the walls and thereby lessen the potential for damage from unequal flood forces due to net hydrostatic pressure (Figure 6-1). While not a requirement for existing buildings built prior to a community adopting National Flood Insurance Program regulations, the National Flood Insurance Program requires hydrostatic openings for all new construction and substantial improvements of existing buildings in Special Flood Hazard Areas.

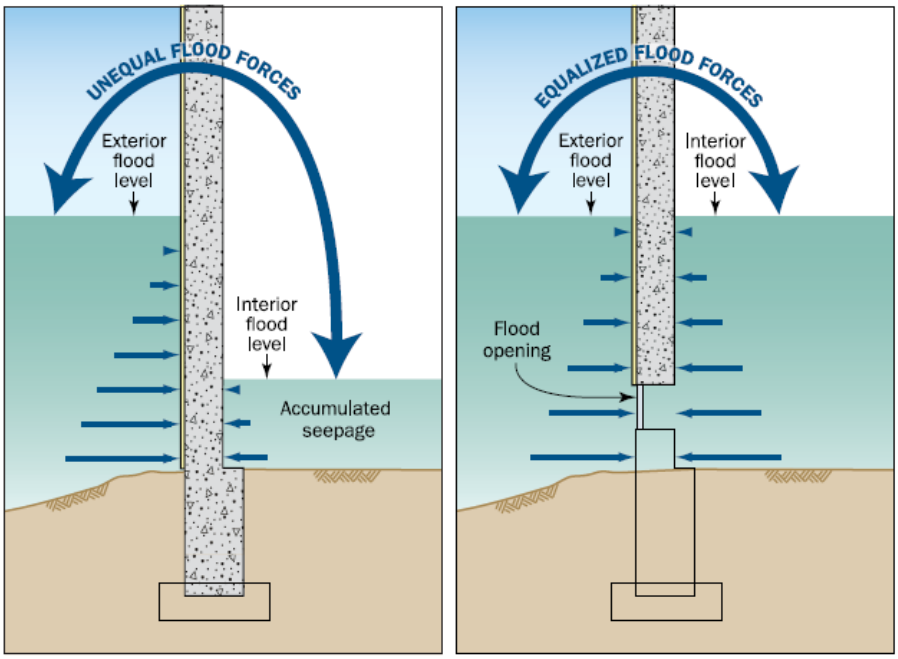


Figure 6-1. Openings to equalize flood forces (hydrostatic forces) on exterior walls (Source: National Flood Insurance Program Technical Bulletin 1, Figure 1)

The following minimum criteria for design of these openings are outlined in National Flood Insurance Program Technical Bulletin 1, *Requirements for Flood Openings in Foundation Walls and Walls of Enclosures Below Elevated Buildings Located in Special Flood Hazard Areas in Accordance with the National Flood Insurance Program* (FEMA, March 2020):

- A minimum of two openings must be provided on different sides of each enclosed area (Figure 6-2), having a total net area of not less than one square inch for every square foot of enclosed area subject to flooding. The one square inch per square foot requirement can be less if openings are engineered and certified.
- The bottom of all openings shall be no higher than one foot above grade (Figure 6-3).
- The openings may be equipped with screens, louvers, or other coverings or devices, provided such components permit automatic entry and exit of floodwater and do not reduce the net open area to less than the required open area.

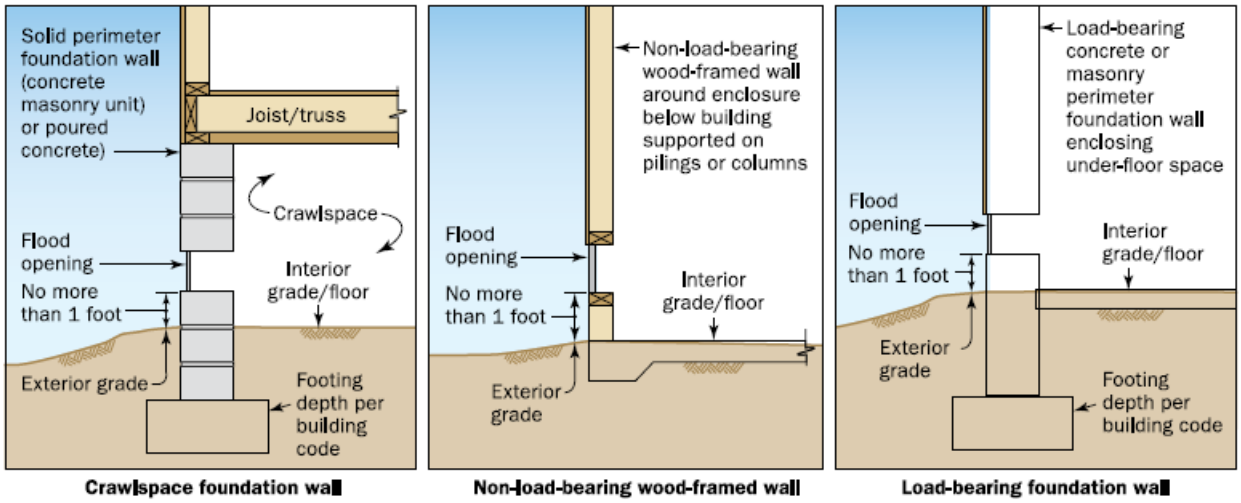


Figure 6-2. Typical enclosures with hydrostatic openings (Source: National Flood Insurance Program Technical Bulletin-1, Figure 2)

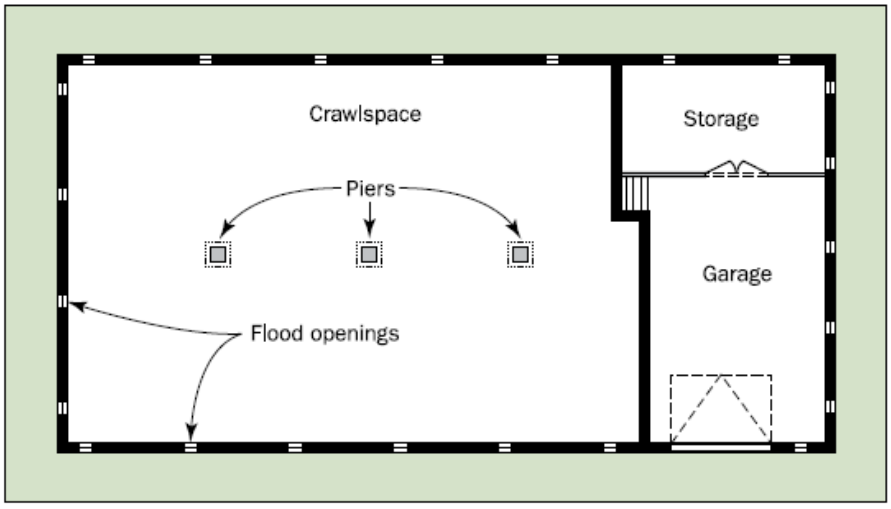


Figure 6-3. Foundation plan of residence showing flood openings for each enclosed area (Source: National Flood Insurance Program Technical Bulletin-1, Figure 3)

In wet floodproofed buildings, hydrostatic openings obstructed by debris, drywall, or other wall coverings can result in significant damage if the opening does not operate as intended. Figure 5-17

in the previous chapter shows an National Flood Insurance Program-compliant house with an attached garage with flood openings to prevent the build-up of hydrostatic loads on the foundation walls.

Cross Reference

For additional information on the regulations and design guidelines concerning foundation openings, refer to FEMA 's National Flood Insurance Program Technical Bulletin 1, *Requirements for Openings in Foundation Walls and Walls of Enclosures Below Elevated Buildings Located in Special Flood Hazard Areas in Accordance with the National Flood Insurance Program* (FEMA, March 2020).

Flood Damage-Resistant Materials

In accordance with the National Flood Insurance Program, all materials exposed to floodwater must be durable, resistant to flood forces, and capable of withstanding direct and prolonged contact with floodwater without sustaining significant damage. "Prolonged contact" means at least 72 hours, and "significant damage" means any damage requiring more than cosmetic repair. "Cosmetic repair" includes cleaning, sanitizing, and resurfacing the material (e.g., sanding, repair of joints, repainting). Interior building elements such as wall finishes, floors, ceilings, roofs, and building envelope openings can also suffer significant damage from flood inundation, which can lead to structure failure, damage, or contamination. 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 not be susceptible to damage from inundation and should be easy to clean and sanitize. Likewise, floors, ceilings, roofs, connectors, fasteners, gaskets, and building envelope openings should be constructed of flood-resistant materials to minimize damage from flooding.

Flood damage-resistant materials performance requirements indicate that masonry or concrete construction is the most suited to wet floodproofing. In some cases, wood or steel structures may be suitable, provided that the wood is preservative-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 National Flood Insurance Program Technical Bulletin 2, *Flood-Resistant Materials Requirements for Buildings Located in Special Flood Hazard Areas in Accordance with the National Flood Insurance Program (*FEMA January 2025). Tables 1 and 2 in Technical Bulletin 2 can be used as a guide to select structural material (framing and some sheathing) and nonstructural material (coverings, finishes, insulation, cabinets, doors, partitions, and windows) building components for use below the Base Flood Elevation. Some combinations of acceptable materials may result in unacceptable conditions. Always refer to the manufacturer's specifications for more information. Additionally, Technical Bulletin 2 provides an alternative approach to assessing performance of flood damage-resistant materials not listed in Tables 1 and 2 using the following ASTM standards:

- ASTM E3075, *Standard Test Method for Water Immersion and Drying for Evaluation of Flood Damage Resistance* (ASTM, 2024a).
- ASTM E3369, *Standard Specification for Determining the Flood Damage Resistance Rating of Building Materials* (ASTM, 2024b).

Finally, Technical Bulletin 2 also explains the criteria for selecting connectors and fasteners for use below the Base Flood Elevation. It should be noted that locally enforced building codes may include stricter provisions than those in Technical Bulletin 2.

Cross Reference

For additional information on flood damage-resistant materials, refer to FEMA's National Flood Insurance Program Technical Bulletin 2, *Flood-Resistant Materials Requirements for Buildings Located in Special Flood Hazard Areas in Accordance with the National Flood Insurance Program* (FEMA, January 2025).

6.1.2. UTILITY EQUIPMENT AND CONTENT PROTECTION

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. Utility systems include HVAC systems, appliances, electrical, and plumbing systems. Isolation of utility equipment components can occur through relocation, elevation, or protection in place (Figure 6-4).

Local codes may require ASCE 24 Section 7.0, which provides guidance on electrical, plumbing, sanitary sewer, mechanical, HVAC systems, and elevators. Depending on the building classification, Chapter 1 of ASCE-24 states minimum elevation requirements for utility and attendant equipment protection. Utilities and attendant equipment below this elevation will require increased load and design requirements. Some of these requirements state minimum load requirements, while others state use requirements during and immediately after a flood. Although utilities and attendant equipment may be located above the minimum requirements, ASCE requirements extend to wires, pipes, lines, etc., located below the minimum elevation.



Figure 6-4. Elevated air conditioning compressor

Site Inspection

A thorough site inspection will provide detailed information about the existing structure to inform calculations concerning the feasibility of using wet floodproofing. Use Figure 6-5 and Figure 6-6 as a guide to record information.

The designer should complete the Flood-Resistant Retrofitting Site Visit Worksheet to confirm the floodproofing approach selected and develop a preliminary concept of wet floodproofing measures.

Then, the designer should discuss the following items with the homeowner:

- Previous flood history, flood depths, and equipment/systems impacted by floods.
- Plan of action for equipment relocation and what equipment will remain below the Design Flood Elevation.
- 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, code violations, and/or exceptions to current codes.

Flood-Resistant Retrofitting Site Visit 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 6-5. Flood-Resistant Retrofitting Site Visit Worksheet (Sheet 1 of 2)

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 6-6. Flood-Resistant Retrofitting Site Visit Worksheet (Sheet 2 or 2)

6.1.3. DESIGN PROCESS AND ALTERNATIVE APPROACHES

The process to design and implement existing building utility systems flood retrofitting may require a combination of elevating and/or protecting in place. The design process involved with wet floodproofing of utilities is shown in Figure 6-7. The two general alternative approaches are to elevate or protect in place.

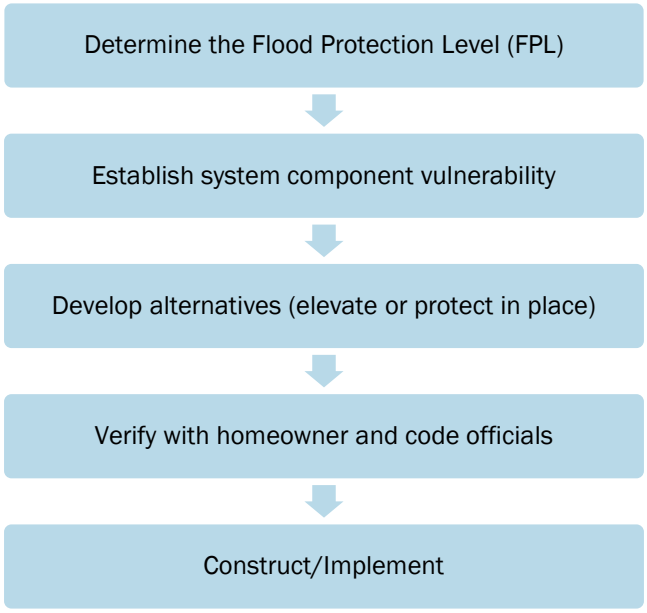


Figure 6-7. Wet floodproofing of utilities design process

- **Elevation.** The most effective protection for equipment and contents is to elevate and/or relocate (permanently or temporarily) threatened items above the flood protection level. Both inside and outside of the flood-prone structure, key components such as HVAC compressors can be elevated on specially constructed platforms or pedestals (see Figure 6-4). Relocated utilities placed on pedestals are subject to wind and earthquake damage, so they require securing against wind and seismic forces.

- **In-Place Protection.** Some utilities can be protected in place through options, such as anchors and tie-downs to prevent flotation, low barriers or shields, and protective coatings. Flood enclosures to protect utilities (see Figure 6-8) should be considered a last resort option if equipment cannot be relocated.

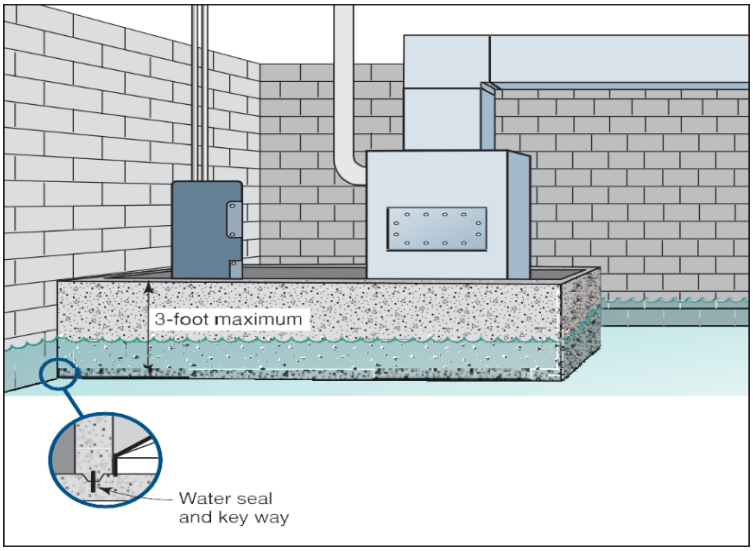


Figure 6-8. Flood enclosure protects basement utilities from shallow flooding

6.1.4. SPECIFIC PROTECTION TECHNIQUES FOR VARIOUS TYPES OF UTILITY SYSTEMS

Heating, Ventilation, and Air Conditioning (HVAC) Systems

HVAC system equipment (i.e., furnaces, boilers, compressors, air handlers, ductwork) should be elevated/relocated above the flood protection level whenever possible (Figure 6-9) or protected within a watertight enclosure as a last resort. 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 the 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 Design Flood Elevation whenever possible.
- Suitability of protective partitions or vaults.
- Reconfiguration of ductwork.
- Consideration of duct construction material.
- Modification of hot water or steam circulation piping.



Note

Generally, if flooded, ducts made of duct board or similar are not reusable.

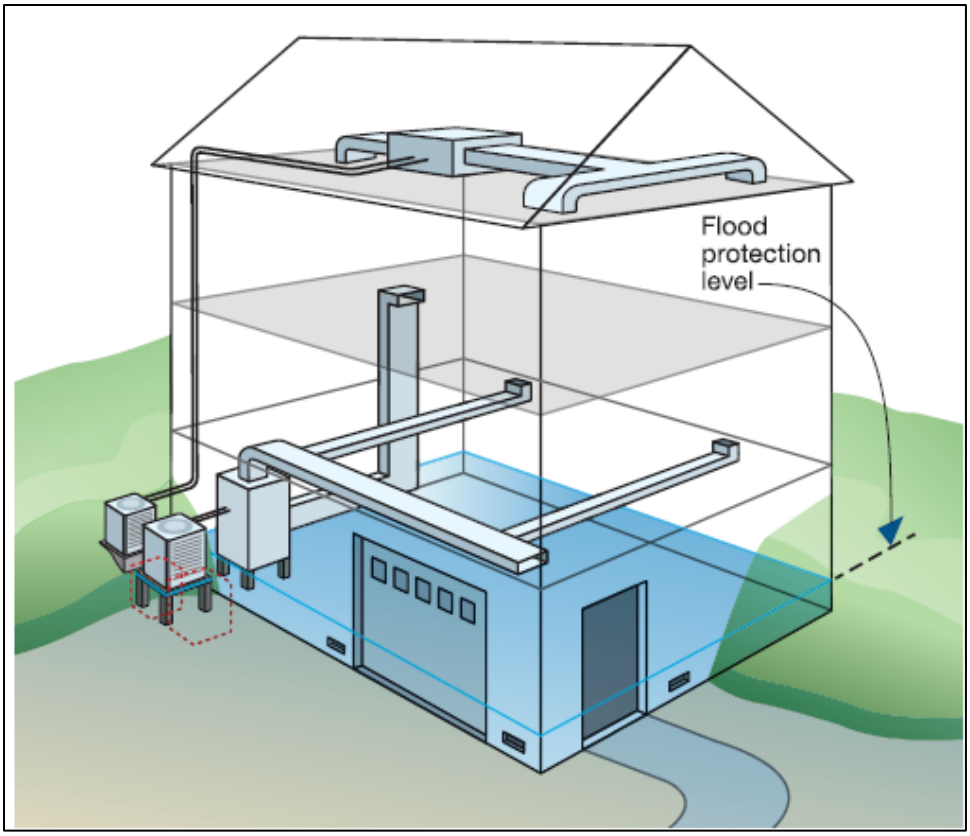
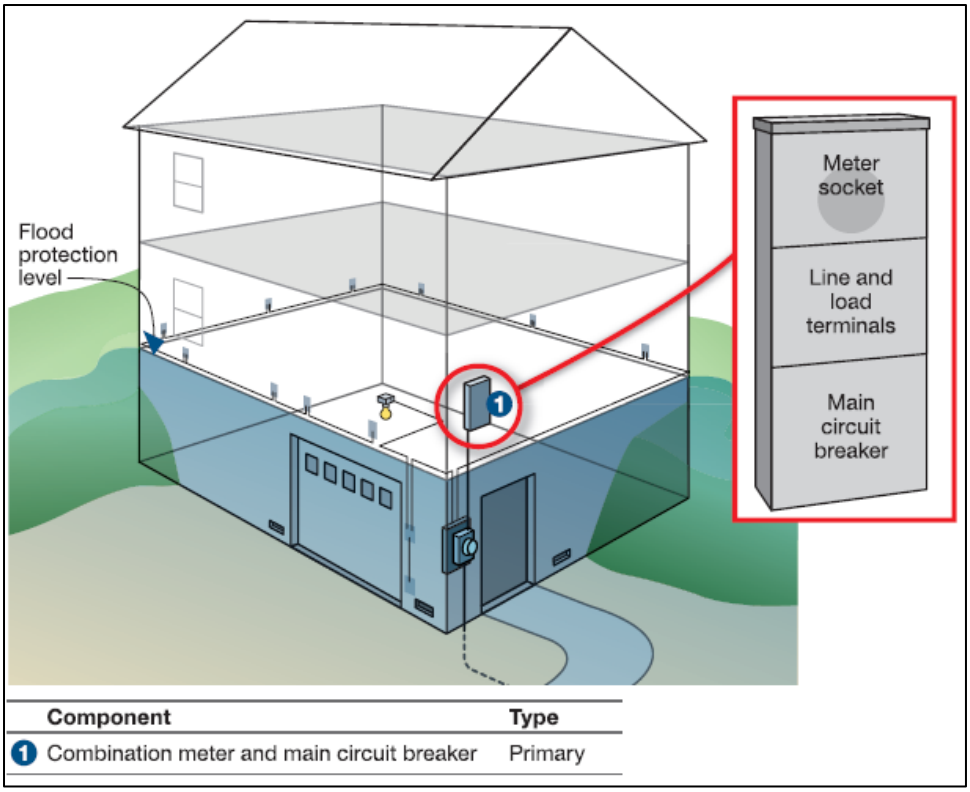


Figure 6-9. Elevation of interior and exterior HVAC equipment (Source FEMA P-348, Figure 4-4)

Electrical Systems

Electrical system components can be seriously damaged by floodwater when either active or inactive (i.e., energized or non-energized). Floodwater affects the operation of electrical devices, circuit breakers, receptacles, and wiring. Although most houses were not designed to mitigate potential flood damage to electrical equipment, there are retrofitting steps that will provide optimum protection for the electrical systems:

- The most important step is to raise or relocate equipment and devices above the Design Flood Elevation (Figure 6-10).
- A second step is to seal electrical equipment penetrations on outside walls, anchor cables, and raceways, and mechanically protect the wiring system in flood-prone locations.



Component	Type
1 Combination meter and main circuit breaker	Primary

Figure 6-10. Elevation of electrical outlets with combined meter socket and circuit breaker service disconnect (Source FEMA P-348, Figure 4-12)

- A third 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 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 is underground, it is important to verify that they are buried to a sufficient depth to eliminate them from being uncovered by erosion or scour. If possible, mount the meter above the flood protection level and sufficiently secure it and the service lines below the flood protection level to resist flood loads.

When it is not feasible to elevate in place, apply the following design considerations and details that govern the retrofitting of electrical equipment and circuits below the flood protection level:

- 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 run vertically, to enable 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.
- All required circuits below the flood protection level should be protected by separate GFCI breakers, clearly marked in the breaker box. This allows power to be turned off to isolated circuits below the flood protection level without affecting the rest of the home.
- Wiring splices below flood protection level 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 P-348, *Protecting Building Utilities From Flood Damage* (Edition 2, February 2017).

Plumbing Systems

Plumbing systems include potable water and wastewater. Floodwater threatens potable water systems with velocity flow damage and contamination. Contamination from flooding 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 potable water systems include:

- Minimization of plumbing fixtures below the Design Flood Elevation (Figure 6-11).
- Protection of system components from high velocity flow.
- Suitability of protective partitions or vaults.
- Modification of the well top using watertight casing.

Note

Adequate protection of 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.

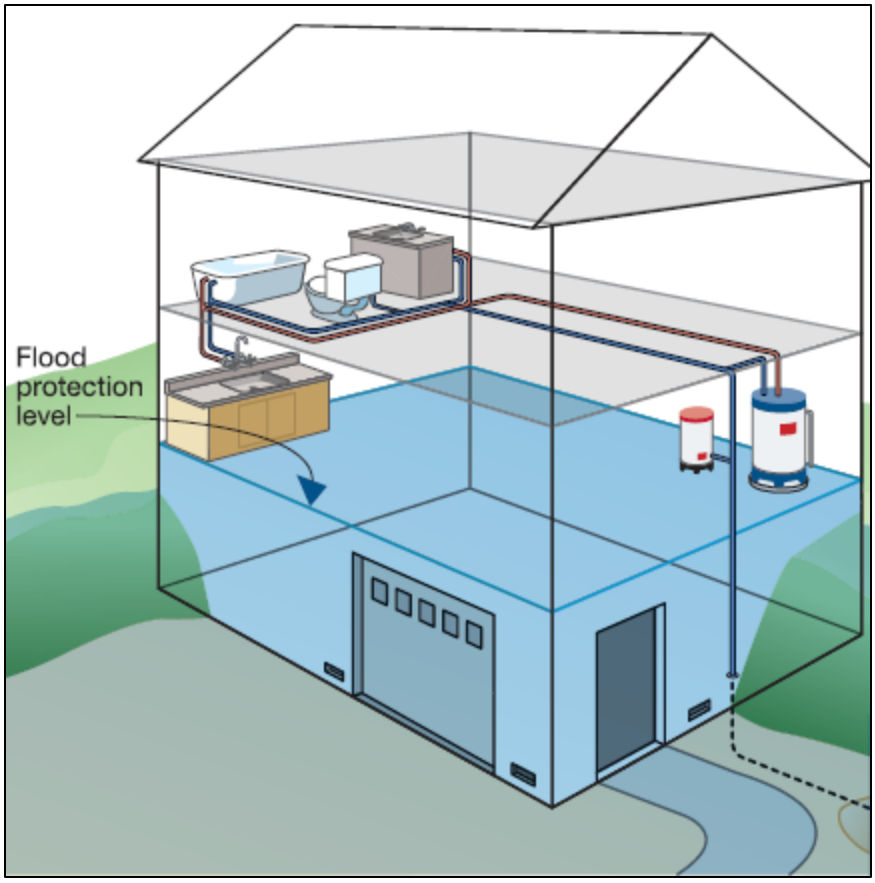


Figure 6-11. Relocation of potable water system components to an upper floor (Source FEMA P-348, Figure 4-22)

Wastewater (Sewer)

The main dangers associated with the flooding of sewer systems are backup of sewage, damage to system components, and contamination. Because these dangers could result in serious health risks, preventive measures reduce contamination risk and minimize post-flood sanitation measures. Retrofitting sewer systems to eliminate or minimize the dangers includes:

- Relocation of collection components to a higher elevation.
- Installation and/or maintenance of backflow prevention devices including a combination of check and gate valves (see Figure 6-12).
- Installation of an effluent ejector pump, with provision of a backup power source.
- Sealing tanks to prevent contamination, and adding adequate anchorage to withstand buoyancy forces.

Note

Septic tank anchoring is applicable to other types of underground storage tanks.

Warning

When subject to flood forces, natural gas, oil, or propane ruptured tanks pose additional risk of explosion or environmental contamination.

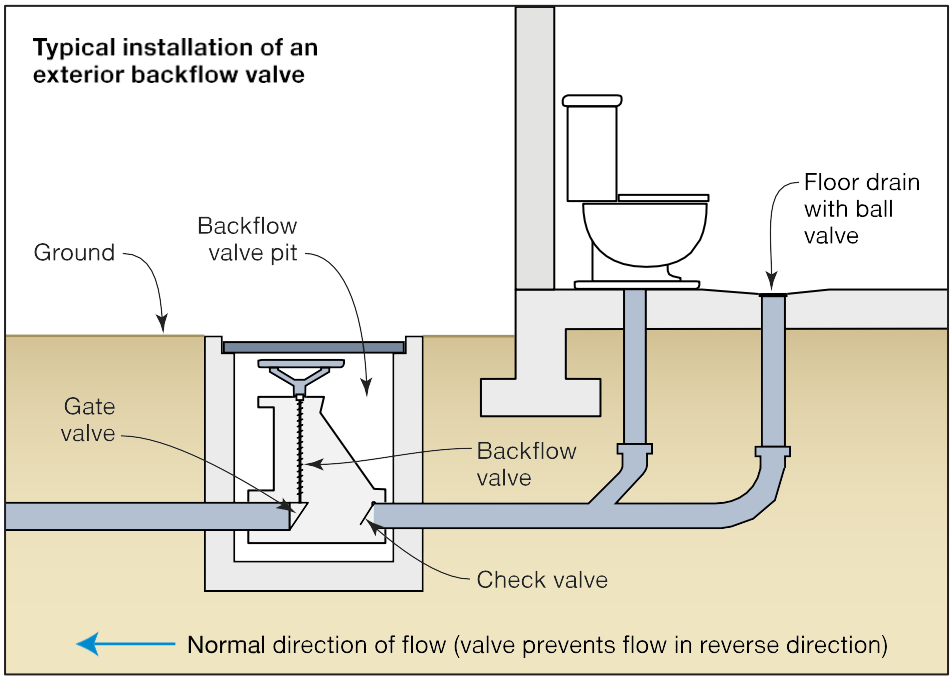


Figure 6-12. Backflow valve – a check valve and gate valve with an effluent pump bypass

It is important to prevent infiltration into and discharge from sanitary sewage storage systems during and immediately following a flood. In areas where ASCE 24 is required, Section 7.3.4 specifically outlines sizing requirements for sealed storage tanks during and after floods while the soil is saturated. The requirements are intended to prevent further contamination of the floodwaters. Even if ASCE 24 is not a required design standard, it can still be used as best practice guidance for sealed sanitary storage tank sizing design.

Fuel Systems and Tanks

While retrofitting HVAC equipment, the designer must consider rerouting and/or extending fuel supply lines (fuel oil, natural gas, and propane) when equipment is relocated. Floodwaters can displace poorly anchored tanks off their foundations, resulting in damage and discharge of toxic liquids. To prevent damaged fuel supply or storage tanks, the following should be considered:

- 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 a braced platform (Figure 6-13) or structural fill
    - Anchoring tanks through proper design and installation of ground anchors
    - Anchoring supply lines to the downstream side of structural members
    - Relocating fuel tank in support of equipment relocation
    - Using automatic cutoff valves

Note

In post-flooding situations, designers may recommend replacing old equipment to meet current codes, improve efficiency, and strengthen anchoring to counter loads associated with the given location. In some cases, old equipment may be replaced with lateral or in-line equipment installed in the attic for flood protection.

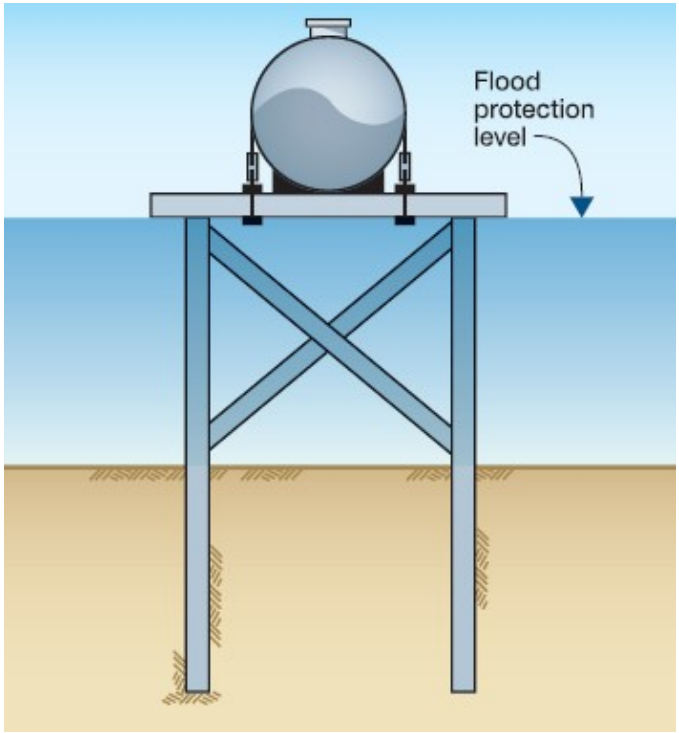


Figure 6-13. Fuel tank elevated on supporting frame (Source: FEMA P-348 Figure 4-32)

Anchoring tank systems consist 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 shown in the net buoyancy force computation in Equation 6-1.

EQUATION 6-1: NET BUOYANCY FORCE ON A TANK

$$F_b = [0.134 V_t \gamma_w FS] - W_t$$

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 6-2.

EQUATION 6-2: CONCRETE VOLUME REQUIRED TO OFFSET BUOYANCY

$$V_c = \frac{F_b}{(S_c - \gamma_w)}$$

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.

Note

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

Warning

Retrofitting of utility systems, whether elevating and protecting in place, must conform to the requirements of local and state building codes, standards, floodplain ordinances, and equipment manufacturer's installation instructions.

6.1.5. ENHANCED PREPARATIONS AND PROCEDURES

Enhanced preparations and procedures for use of wet floodproofing techniques involve planning to ensure the structure maintains its key requirements for daily use by allocating space with consideration of each element's potential for flood damage. Daily operations and space use can be organized and modified to minimize damage caused by floodwater before, during, and after a flood.

Flood Warning System

Wet floodproofing will, in most cases, require some human intervention when a flood is imminent, so it is extremely important that there be adequate time to implement an active floodproofing system. This may be as simple as monitoring local weather reports, the National Weather Service alert system, or a local flood warning system.

Emergency Operations Plan

An emergency operations plan is essential when floodproofing requires human intervention, such as relocation of key contents and equipment, such as valuable items, computers, electronics, and small appliances. A list of specific actions and the location of necessary materials to perform these actions should be developed for the floodproofed home.

Inspection and Maintenance Plan

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

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 flooding to facilitate quickly moving stored items to safety.

Some owners have marked a wall to memorialize the flood protection level or historic flood level as a reference/reminder of how high to elevate building contents.

After flooding, it is important that all inundated building elements, especially utility system components, be thoroughly inspected for damage to determine whether they are safe to use or re-energize. Simply drying out systems may not be adequate to prevent the potential negative health effects of contamination or mold, or the threat of fire from corroded system components.

The following basic procedures should be followed when cleaning up or restoring buildings after they have been flooded:

1. **Air out:** Open windows and doors to maximize air flow.
2. **Move out:** Remove contents for restoration or disposal.
3. **Tear out:** Remove flood-affected porous wall materials, insulation, carpeting, flooring, and electrical components.
4. **Clean out:** Thoroughly clean and sanitize interior surfaces.
5. **Dry out:** Allow sufficient time for drying before initiating reconstruction.



Note

When cleaning out a flooded building, it is best to use a pressure washer using a solution of water and disinfectant to clean and sanitize the remaining surfaces including wood framing and concrete flooring.

Allowing flooded building materials sufficient time to dry is perhaps the most important step in the process to avoid growth of mold in wood framing and other restored components. A moisture meter can be used to conduct moisture readings to confirm wood framing materials have adequately dried.



Cross Reference

For additional details regarding post-flood cleanup and associated safety precautions, refer to Hurricane Katrina MAT Recovery Advisory, *Initial Restoration of Flooded Buildings* (FEMA 549, July 2006), Hurricane Katrina MAT Recovery Advisory, *The ABCs of Returning to Flooded Buildings* (FEMA 549, November 2005), and Hurricane Sandy MAT Fact Sheet, *Cleaning Flooded Buildings* (FEMA P-942, November 2013).

6.2. Dry Floodproofing

This section discusses the dry floodproofing process (Figure 6-14). Sections 6.2.1 and 6.2.2 outline the design and selection of dry floodproofing design components. "Dry floodproofing" means a combination of measures that make a building and attendant utilities and equipment watertight (substantially impermeable) to floodwater (see Note). The building's structural components must have the capacity to resist flood loads.



Note

FEMA National Flood Insurance Program Technical Bulletin 3, *Requirements for the Design and Certification of Dry Floodproofed Non-Residential and Mixed-Use Buildings Located in Special Flood Hazard Areas in Accordance with the National Flood Insurance Program* (FEMA, January 2021), provides the following definition of **substantially impermeable**: "The use of materials and techniques that restrict the passage of water and seepage through pathways (joints, cracks, openings, channels) and points of entry and that limit the accumulation of water during flooding. According to ASCE 24 and the U.S. Army Corps of Engineers (USACE), a structure is considered substantially impermeable if the maximum accumulation of water is not more than 4 inches in a 24-hour period without relying on devices for the removal of the water (USACE, 1995)."

Buildings that are dry floodproofed may be subject to enormous hydrostatic and imbalanced forces against the foundation, exterior walls, and floor surfaces. Hydrostatic and saturated soil pressures increase with the depth of flooding. For that reason, typical residential foundation walls have severe limitations regarding dry floodproofing measures. Thus, a primary design consideration for dry floodproofing is determination of the existing structure's (foundation, exterior wall, and floor systems) ability to withstand the forces from the design flood event. If the structure's strength is found to be inadequate, options to achieve a design level of performance must be determined.



Warning

FEMA Building Science observations following Hurricanes Ian (2022), Helene (2023), and Milton (2024) indicated an increase in the number of owners dry floodproofing grade-level enclosures beneath elevated houses, rather than the house itself. Although dry floodproofing enclosures beneath an elevated residence may protect the enclosures and their contents from low-level flood damage, it presents significant physical and financial risks and is not recommended. Dry floodproofing an enclosure to resist all hydrostatic and hydrodynamic forces can impose additional lateral and vertical loads on the enclosure during a flood event that can cause damage or collapse the enclosure and the elevated residence above it, especially when floodproofing an enclosure greater than 3 feet in height. If an owner decides to dry floodproof an enclosure beneath an elevated building, floodplain managers and building officials are encouraged to only accept enclosures that meet all of the following requirements:

1) maximum area of 300 square feet, 2) maximum dry floodproof design height of 3 feet, 3) constructed using plans prepared, signed and stamped by a licensed design professional, 4) permitted and inspected by the community, and 5) do not constitute a substantial improvement to an existing structure in the Special Flood Hazard Area.

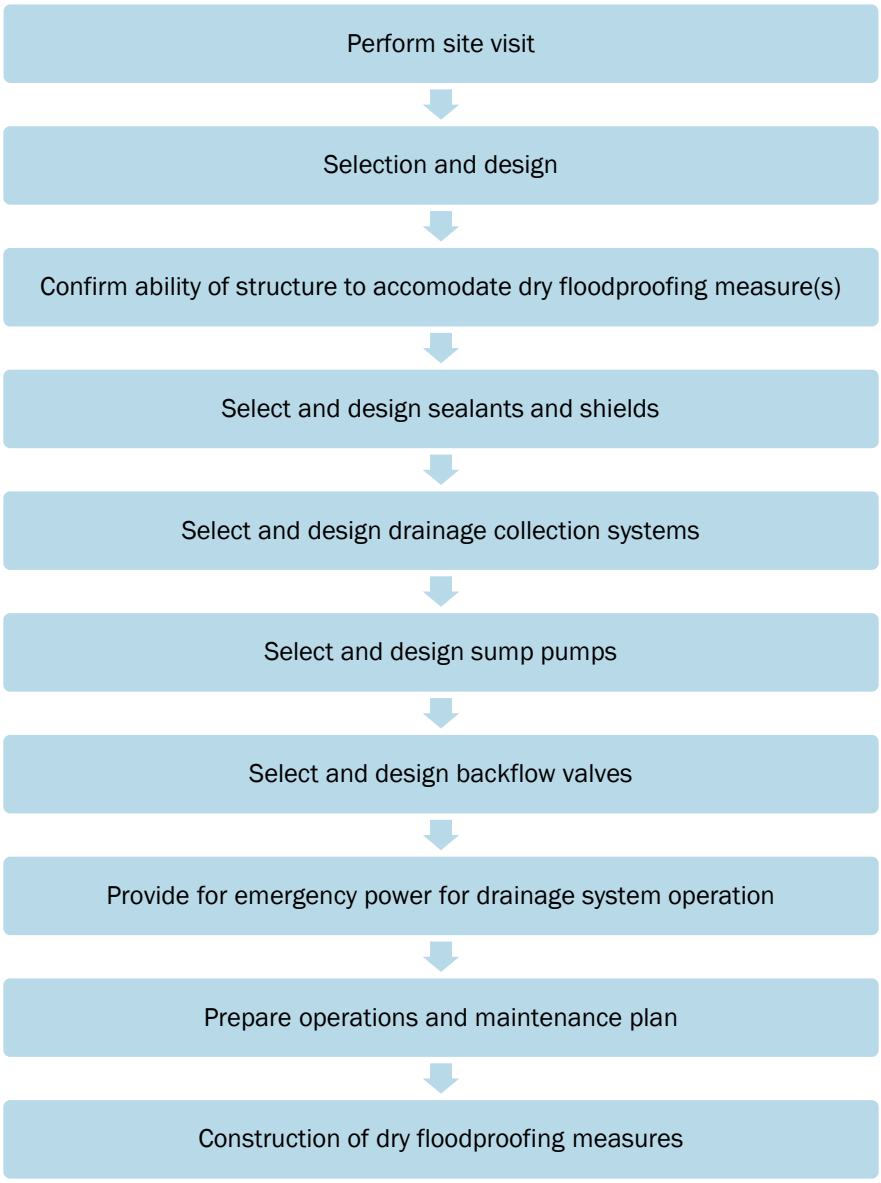


Figure 6-14. Process of selection and design for dry floodproofing

National Flood Insurance Program regulations do not permit the use of dry floodproofing for residential buildings in Zone A or for any buildings in Special Flood Hazard Areas subject to high velocity wave action (coastal high hazard areas identified on Flood Insurance Rate Maps as Zone V) to achieve compliance. For this reason, dry floodproofing is not discussed at length in this

publication. There are limited circumstances where dry floodproofing is appropriate for residential structures. Considerations for determining if dry floodproofing is an appropriate measure include:

- Dry floodproofing is only appropriate for shallow flooding (typically 3-foot maximum flood depth) with low velocity (recommended less than 5 feet per second) and no wave action.
- Dry floodproofing is best suited to slab-on-grade structures where the foundation floor is reinforced and able to withstand buoyancy forces. The foundation and exterior walls must be reinforced to withstand hydrostatic and saturated soil pressures.
- There will be sufficient flood warning time to implement the dry floodproofing measures, such as flood shields that meet the requirements in Chapter 6 of ASCE 24-24, drainage systems, and associated equipment.
- Homeowners can inspect, evaluate, and maintain dry floodproofing systems.

ASCE 24 provides the standard of practice for the design of dry floodproofed buildings and is a referenced standard in the International Codes® (I-Codes®). The concepts in the listed references may be helpful for residential dry floodproofing in rare situations when it is feasible.

The process of dry floodproofing includes determining design flood protection level, evaluating the structural systems for strength and suitability for dry floodproofing, evaluating and selecting sealants, shields, drainage collection systems, sump pumps, backflow valves, and providing emergency power to operate necessary drainage systems. The designer must understand that some form of dry floodproofing measures may be necessary. A critical element of a successful dry floodproofing measure is the development and practice of the owner's Emergency Operations and Maintenance Plans (Section 6.2.3). Since dry floodproofing measures are not typically passive and require an active role of systems and owner operators, there are many more components that must be evaluated, serviced, maintained, and retired when appropriate. These systems require annual review for suitability and function, while some items with limited shelf life (caulks and sealants) will need to be replaced regularly. Some of the important elements of these plans are presented below.



Warning

Dry floodproofing cannot be used to bring a residential structure into compliance with National Flood Insurance Program requirements when it is new construction, substantially improved, or substantially damaged and located in a Special Flood Hazard Area. A brief discussion of non-residential dry floodproofing for mixed-use residential structures is provided in Section 6.2.4

6.2.1. DESIGN PROCESS

Site Visit

The dry floodproofing design process begins with a site visit. Along with information compiled on the existing building/building systems data sheet (Figure 4-3), the designer should collect or verify the following items:

- Condition of existing superstructure, foundation, and footings.
- Existing building materials used in the house for dead weight calculation.
- Soil type, lateral earth pressures, permeability, and seepage potential.
- Lateral stability system and adequacy of structural load transfer connections of the structure.
- Foundation wall, footing, and slab information (thicknesses, reinforcement, condition spans, etc.).
- Number, size, and location of openings or penetrations below the flood protection level.
- Expected flood warning time.
- Evidence of previous, and potential for continued settlement, which could cause cracking after sealant is applied.
- Estimate of leakage through the exterior walls and floor.
- Manufacturer's data to determine applicability of sealant materials in terms of above- and below grade applications, and duration of water resistance.
- Potential anchorage to secure wrapped systems.
- Preliminary selection of shields based upon the length and height of the openings and duration of flooding.
- Preliminary selection of shield anchorage system (hinged, slotted track, bolted, etc.) considering accessibility, ease of installation, and activation/installation time.

Using this information, a designer can determine if sealant and opening shield system is a viable option. Further calculations or conditions may dictate otherwise, and modifications should be made to accommodate the system. The designer can take the information gathered during the site visit and begin to develop type, size, and location for various floodproofing options.

Sealant alternatives include:

- Cement- and asphalt-based coatings, epoxies, and polyurethane-based caulks/sealants.

- Membrane wraps such as polyurethane sheeting.
- Brick veneers over a waterproof coating on the existing concrete or CMU block foundation; brick veneers below the flood protection level must be fully grouted in all cells in order to be effective.

Shield alternatives include:

- A permanent low wall to protect doors and window wells against low-level flooding.
- Covering nonessential openings with an impermeable membrane.
- Drop-in, bolted, and hinged shields that cover openings.

Additional Information

The Flood Mitigation Certification Program tests flood mitigation products to the American National Standards Institute ANSI/FM 2510 standard. This program was created in 2012 by the Association of State Floodplain Managers in partnership with FM Approvals and the U.S. Army Corps of Engineers. See https://floodmitigationcertification.org/.

Confirm Structure Can Support Dry Floodproofing

In scoping of the type, size, and location of the sealant and shield systems, the ability of the existing superstructure and foundation to resist the expected flood- and non-flood-related forces must be evaluated (Figure 6-14 and Figure 6-15).

Step 1: Calculate flood and flood-related forces.

Calculation of flood and flood-related forces (hydrostatic, hydrodynamic, buoyancy, soil, and debris impact forces) as well as determination of seepage and interior drainage rates was presented in Chapter 3. The designer should account for any non-flood-related forces (i.e., wind, seismic, etc.) by incorporating those forces into Steps 2 through 6. Determination of non-flood-related forces was presented in Chapter 3.

Step 2: Check flotation of the superstructure.

Residential structures determined to be watertight (substantially impermeable – see Note) should be checked to ensure that the entire sub- and superstructure is heavy enough or adequately anchored and will not float due to buoyant loads. It is reasonable to assume that most residential buildings will fail prior to flotation. This failure will most likely occur through slab-on-grade breaking (heaving/cracking), a window or door failing inward, or extensive water entry through wall penetrations. Should the designer wish to check the failure assumption, guidance is provided in Step

5. If floodwaters meet a wood floor diaphragm (elevated floor or crawlspace home), the floor system/building superstructure should be checked for resistance to flotation (Figure 6-15).

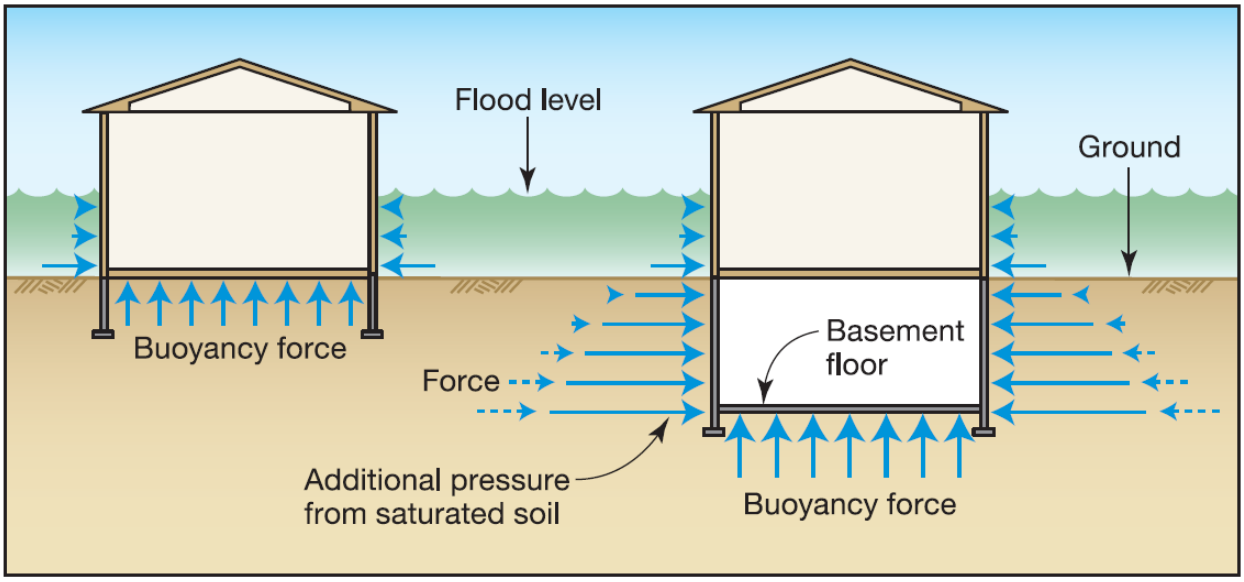


Figure 6-15. Illustration of hydrostatic force

Check the sum of the vertical hydrostatic (buoyancy) forces acting upward against the gravity forces (dead load) acting downward on the structure. The gravity forces acting downward should be greater than the buoyancy forces acting upward (Figure 6-16). If this is not the case (Figure 6-17), the designer should consider choosing another floodproofing method. Technical and cost information supplied by the designer will inform the selection of the floodproofing system.

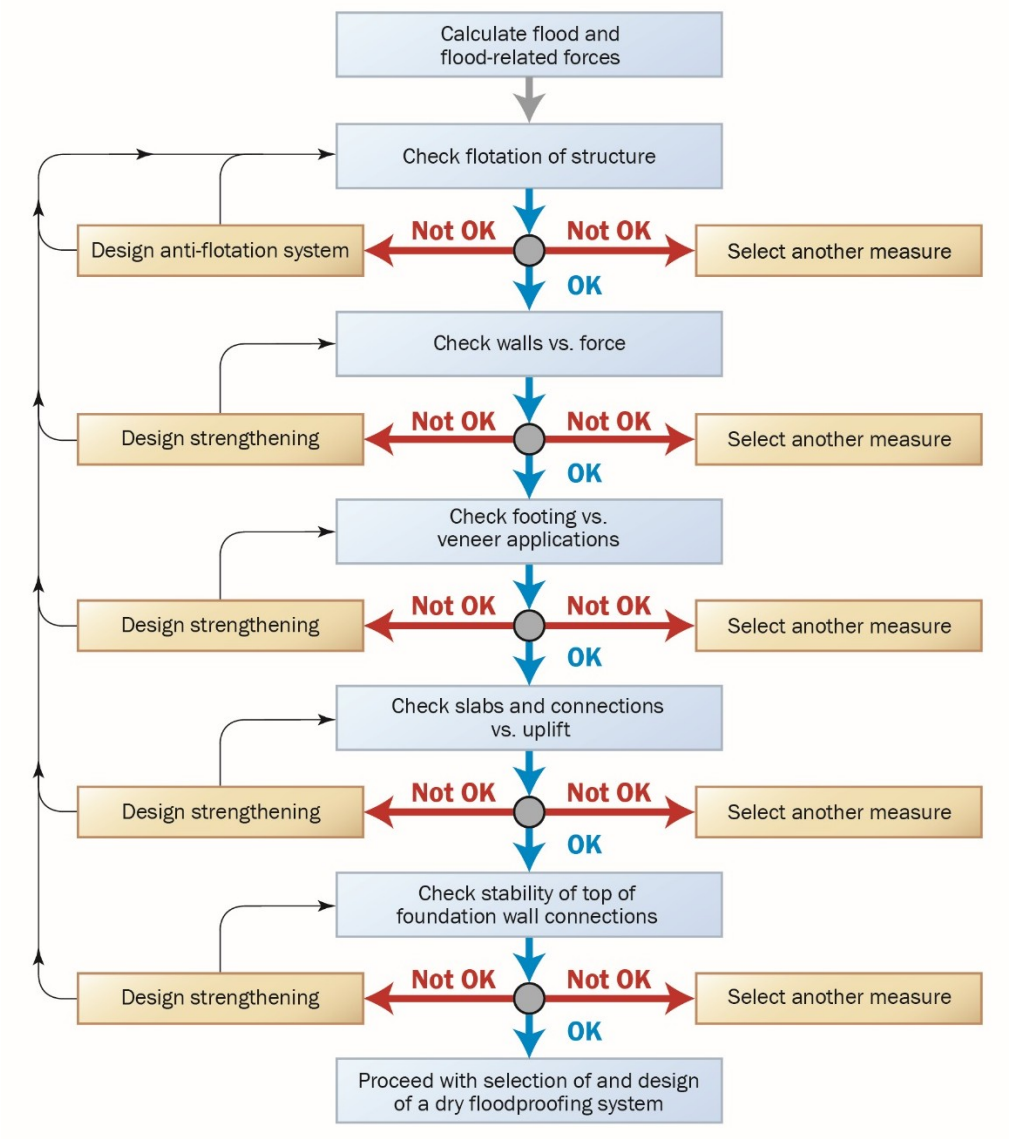


Figure 6-16. Existing building structural evaluations



Figure 6-17. This house was displaced from its foundation into the adjacent roadway adjacent. The photo on the right shows the house's original location in the Special Flood Hazard Area.

Step 3: Check the ability of walls to withstand expected forces.

Wall systems may benefit from the addition of fiber reinforced polymers, grouting, or other retrofit measures, which may improve wall resistance to flood loads while reducing leaking and seepage. Frames and connections for closures transfer retained forces into the adjacent walls. Typically, a vertical strip on each side of the opening must transfer the load up to the floor diaphragm and down to the floor or foundation. This "design strip" must be capable of sustaining imposed loads and loads from openings (Figure 6-18). The designer should consider all forces acting on the design strip for the following:

- Check design strip based on simple span, propped cantilever, cantilever, and other end conditions. Consider the moment forces on the foundation.
- Check design strip for bending and shear based on concrete, masonry, or other wall construction (Figure 6-19).
- Consider the path of forces from shields to the design strip through the various connections including hinges, drop-in slots, frames, and others.
- The designer may want to refer to the American Institute of Steel Construction (AISC) Steel Manual, American Concrete Institute (ACI) resources for concrete and masonry construction, and other applicable codes and standards for more information on mitigation of expected flood and flood-related forces.



Note

The typical failure mode for a shield installation is the "kick-in" of the bottom wall-to-floor connection, where hydrostatic forces are the greatest.



Cross Reference

Refer to ACI 530, Building Code Requirements for Masonry Structures (ACI, 2008b), for design of reinforced masonry. Typically, the effective design strip width, b_{eff}, equals the minimum of:

- center-to-center spacing, S (inches)
- six times wall thickness, tw (inches)
- 72 inches

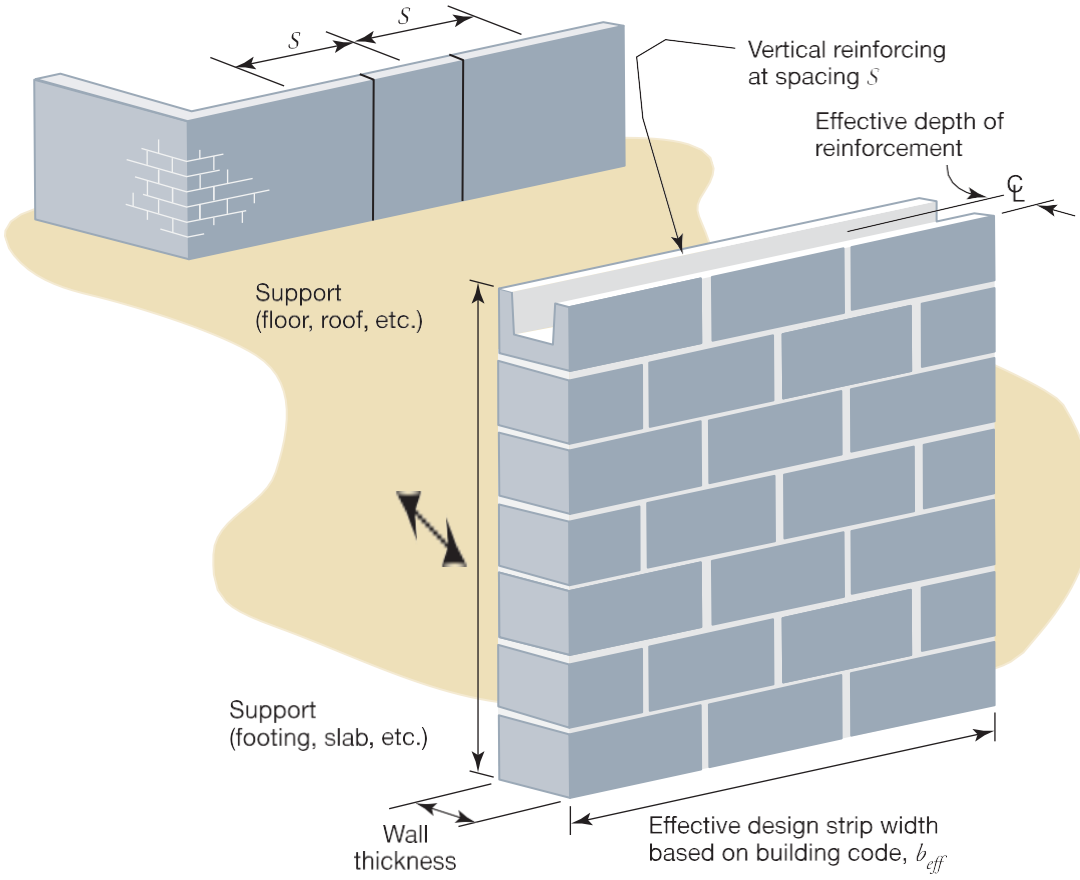


Figure 6-18. Typical design strip for reinforced masonry.



Figure 6-19. This house's foundation walls could not withstand flood forces. Rebar would need to be added to reinforce the concrete masonry unit foundation.

Step 4: Check ability of the footing to support veneer applications.

Masonry veneer added to the exterior face of an existing wall must be supported at the footing level. The designer should consider all forces acting on the existing footing, as well as the following considerations:

- Supporting the masonry veneer on an existing footing can add an eccentric load onto the footing and can create soil pressure problems. The designer should analyze the footing with the additional load considering all load combinations, including the flooded condition.
- The actual pressure on the footing should not overload the bearing capacity of the existing soils. Consult a geotechnical engineer, if necessary.
- The designer may want to refer to ACE 318-08, Building Code Requirements for Structural Concrete and Commentary (ACI, 2008a), various soils manuals/textbooks for detailed footing design, and applicable codes and standards.

Step 5: Check slab and connections against uplift forces.

As floodwaters rise around a structure, a vertical hydrostatic (buoyancy) force builds up beneath floor slabs. For *floating* slabs, this buoyancy force is resisted by the structure's dead load and saturated soil above the footing; for *keyed-in* slabs, this buoyancy force is resisted by the structure's dead load and the flexural strength of the slab. These slabs must be capable of spanning from support to support with the load being applied beneath the slab (see Figure 6-20).

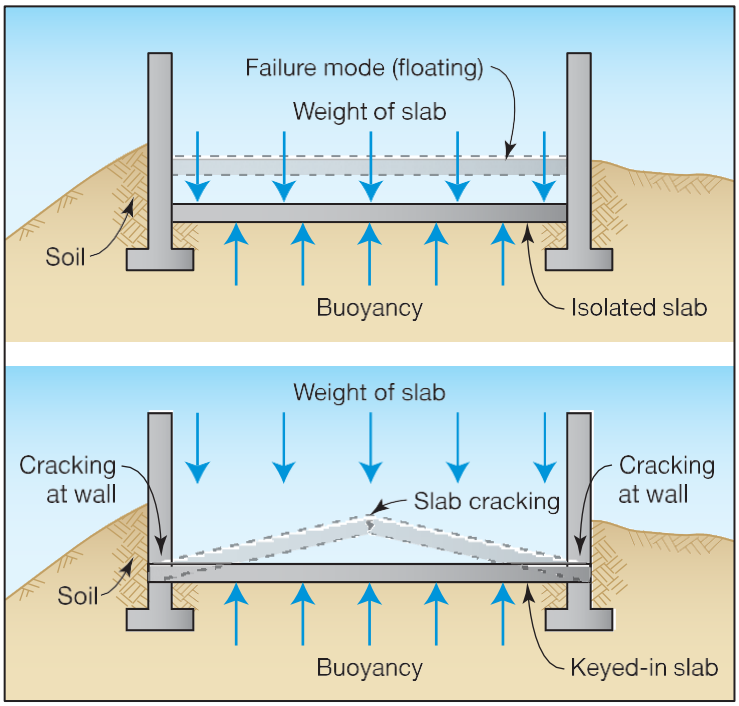


Figure 6-20. Typical slab uplift failure

The designer should consider all forces acting on the existing slab and connections, as well as the following additional considerations:

- Verify the existing slab conditions, including thickness, reinforcement (size and location), joint locations, existence of continuous slab beneath interior walls, existence of ductwork in slab, and edge conditions. If reinforcement and thickness are not easily determined, consult with the local building official or contractors and make a conservative estimate.
- Confirm the slab design by checking reinforcement for bending and edge connection for shear load.

Step 6: Check stability of the top of foundation wall connections.

Foundation walls may retain water in some situations. These walls must transfer the additional hydrostatic load down to the footing or slab and up to the floor diaphragm. The designer should consider all forces acting at the top of the existing foundation wall connections, as well as the following additional considerations:

- Verify existing wall conditions, including construction material, reinforcement, design conditions (simple span, propped cantilever, cantilever, and other end conditions), and connections.
- Connections between the wall and floor are of major importance in consideration of foundation wall stability. The designer should check the following:
    - Masonry/concrete for shear from bolt.
    - Anchor bolt for shear.
    - Sill for bending from bolt loads.
    - Loads have a pathway out of the structure. Additional bracing and/or connectors may be required to support a load pathway out of the structure. Analyze the superstructure and be cognizant that all sides may be loaded.
- The designer may want to refer to ACI 318-25, *Building Code for Structural Concrete – Code Requirements and Commentary* (ACI, 2025), for anchor bolts, and applicable codes and standards.

Step 7: Design foundation supplementation system, as required.

If the checks in Steps 2 through 6 determine that any structural members are unable to withstand expected flood and flood-related loads (wind, seismic, and other forces can be evaluated as presented in Chapter 3), the designer can either select another retrofitting measure or design foundation supplementation measures (see Figure 6-21). These supplementation measures can range from increasing the footing size to adding shoring to the foundation walls, or simply modifying

the type, size, number, and location of connections. The homeowner should make this decision based upon technical and cost information supplied by the designer.

Footing Reinforcing: In some cases, the footings for walls must be modified to accommodate expected increased loads. The following should be considered during the design of this modification:

- The wall footing must be checked for the increased soil pressure and sliding. Moment and vertical loads from the wall above should be added.
- The footing may need more width and reinforcement to distribute these forces to the soil.



Figure 6-21. The foundation of this house was rebuilt after collapse from saturated soil forces after a flood. The blue lines on the wall indicate locations of internal wall joint reinforcing, the yellow lines indicate location of vertical reinforcing bars, and the exterior reinforcement can be seen in the pictures (red arrows).

- For some extreme cases (poor soils, high flood depths, flood-related wind, and/or earthquake loads), a geotechnical engineer may be required to accurately determine specific soil loads and response.
- The designer should consider multiple loading situations, considering building dead and live loads that are transferred into the footing, using whatever load combinations are necessary to design the footing to meet local building code requirements. Consider the materials used in the construction of the structure and how the entire house load is transferred into the foundation.
- The designer may want to refer to ACI 318-0825, *Building Code Requirements for Structural Concrete – Code Requirements and Commentary* (ACI, 2025) for footing design, recent guidance for wall and footing design, and applicable codes and standards.

Step 8: Repeat process in Steps 1-7 incorporating exterior wall foundation supplementation system.

Proceed with Selection of Key Design Components

Once the designer has verified that the existing structure and foundation are suitable for the application of sealants or shields, or that reinforcement can be added to make the existing superstructure and foundation suitable for the application of sealants or closures, selection of specific design components can begin.

6.2.2. KEY DESIGN COMPONENTS

Sealants and Shields

Sealants and shields are methods that can be used to protect a structure from low-level flooding. Miniature floodwalls (low-level) can be used as an alternative to shields for protection of windows, window wells, or basement doors (Figure 6-22). These systems are easily installed and can be less costly than elevation or relocation. However, by sealing a structure against flood inundation, the owner must understand that the typical building will not be capable of resisting loads from more than a few feet of water. The level of flooding the building can resist should be determined by a competent design professional. There is a flood level where sealants and shields will do more harm than good, and the building must be allowed to flood to prevent structural failure from unequalized hydrostatic forces.

The U.S. Army Corps of Engineers National Nonstructural/Flood Proofing Committee has investigated the effect of various depths of water on masonry walls, as discussed in their reports found at https://usace.contentdm.oclc.org. The cumulative results of their work show that, as a general rule, no more than a maximum of three feet of water – which already includes one foot of freeboard - should be allowed on an unreinforced, or under-reinforced concrete block wall unless it as been specifically designed and constructed to withstand flood loads. Application of sealants and shields should not occur without an evaluation of the structural soundness of the building, the walls, and the floor slab, and their corresponding ability to resist flood and flood-related loads.

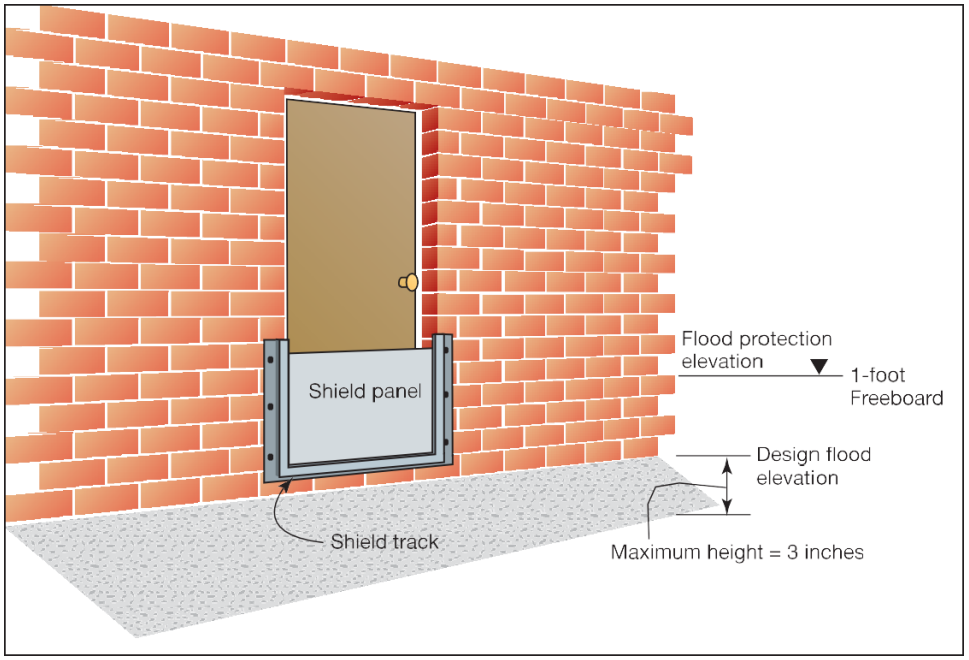


Figure 6-22. Flood shield for door opening

Coatings and Membranes

The selection of a coating or membrane follows the flow chart presented in Figure 6-23. If additional structural reinforcing is required, it should be performed in accordance with the guidance presented in Section 6.2.1.

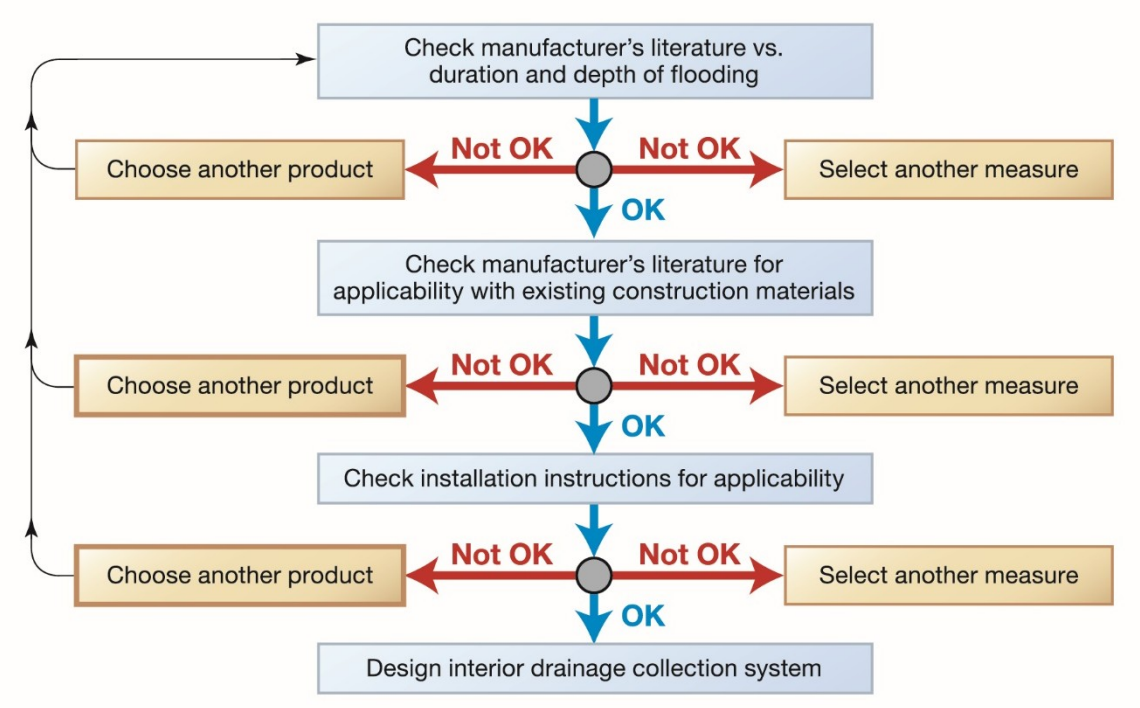


Figure 6-23. Selection of sealants/coatings

Drainage Collection Systems

Drainage systems are typically designed to eliminate accumulation from inevitable seepage and prevent excess hydrostatic loads from developing due to storm runoff or high water tables. They are not designed to remove high flow or deep floodwaters. For short duration flooding at low levels, underdrain systems may reduce flood loads for dry floodproofing designs. These systems may also be utilized in concert with elevation, floodwall, and levee measures. These systems collect drainage and seepage from areas along, adjacent to, or inside the retrofitting measure and the sump pump installation, which transmits the collected drainage and seepage away from the building's foundation. Determination of the amount of surface water inflow and infiltration was presented in Chapter 3. This section presents the parameters that govern the design of these systems.



Note

Check building codes to see if any maximum height or unbalanced fill requirements apply for the given construction.

Typical homes with basements are constructed on concrete footings upon which concrete or CMU block foundation walls are constructed. In some instances, the foundation walls are parged and covered with a waterproof coating, and/or perforated pipe underdrains are installed to carry water away from the exterior foundation walls. The excavations are then backfilled and compacted. However, in practice, this fill material is not and often cannot be compacted to a density equal to that of the undisturbed soils around the house. Because of the density difference, the fill material is capable of conducting and holding more water than the soil around it and frequently provides a storage area for the soil water. As flood levels rise around the structure, the combined water and soil pressure in the areas adjacent to the foundation increases to the point of cracking foundation walls and/or entering the basement and other below grade spaces through existing cracks to relieve the pressure (see Figure 6-24).

Depending upon site-specific soil conditions, high water tables, and local drainage characteristics, slab-on-grade houses may experience similar seepage problems. In addition, elevating and/or dry floodproofing a slab-on-grade house may also necessitate the installation of drainage collection systems to counteract buoyancy and lateral hydrostatic forces. Several types of drainage collection systems exist, including French drains, exterior underdrains, and interior drains. These drainage systems are typically supported by sump pumps. However, poorly conceived drainage collection systems can result in water being drained into sumps at a rate that will exceed the capacity of practical methods for removing the water (e.g., sump pumps). Although these systems typically drain storm runoff, excessive flood loads can overwhelm sump pumps and flood basements. Drainage systems may provide the most benefit to properties that are adjacent to floodplains, where floodwaters may quickly elevate the water table a few feet above normal. In these situations, drainage systems may limit water seepage into basements or the lowest floors.

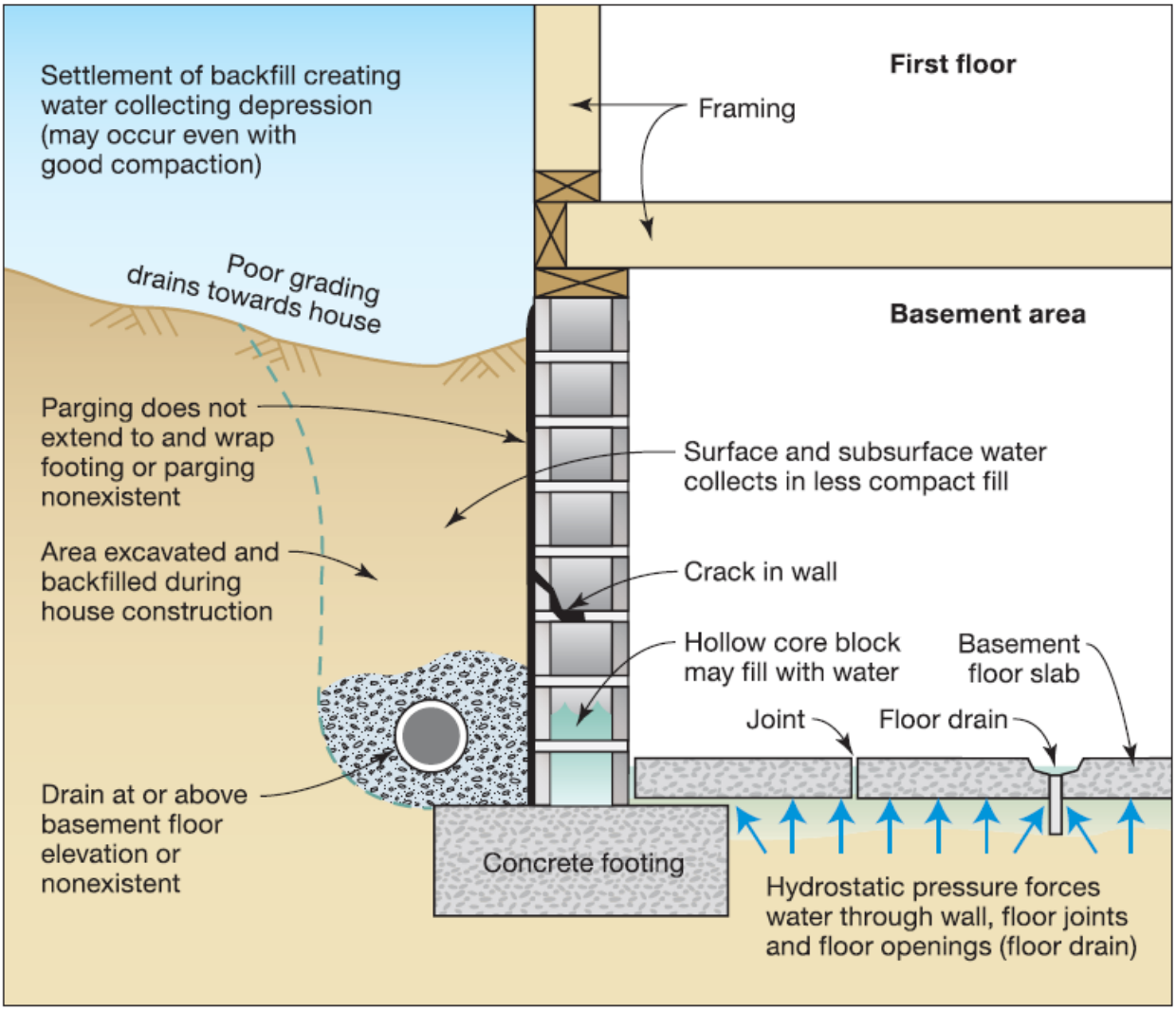


Figure 6-24. Common faults contributing to seepage into basements

French Drains

French drains are used to help dewater saturated soil adjacent to a foundation. They are simply trenches filled with gravel, filter fabric, and sometimes plastic pipe. A typical French drain section is shown in Figure 6-25. The effectiveness of French drains is closely tied to the existence of a suitable discharge point and the slope/depth of the trench. A suitable discharge for the drain usually means an open stream, swale, ditch, or slope to which the drain can be run. If such a discharge point is not available, a French drain is generally not feasible.

Note

French drains are generally not suitable for areas subject to frequent inundation due to the lack of a gravity discharge point during a flood. However, they can be effective in keeping localized drainage away from the foundation (providing a significant flood doesn't occur). In some flood conditions, French drains can provide an easy way for floodwaters to inundate a foundation.

If feasible, the French drain should be dug to a sufficient depth to ensure the capture of soil water that might infiltrate the fill material in the footing area of the basement. The slope of the trench should be such that good flow can be maintained between the gravel stones. This typically means a minimum slope of 1.0%or more.

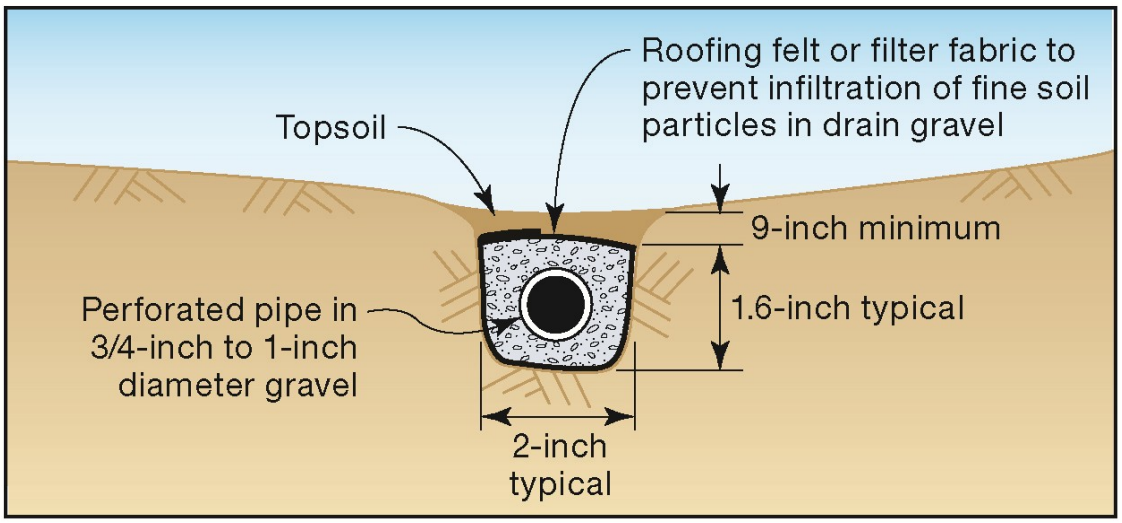


Figure 6-25. Typical French drain system

Exterior Underdrain Systems

Exterior underdrain systems are generally the most reliable drainage collection system when combined with some type of foundation parging and waterproofing. Their chief advantage is that they will remove water that would otherwise exert pressure against the foundation walls and floors.

Underdrains are normally constructed of continuous perforated plastic pipe laid on a gravel filter bed, with drain holes facing up. The underdrains are placed along the building foundation just below the footing and carry water that collects to a gravity discharge or sump pump for disposal into a public drainage system, natural drainage course, or ground surface as permitted by local agencies (see Figure 6-26). These systems may not be sufficient when water tables or floodwaters exceed a few feet above the lowest floor (or basement).

Note

Similar to French drains, an exterior underdrain system with gravity discharge will not work when inundated during a flood. Sump pump discharge with a backup energy source may provide some dewatering benefits in more frequent low-level flooding conditions, but may not be sufficient in high floodwaters.

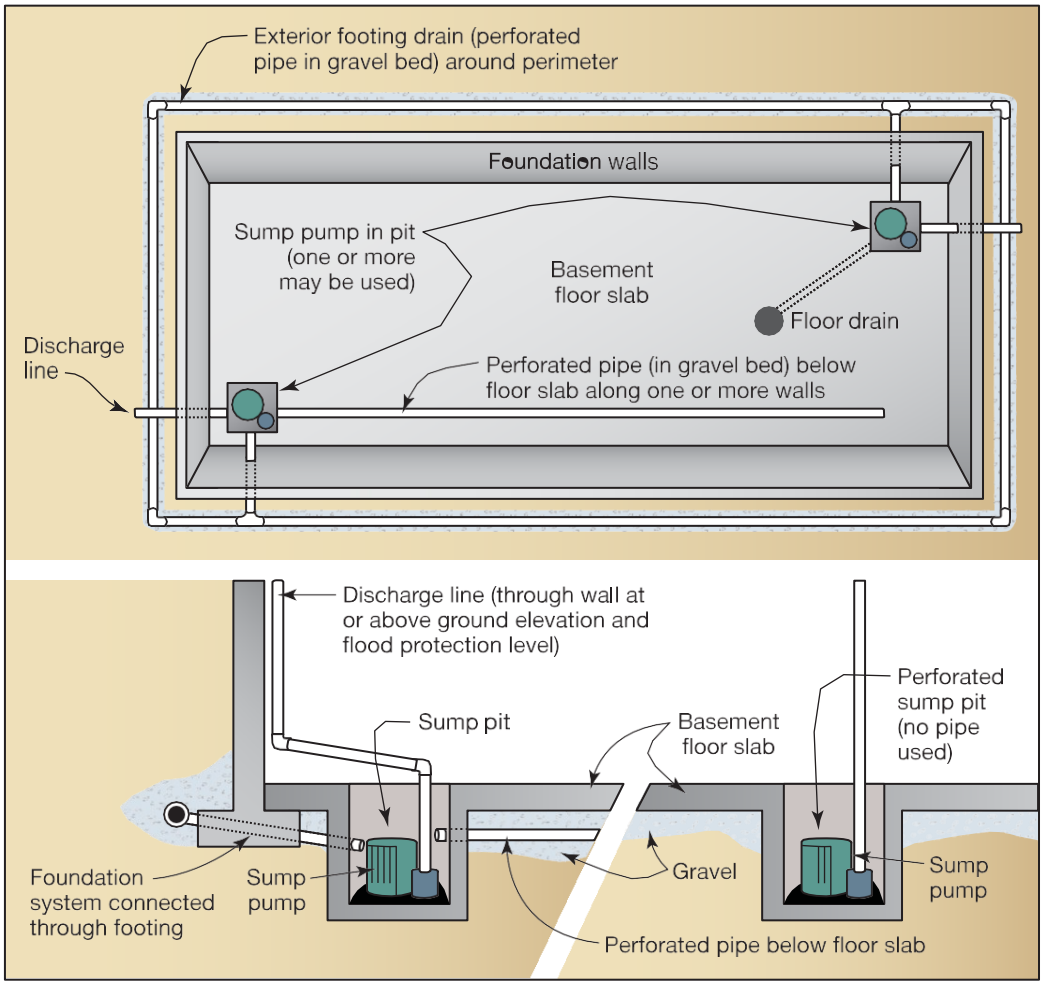


Figure 6-26. Typical exterior underdrain system with sump pump showing two alternative configurations in the side view

Interior Drain Systems

Interior drain systems are designed to relieve hydrostatic pressure from the exterior basement walls and floors and do not require that the soil be excavated from around the exterior basement walls for installation. Sump pumps are perhaps the most familiar of all methods used to dewater basements. The sump is generally constructed so that its bottom is well below the base of the basement floor slab. Water in the areas adjacent to the basement walls and floor migrates toward the area of least pressure along the lines of least resistance, in this case toward and into the sump. It may be

necessary to provide a more readily accessible path of least resistance for water that has collected in the fill material and around the house to follow. To achieve this, pipe segments are inserted and sometimes drilled through the basement wall and into the fill behind. These pipe segments are then connected to larger diameter pipes running along a gravel-filled trench or cove area into the basement floor and into one or more sumps (see Figure 6-27). These systems may be overwhelmed by quickly rising water tables.

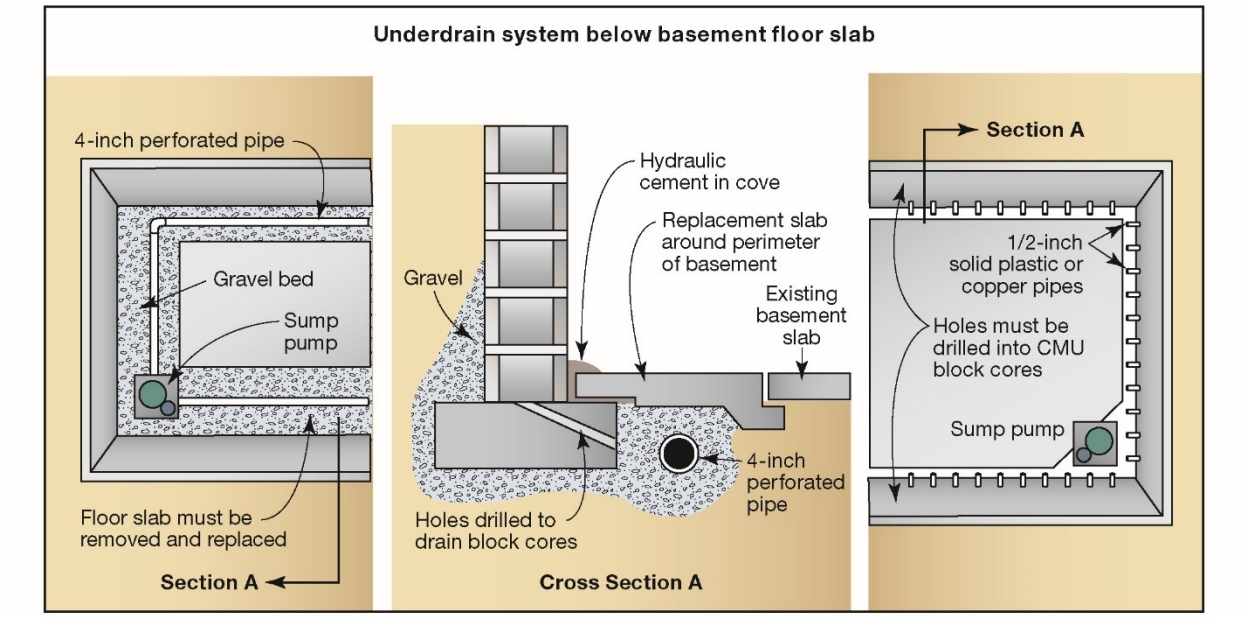


Figure 6-27. Typical interior drain systems.

Sump Pumps

Two types of sump pumps commonly used to support drainage collection systems are the submersible and the pedestal. The submersible type has a watertight motor that is directly connected to the pump casing and installed at the bottom of the sump. The pedestal sump pump uses an open motor supported on a pipe column with the pump at its base. A long shaft inside the column connects the motor to the pump impeller. Figure 6-28 depicts both of these pumps. Submersible pumps are preferred because they will continue to operate if the flood level exceeds the height of the pump.

In selecting a sump pump for use in residential floodproofing, the designer should consider the advantages of each pump type and make a selection based on requirements determined from an investigation of the residence. Considerations include pump capacity (gallons per minute or gallons per hour), pump head (vertical height that the water is lifted), and electrical power required (residential electrical power is usually 120/240 volts AC, single phase). Sump pump motors generally range in size from 1/4 horsepower to 1/2 horsepower, designed to operate on either 120 or 240 volts.

Note

Battery powered marine-type bilge pumps are an alternative to sump pumps/electrical generator installations.

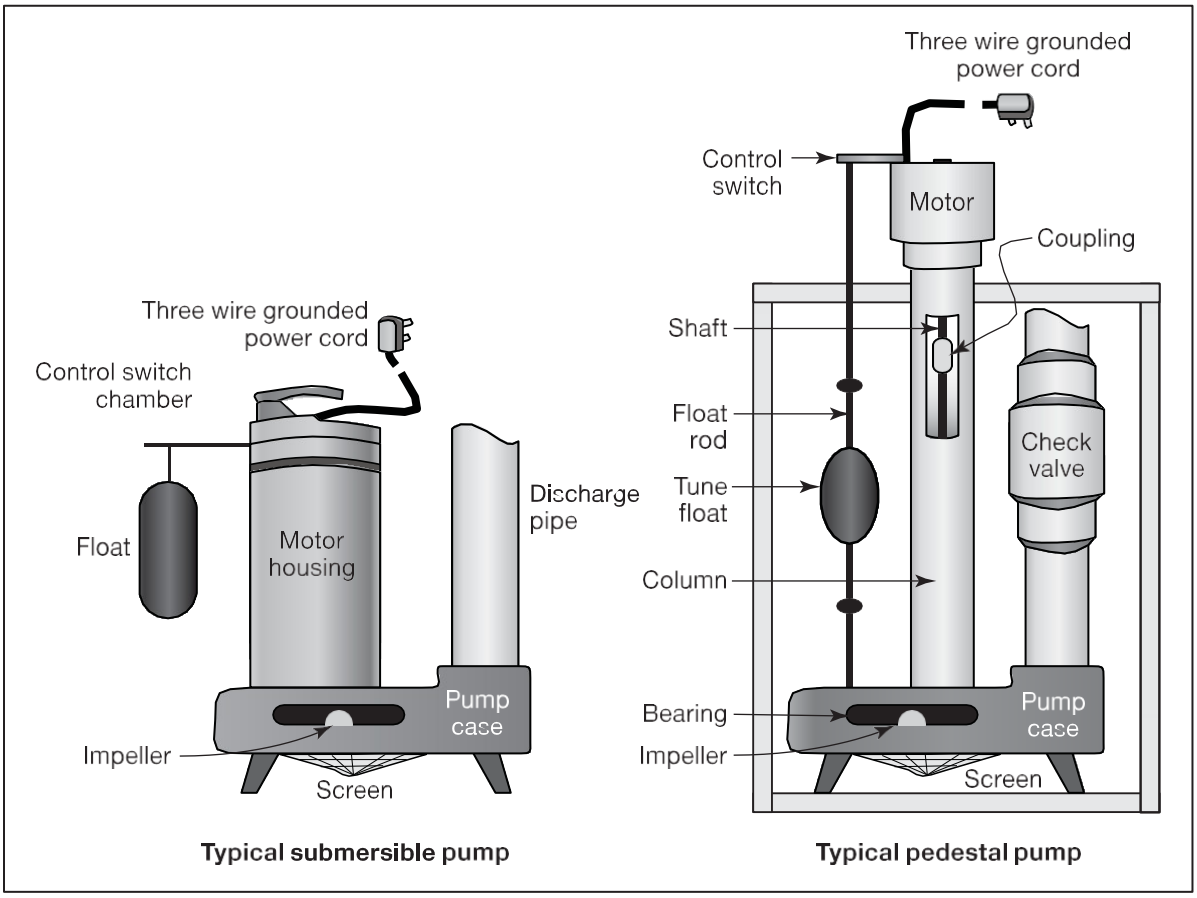


Figure 6-28. Types of sump pumps

The type of float switch system to turn on the pump is also an important component. Many pumps use one of four types of switches. The diaphragm switch is activated by water pressure and is the most expensive type, but not necessarily the most reliable. A vertical action float switch has a float attached to a vertical rod, which activates the switch as it rises from the water level. This is inexpensive and relatively reliable. The tethered float switch works similarly to the vertical action, but is only tethered by a line instead of a vertical rod. This method is inexpensive but can experience many problems. The final common option is an electronic float free switch, which uses a wire that senses contact with water. This switch system may also include an audible alarm, and some more expensive units also include options for connecting a backup pump. While all of these are viable options for residential applications, it is important to evaluate the benefits and understand the reliability of each system.

If a pump system is necessary for dry floodproofing, it is important to verify that the pump(s) are working properly. A sump pump site visit worksheet is shown in Figure 6-30. One of the most common failure modes with sump pumps is the malfunction of the switch from internal or external causes. It is important to be familiar with pump switches and the proper procedure for replacing the switch. Although this can be an inexpensive part, the malfunction of a switch can negate the effectiveness of other floodproofing measures. Other common issues are an improperly working float (tells the sump pump when to operate), which may be caused by an obstruction that needs to be cleared or debris attached to the float, which makes it less buoyant. A blocked intake or impeller is another issue associated with the failure of sump pumps to operate properly. Prior to doing any maintenance on a sump pump, it is important to make sure it is unplugged or disconnected from its power source.

Warning

The capacities of sump pumps used in residential applications are limited. In floodproofing, sump pumps are used to prevent accumulation of water within the residence. In conjunction with other floodproofing methods, sump pumps may be used to protect areas around heating equipment, water heaters, or other appliances from floodwaters. Sump pumps are useful to protect against infiltration of floodwaters through cracks and small openings in frequent low floodwater situations. However, if there are large openings or the structure is totally inundated, the pumping capacity of sump pumps will likely be exceeded, but they are useful for controlled dewatering after floodwaters slowly recede (if submersible pumps are used).

Additionally, owners should be warned that, even if an area is intended to be dry, if floodwaters exceed the wall and floor slab design elevation, attempting to pump out an area prior to floodwaters receding is unwise. It is common in these situations for basement walls to collapse and cause major structural issues (Figure 6-29).



Figure 6-29. Foundation wall failure due to pumping out basement while ground was still saturated with water

Owner Name:_____ Prepared By:_____

Address: _____Date: _____

Property Location: _____

Sump Pump Site Visit Worksheet

Document physical location and characteristics of electrical system on a sketch or plan of the structure.

Determine base flood elevation: _____

Check with local building official's office for version of National Electrical Code (NEC) National Fire Protection Association (NFPA) 70 and, local electrical code requirements:

_____

Check with local building official's office for established regulations concerning flooded electrical equipment:

_____

Check with the regulatory agencies to determine which State and local codes and regulations regarding the design and installation of plumbing systems may apply to the installation of a sump pump:

_____

Determine location and condition of any existing drainage collection systems, including sump pits and pumps.

Does residence have subterranean areas such as a basement? _Yes ___ No

Is there a sump pump installed presently? _____Yes ____ No: If so: _____

_____

Record nameplate data from pump: capacity (__gph or gpm @ _____ FT HEAD), motor horsepower, voltage, and manufacturer's name and model number. _____

Sketch plan of basement indicating location of sump, heating and cooling equipment, water heaters, and floor drains.

How high above floor is receptacle outlet serving cord and plug connected to sump pumps?_____

Once this data is collected, the designer should answer the questions below to develop a preliminary concept for the installation of a sump pump.

If there is no sump pump and one is needed, note potential location for a sump and tentative location for pump discharge piping on above sketch plan.

Is there an electrical outlet nearby? _____ Yes ____ No

Does electrical panel have capacity to accommodate additional Ground Fault Interrupter (GFI) circuit if necessary? _____Yes ____ No

If other floodproofing measures are to be considered, such as placing a flood barrier around heating equipment or other appliances, is the existing sump pump in an appropriate location? _ Yes ____ No

Does another sump and sump pump need to be provided?_____ Yes ____ No

Select emergency branch circuit routing from sump pump to emergency panel. Note on sketch or plan.

Is sump pump branch circuit located above flood protection elevation and is it a GFI circuit? _ Yes ____ No

Locate sump pump disconnect or outlet location near sump pump location above Flood Protection Elevation (FPE).

Once these questions have been answered, the designer can confirm sump pump installation applicability through:

Verify constraints because of applicable codes and regulation._____

_____

Sump pump needed? _____Yes ____No

Is sump pump required by code? __Yes ____ No

Code constraints known? ___Yes ____ No

Proceed to design? ___ Yes ____ No

Confirm that wiring can be routed exposed in unfinished areas and concealed in finished areas. __ Yes __ No

Confirm that panel has enough power to support sump pump addition. _ Yes ____ No

Figure 6-30. Sump Pump Site Visit Worksheet

Emergency Power

Emergency power equipment can be applied to residential applications if the proper guidelines are observed. First, it is not feasible to apply emergency power equipment to the operation of a whole house with electric resistance heat, heat pumps, air conditioning equipment, electric water heater, electric cooking equipment, or sump pump(s). These large loads would require very expensive emergency power equipment that would have considerable operating costs. However, small, economical, residential portable generators or battery backup units can be successfully installed to operate selected, critical electrical devices or equipment from the limited power source.

A list of appliances or equipment that a homeowner might choose to operate is listed below. It is important to note that not all of the appliances will most likely be operated simultaneously.

Critical items to ensure retrofitting effectiveness include:

- Floodwater sump pump – typically 1/3 to 1/2 horsepower (hp), 120 volt single phase
- Domestic water pump – typically 3/4 to 1 hp, 120 volt single phase

Important Items to consider powering, if possible:

- Refrigerator – 350 watts to 615 watts
- Freezer – 341 watts to 440 watts
- Gas or oil furnace – 1/7 hp burner, 1/3 to 1/2 hp blower motor (important in cold climates)

Non-critical items may include:

- Lighting or light circuit – limit to approximately 400 watts
- Receptacle or receptacle circuit – limit to approximately 600 watts
- Air Conditioner
- Heat pump
- Electric water heater

Several sources of technical information are available to assist in the design and installation of emergency residential generator sets.

- Some manufacturers provide application manuals and sizing forms to select small gasoline-powered, natural or liquid petroleum gas, or battery sets.
- Other manufacturers even offer software to size the small generator/battery sets.
- Another good source is the supplier of the standby generator/battery set. They have additional application data for sizing the unit to suit the anticipated load.
- The manufacturer of the set will provide a wattage and volt-ampere rating for each size at a particular voltage rating.

Selection of a generator/battery set is a matter of matching the unit capacity to the anticipated maximum load. The chief complication in sizing the generator/battery set is the starting characteristics of the electric motors in the pumps and appliances to be served.

Since most power outages are temporary and relatively short lived, a battery backup source for sump pumps (only) may be the simplest solution for a homeowner. However, as the duration of the power outage increases, the suitability of battery backup systems decreases. Generator sets are a more secure source of power in these situations, especially for those residents who need/desire power to operate medical equipment or standard household appliances during power outages.



Note

Emergency power equipment should be located above the flood protection elevation. If generator problems occur, turn off existing panel circuit breaker feeding the transfer switch before investigating problems with faulty connections or wiring.

Backflow Valves

Backflow valves can help prevent backflow through the sanitary sewer and/or drainage systems into the house. They should be considered for sanitary sewer drainage systems that have fixtures below the flood protection elevation. In some instances, combined sewers (sanitary and storm) present the greatest need for backflow valves because they can prevent both a health and a flooding hazard. Backflow valves are not foolproof: their effectiveness can be reduced due to fouling of the internal mechanism by soil or debris. Periodic maintenance is required.

The backflow valve is similar to a check valve used in domestic water systems (Figure 6-31). It has an internal hinged plate that opens in the normal direction of flow. If flow is reversed ("backflow"), the hinged plate closes over the inlet to the valve. The valve generally has a cast-iron body with a removable cover for access and corrosion-resistant internal parts. The valves are available in nominal sizes from 2 to 8 inches in diameter. Figure 6-32 illustrates the typical installation of an exterior backflow prevention valve.

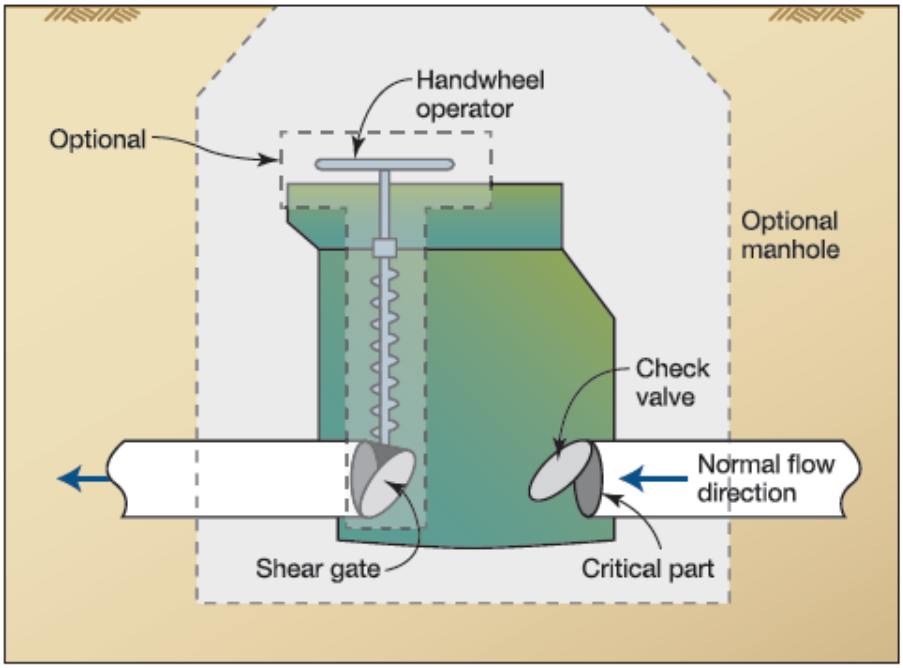


Figure 6-31. Backflow valve

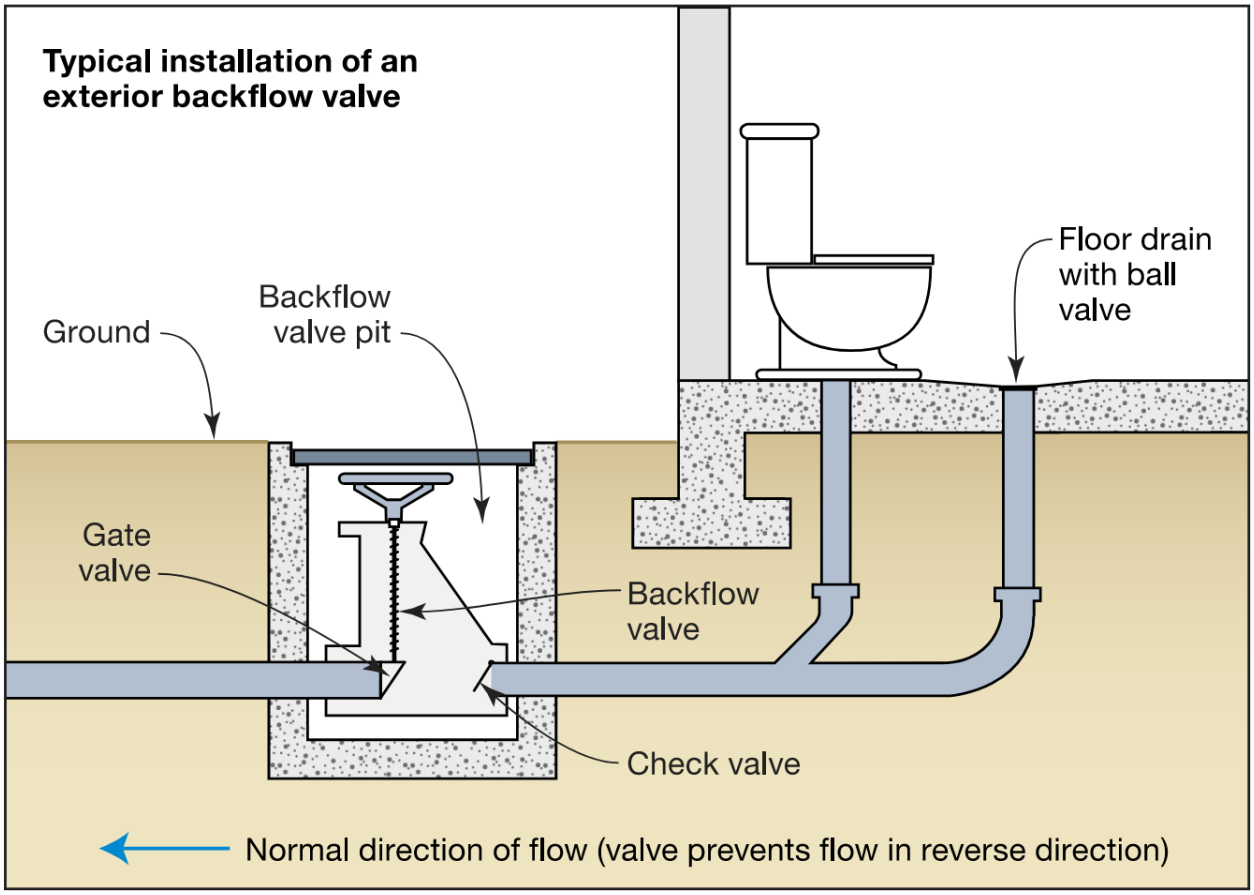


Figure 6-32. Typical installation of an exterior backflow prevention valve

As an added feature, some manufacturers include a shear gate mechanism that can be manually operated to close the drain line when backflow conditions exist. The valve would remain open during normal use. A second type of backflow valve is a ball float check valve 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.

Advanced backflow valve systems have ejector pump attachments that are used to pump sewage around the backflow valve, forcing it into the sewer system during times of flooding. This system is useful in maintaining normal operation of sanitary and drainage system components during a flood. A backflow valve site visit worksheet is shown in Figure 6-33, a guide to record information about the residence.

Owner Name:_____ Prepared By:_____

Address: _____Date: _____

Property Location: _____

Backflow Valve Site Visit Worksheet

Does residence have plumbing fixtures or floor drains below flood protection elevation (FPE): _____ Yes ___ No

Is building drainage system equipped with backflow valves, or do floor drains have backflow device? _ Yes ___ No:

If so, locate on a floor plan sketch of the residence.

If there are no backflow valves and they are needed, consider the following in selecting a location for their installation.

Can adequate clearance be maintained to remove access cover and service valve? _ Yes ___ No

Are there any codes that regulate or restrict installation of such valves? _____ Yes ___ No

If yes, explain: _____

Tentatively locate on sketch box where backflow valves might be installed.

Proceed To Design? _____Yes _____No

Figure 6-33. Backflow Valve Site Visit Worksheet



Cross Reference

For additional information on various elements of dry floodproofing discussed in this section, refer to the following FEMA publications (links can be found in Appendix G):

- National Flood Insurance Program Technical Bulletin 3, Requirements for the Design and Certification of Dry Floodproofed Non-Residential and Mixed-Use Buildings Located in Special Flood Hazard Areas in Accordance with the National Flood Insurance Program, January 2021.
- FEMA P-348, *Protecting Building Utilities From Flood Damage*, Edition 2, February 2017.
- FEMA P-936, *Floodproofing Non-Residential Buildings*, July 2013.
- FEMA P-1019*, Emergency Power Systems for Critical Facilities: A Best Practices Approach to Improving Reliability*, September 2014.

6.2.3. PREPAREDNESS, OPERATIONS, AND MAINTENANCE

Flood Warning System

Given that dry floodproofing is active mitigation, a community flood warning system is necessary to effectively implement the various measures associated with dry floodproofing. Although the design of a community flood warning system is beyond the scope of this publication, the National Flood Insurance Program requires a minimum flood warning time of 12 hours (for Flood Design Class 2

structures) to implement active measures associated with dry floodproofing and to safely evacuate the site, based on National Flood Insurance Program Technical Bulletin 3 and provisions of ASCE 24.

Operations and Maintenance

Dry floodproofing requires both emergency operations and maintenance plans. In addition to a community flood warning system, an effective emergency operations plan must specify the steps and resources necessary to install dry floodproofing components and then evacuate the flood hazard area. To ensure a more favorable outcome from a flood event, an emergency operations plan should include periodic review and training in the installation of dry floodproofing measures. Refer to FEMA's National Flood Insurance Program Technical Bulletin 3 (January 2021), FEMA P-2022 Hurricane Harvey in Texas Recovery Advisory 1, *Dry Floodproofing: Planning and Design Considerations* (April 2018), and FEMA P-2023 Hurricane Irma in Florida Recovery Advisory 1, *Dry Floodproofing: Operational Considerations* (May 2018), for additional guidance concerning minimum recommendations for Emergency Operations Plans and Inspection and Maintenance Plans. While these documents were prepared for non-residential structures (Section 6.2.4), they contain sound advice for the development of emergency operations, inspection, and maintenance plans.

Given the number of elements associated with dry floodproofing systems, some degree of periodic annual maintenance and inspection is critical to ensure that all components will operate properly under flood conditions. Components that should be inspected as part of an annual maintenance, inspection, and replacement program include:

- All mechanical equipment, such as sump pumps, switches, piping, valves, and generators.
- Flood shields, to ensure that they fit properly and that the gaskets and seals are in good working order, properly labeled, and stored in an accessible area.
- Sealed walls and wall penetrations, for cracks and potential leaks.

6.2.4. NON-RESIDENTIAL CONSTRUCTION

Dry floodproofing has also been used with varying degrees of success on buildings originally built for non-residential purposes, such as existing factories and warehouses in urban or suburban areas converted to apartments and condominiums. Dry floodproofing is the same for any structure, regardless of its use and occupancy. The application of floodproofing concepts can vary as to the size and nature of the building and its use. Due to the more robust nature of most non-residential construction, a thorough evaluation of load path and a more rigorous inspection cycle, non-residential engineered buildings are more likely to have owners and operators effectively implement dry floodproofing measures during flooding. Extreme caution is still required to avoid flood damage. Potential building and structural options and considerations available for non-residential engineered building floodproofing to include, but are not limited to:

- Permanent closure of nonessential vulnerable openings
- Watertight core areas (vaults)
- Enhanced flood shields
- Pressure relief systems to protect against structural failure

Note

Although the focus of FEMA P-259 is residential buildings, this section on non-residential buildings is included, since it provides engineering concepts, principles, considerations, and useful best practices to also help successfully implement dry floodproofing measures for residential buildings.

Permanent Closure of Openings

An owner may be able to permanently close some vulnerable openings lower in the structure (window wells and coal chutes) on non-residential structures that are not required for safety egress; this is not an option for residential occupancy. The types of walls, doors, and openings used in non-residential construction are more likely to withstand moderate flood loads than residential construction. Non-residential construction is designed by an engineer and tends to feature more durable and stronger materials, such as concrete or concrete masonry unit walls and steel doors. See Figure 6-34 for an example of an infilled opening.



Figure 6-34. Permanent closure of an opening to prevent floodwaters from entering the building

Watertight Core Areas

In some cases, there may not be a need or ability to dry floodproof the entire building footprint. This may be due to the building geometry and use, or simply because of dry floodproofing cost. In these cases, only critical core components and areas can be dry floodproofed. Typical protected areas include utilities such as electrical distribution and switching areas, emergency generators, emergency fuel supplies, and other critical components that cannot be moved or elevated. FEMA *Hurricane Sandy Recovery Advisory 2, Reducing Flood Effects in Critical Facilities*, April 2013, describes concepts for dry floodproofing. See Figure 6-35 for an example of a watertight door.



Figure 6-35. A watertight door used to protect mechanical equipment for a hospital that is at risk of basement flood intrusion

Enhanced Flood Shields

Non-residential buildings are likely to have different opening configurations and sizes than residential structures. Since flood shields are a commonly used floodproofing method, special attention to the installation is required. Walls intended to support the flood shields must be able to support the installed shields and water pressure.

There are various types of deployable flood shields that can be used, each with differing degrees of cost and ease of use. Chapter 6 of ASCE 24-24 lists various requirements for flood shields including testing and certification in accordance with ANSI/FM 2510, American National Standard for Flood Mitigation Equipment. Deployable flood shields include lift out, counter balanced, and hinged shields. Some have deformable gaskets and others have inflatable gaskets. Figure 6-36 shows flood shields that can be raised and lowered to provide protection. These deployable flood shields act as passive systems that have the advantage of eliminating the need for human intervention; however, passive floodwalls are extremely expensive and unaffordable to the average homeowner.



Figure 6-36. Flood shields that can be raised and lowered to protect a hospital mechanical room from floodwaters

Pressure Relief Systems

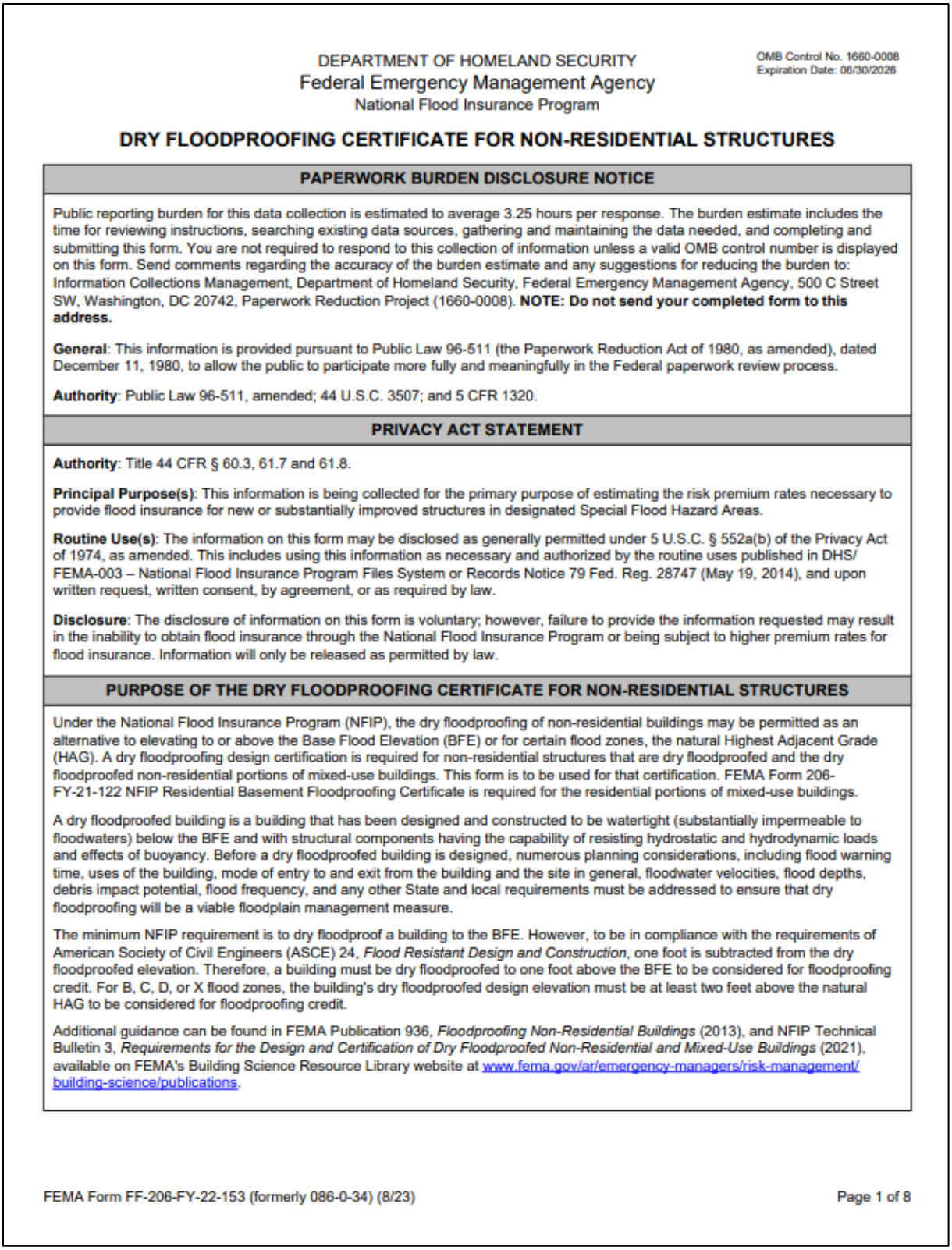
Pressure relief systems are like wet floodproofing measures. They allow some level of dry floodproofing and then release the hydrostatic pressure if water levels exceed a specific height. A pressure relief system can provide an added degree of protection against structural failure of a new building or for an existing structure that cannot be modified to reduce uplift pressures. It is preferable to install pressure relief systems with other dry floodproofing measures.

Dry Floodproofing Certificate

FEMA has developed a Dry Floodproofing Certificate for Non-Residential Structures that can be completed for non-residential building owners who want to receive flood insurance credit for dry floodproofing their buildings. The first page of the certificate currently available at the time of this publication is shown in Figure 6-37 (see Cross Reference).

Cross Reference

FEMA's Dry Floodproofing Certificate for Non-Residential Structures can be downloaded from the FEMA website.



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

OMB Control No. 1660-0008
Expiration Date: 06/30/2026

DRY FLOODPROOFING CERTIFICATE FOR NON-RESIDENTIAL STRUCTURES

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Authority: Public Law 96-511, amended; 44 U.S.C. 3507; and 5 CFR 1320.

PRIVACY ACT STATEMENT

Authority: Title 44 CFR § 60.3, 61.7 and 61.8.

Principal Purpose(s): This information is being collected for the primary purpose of estimating the risk premium rates necessary to provide flood insurance for new or substantially improved structures in designated Special Flood Hazard Areas.

Routine Use(s): The information on this form may be disclosed as generally permitted under 5 U.S.C. § 552a(b) of the Privacy Act of 1974, as amended. This includes using this information as necessary and authorized by the routine uses published in DHS/ FEMA-003 – National Flood Insurance Program Files System or Records Notice 79 Fed. Reg. 28747 (May 19, 2014), and upon written request, written consent, by agreement, or as required by law.

Disclosure: The disclosure of information on this form is voluntary; however, failure to provide the information requested may result in the inability to obtain flood insurance through the National Flood Insurance Program or being subject to higher premium rates for flood insurance. Information will only be released as permitted by law.

PURPOSE OF THE DRY FLOODPROOFING CERTIFICATE FOR NON-RESIDENTIAL STRUCTURES

Under the National Flood Insurance Program (NFIP), the dry floodproofing of non-residential buildings may be permitted as an alternative to elevating to or above the Base Flood Elevation (BFE) or for certain flood zones, the natural Highest Adjacent Grade (HAG). A dry floodproofing design certification is required for non-residential structures that are dry floodproofed and the dry floodproofed non-residential portions of mixed-use buildings. This form is to be used for that certification. FEMA Form 206-FY-21-122 NFIP Residential Basement Floodproofing Certificate is required for the residential portions of mixed-use buildings.

A dry floodproofed building is a building that has been designed and constructed to be watertight (substantially impermeable to floodwaters) below the BFE and with structural components having the capability of resisting hydrostatic and hydrodynamic loads and effects of buoyancy. Before a dry floodproofed building is designed, numerous planning considerations, including flood warning time, uses of the building, mode of entry to and exit from the building and the site in general, floodwater velocities, flood depths, debris impact potential, flood frequency, and any other State and local requirements must be addressed to ensure that dry floodproofing will be a viable floodplain management measure.

The minimum NFIP requirement is to dry floodproof a building to the BFE. However, to be in compliance with the requirements of American Society of Civil Engineers (ASCE) 24, *Flood Resistant Design and Construction*, one foot is subtracted from the dry floodproofed elevation. Therefore, a building must be dry floodproofed to one foot above the BFE to be considered for floodproofing credit. For B, C, D, or X flood zones, the building's dry floodproofed design elevation must be at least two feet above the natural HAG to be considered for floodproofing credit.

Additional guidance can be found in FEMA Publication 936, *Floodproofing Non-Residential Buildings* (2013), and NFIP Technical Bulletin 3, *Requirements for the Design and Certification of Dry Floodproofed Non-Residential and Mixed-Use Buildings* (2021), available on FEMA's Building Science Resource Library website at www.fema.gov/ar/emergency-managers/risk-management/building-science/publications.

FEMA Form FF-206-FY-22-153 (formerly 086-0-34) (8/23)

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Figure 6-37. First page of FEMA Dry Floodproofing Certificate for Non-Residential Structures

6.3. Flood Barrier Systems

A properly designed and built floodwall or berm can often effectively repel floodwaters. Floodwalls and berms provide barriers against inundation, help protect buildings from being subjected to hydrostatic and hydrodynamic forces, and may deflect flood-borne debris and ice away from buildings. Floodwalls and berms differ in their design, construction, site characteristics, and application.

Floodwalls are free-standing, permanent, engineered structures designed to prevent encroachment of floodwaters. They are usually built of materials such as reinforced concrete or reinforced masonry. The selection of a floodwall design is determined by the type of flooding expected at the building location. High water levels and velocities can exert hydrodynamic and hydrostatic forces and impact loads, which must be accounted for in the floodwall design. The floodwall must address three broad concerns:

- Overall stability of the wall as related to the external loads.
- Sufficient strength as related to the calculated internal stresses.
- Ability to provide effective enclosures to repel floodwaters.

Internal and external forces pose a significant safety hazard if floodwalls are not properly designed and constructed, or if they are overtopped. Additionally, a tall floodwall can become very expensive to construct and maintain, and requires additional land for grading and drainage. Therefore, residential floodwalls are practical only up to a height of three or four feet above existing grade, although residential floodwalls can be engineered for greater heights.

Berms are embankments of compacted soil that can prevent shallow to moderate floodwaters from reaching a structure. A well designed and constructed berm should resist flooding up to the design storm flood elevation, eliminating exposure to potentially damaging hydrostatic and hydrodynamic forces.



Note

Floodwalls and berms are not considered dry floodproofing measures for buildings because they are separate structures and not part of the buildings. Although floodwalls and berms can be used to prevent flood damage, they will not bring a building into compliance with National Flood Insurance Program requirements. The National Flood Insurance Program requires that all new construction and substantial improvements of residential structures within Zones A1–30 and AE and AH zones on the community's FIRM have the lowest floor (including basement) elevated to or above the base flood level. (Title 44 Code of Federal Regulations Section 60.3(c)(2)).

This section outlines the fundamentals of flood barrier design and provides the designer with empirical designs suitable for a limited range of situations.

Note

FEMA strongly encourages flood retrofits to provide protection to the Design Flood Elevation. However, since floodproofing, floodwalls, and berms do not bring residential buildings into National Flood Insurance Program compliance, for new construction or substantial damage/substantial improvement in the Special Flood Hazard Area, the flood protection level can be used instead of the Design Flood Elevation. Homeowners and design professionals should meet with a local building official to discuss the selected retrofit measure and the elevation to which it will help protect the residence. The text and graphics in Sections 6.3.1 and 6.3.2 assume flood protection measures will be implemented to the flood protection level (also known as FPL).

Warning

Placement of floodwalls in the floodway is not allowed under National Flood Insurance Program regulations.

6.3.1. FLOODWALLS

Floodwalls used as a flood mitigation measure in residential areas are not as common as many of the other retrofitting methods detailed in this publication. However, in instances where this measure is appropriate, the following sections provide general design and construction considerations.

6.3.1.1. Types of Floodwalls

Figure 6-38 and Figure 6-39 illustrate the use of floodwalls in typical residential applications. Figure 6-40 and Figure 6-41 illustrate several types of floodwalls, including gravity, cantilever, buttress, and counterfort. Gravity and cantilever floodwalls are more commonly used.

Gravity Floodwall

A gravity floodwall depends upon its weight for stability. The gravity wall's structural stability is attained by effective positioning of the mass of the wall, rather than the weight of the retained materials. The gravity wall resists overturning primarily by the dead weight of the concrete and masonry construction. It is simply too heavy to be overturned by the lateral flood load.

Frictional forces between the concrete base and the soil foundation resist sliding of the gravity wall. Soil foundation stability is achieved by ensuring that the structure neither moves nor fails along possible failure surfaces. Figure 6-42 illustrates the stability of gravity floodwalls. Gravity walls are appropriate for low walls or lightly loaded walls. They are relatively easy to design and construct. The disadvantage of a gravity floodwall is that a large volume of material is required. As the required height of a gravity floodwall increases, it becomes more cost-effective to use a cantilever wall.

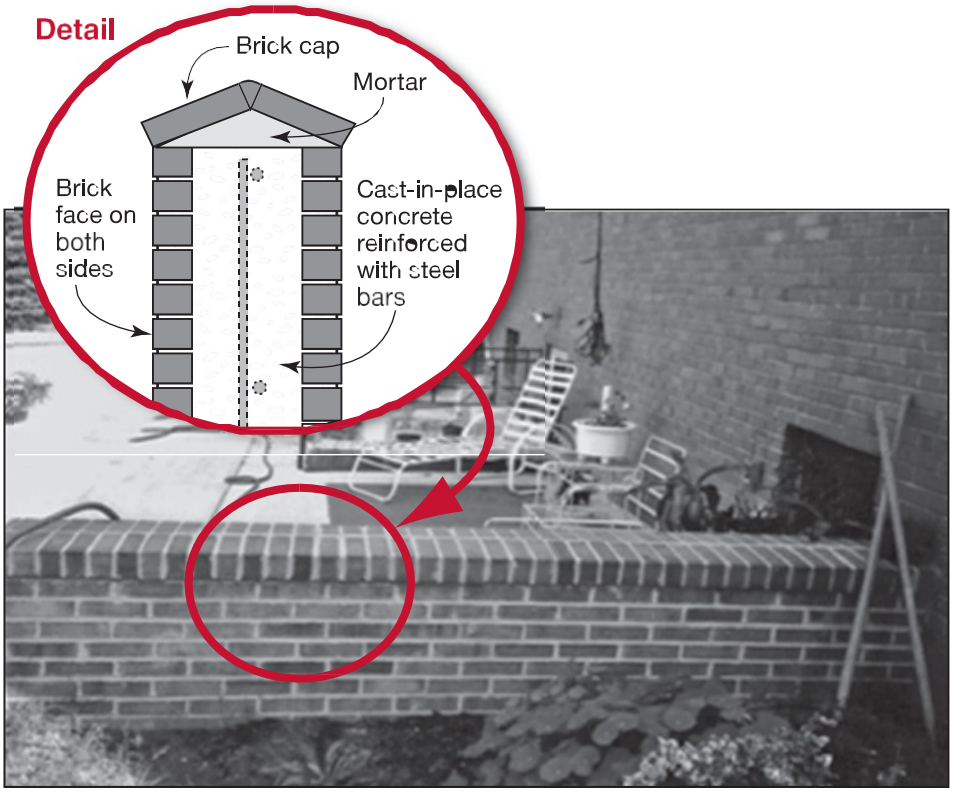


Figure 6-38. Typical residential floodwall



Figure 6-39. Typical residential floodwall

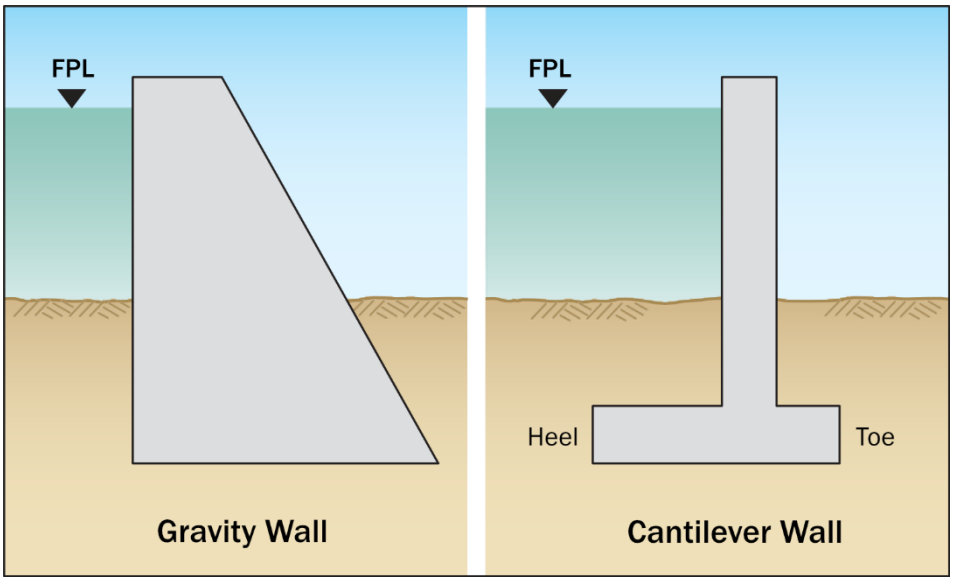


Figure 6-40. Gravity and cantilever floodwalls

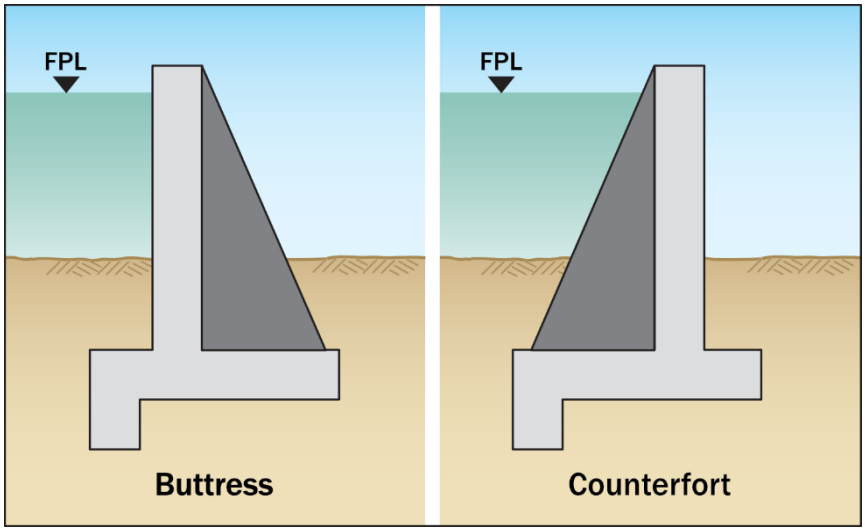


Figure 6-41. Buttress and counterfort floodwalls

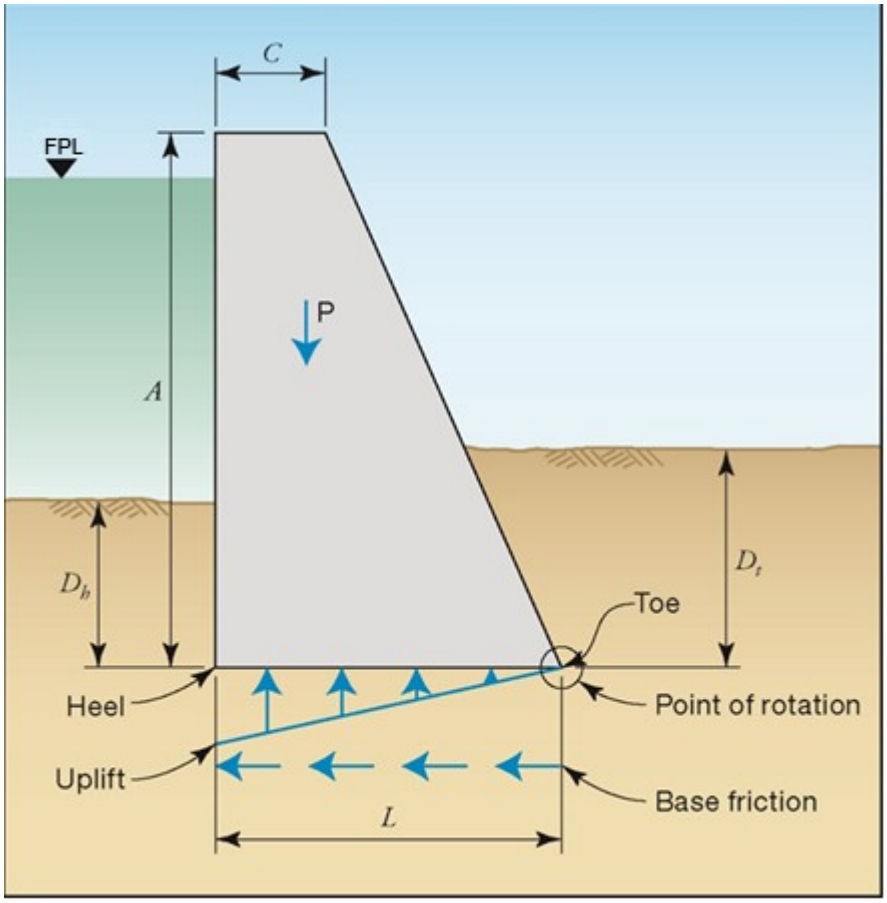


Figure 6-42. Stability of gravity floodwalls

Cantilever Floodwall

Cantilever floodwalls are the most common type of floodwall because they are economical to design and construct. A cantilever wall is a reinforced concrete wall (cast-in-place or built with concrete block) that utilizes cantilever action to retain the mass behind the wall. Reinforcement of the wall is attained by steel bars embedded within the concrete or block core of the wall (Figure 6-43). Stability of cantilever walls is partially achieved from the weight of the soil on the heel portion of the base (Figure 6-44).

The floodwall is designed as a cantilever retaining wall, which considers buoyancy effects and reduced soil bearing capacity. Other elements of a floodproofing project (i.e., bracing effects of any slab-on-grade, the crosswalks, and possible concrete stairs) may help provide stability. This results in a slightly conservative design for the floodwall but provides a safety factor against flood risk. Backfill can be placed along the outside face of the wall to keep water away from the wall during flooding conditions.

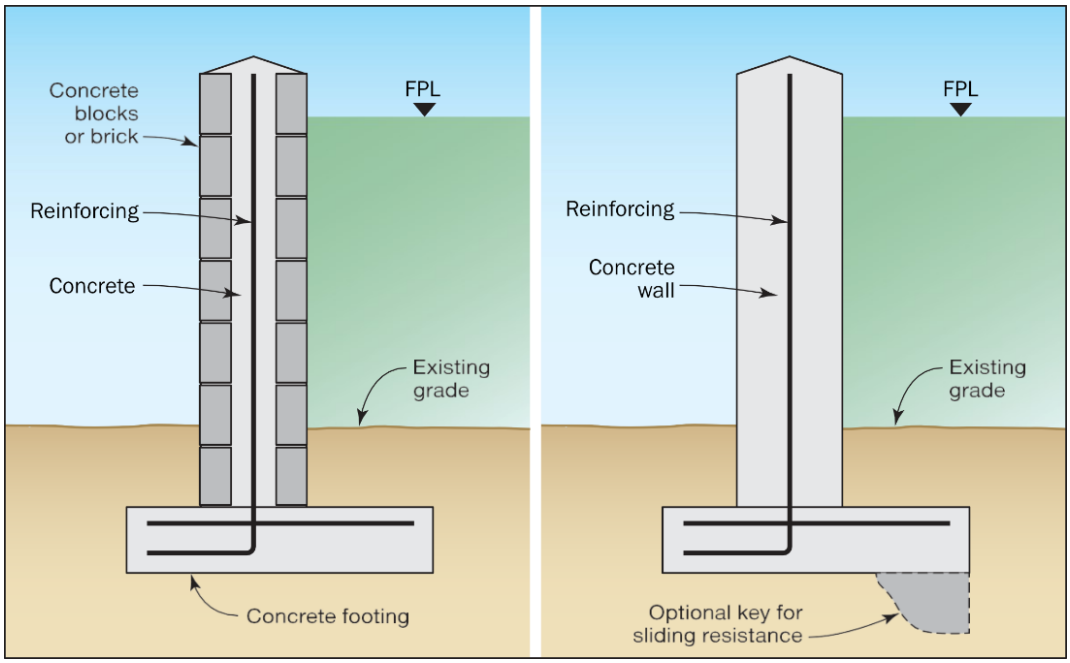


Figure 6-43. Concrete cantilever floodwall reinforcement

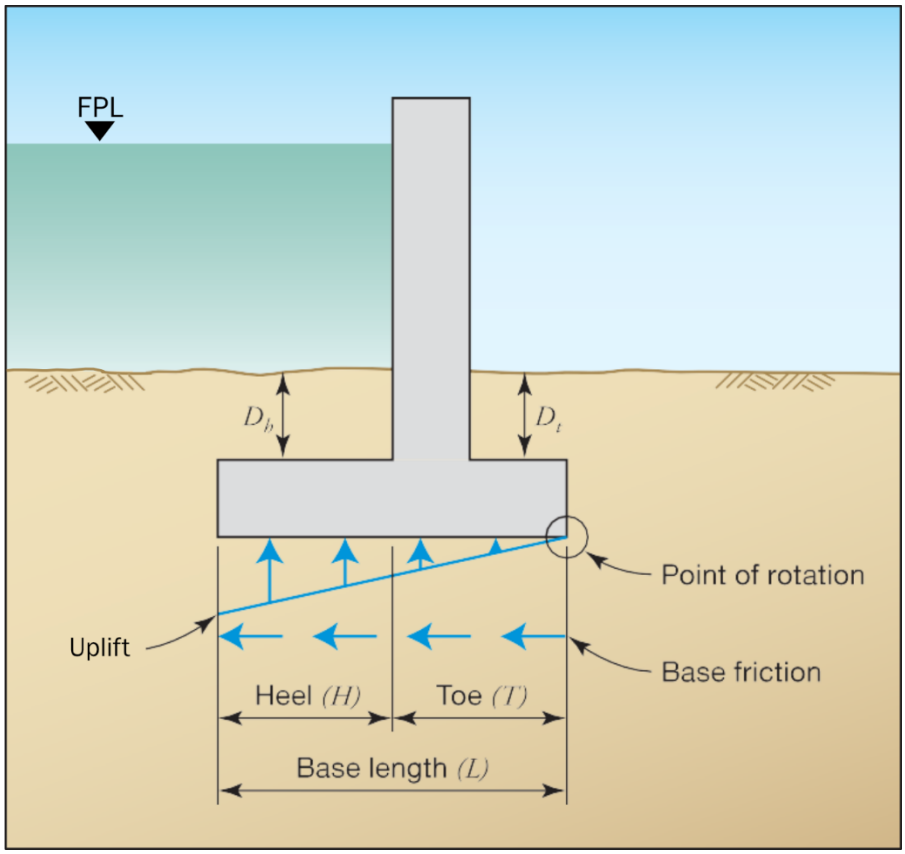


Figure 6-44. Stability of cantilever floodwalls

Note

Reinforced concrete provides an excellent barrier that resists water seepage since it is monolithic. The reinforcement not only gives the wall its strength but also limits cracking.

The concrete floodwall may be aesthetically altered with a double-faced brick application on either side of the monolithic cast-in-place reinforced concrete center (Figure 6-45). The reinforced concrete core is the principal structural element of the wall that resists the lateral hydrostatic pressures and transfers the overturning moment to the footing. The brick-faced wall is typically used on homes with brick facades. Thus, the floodwall becomes an attractive modification to the home. In terms of the structure, the brick is considered in the overall weight and stability of the wall and in the computation of the soil pressure at the base of the footing, but is not considered to add flexural strength to the floodwall.

Cross Reference

When the flood protection elevation requirements of gravity or cantilever walls become excessive in terms of material and cost, alternative types of floodwalls can be examined. Selection of floodwall alternatives is determined by the cost of construction and materials, and the required reinforcement. The US Army Corps of Engineers EM 1110-2-2502 *Engineering and Design Floodwalls and Other Hydraulic Retaining Walls* (2022) provides guidance and information for the selection, design, inspection, evaluation, maintenance, repair, and rehabilitation of floodwalls and other hydraulic retaining walls. Information and details for a standard reinforced concrete floodwall are provided in Case Study 1 in Chapter 6.

Buttressed Floodwall

A buttressed wall is very similar to a counterfort wall. The difference is that the transverse support walls are located on the side of the stem, opposite the retained materials (see Figure 6-41).

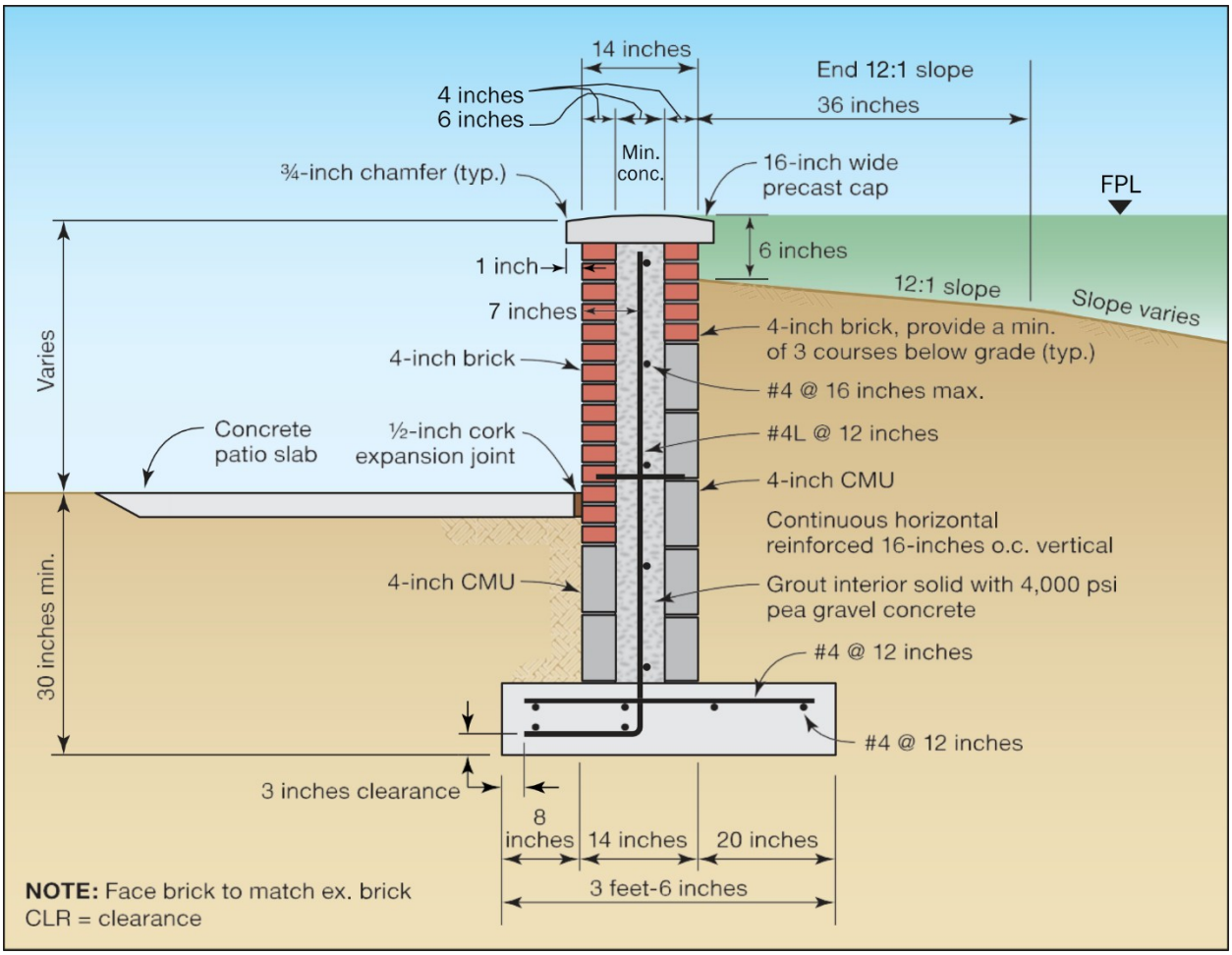


Figure 6-45. Typical section of a brick-faced concrete floodwall

The counterfort wall is more common than buttress walls because the support stem is hidden beneath the retained material (soil or water), whereas the buttress occupies what may otherwise be usable space in front of the wall.

Warning

While the double-faced brick floodwall application is used on either side of concrete block with reinforced and grouted cores, it is not as strong or leak-proof as monolithic cast-in-place applications.

Counterfort Floodwall

A counterfort wall is like a cantilever retaining wall except that it can be used where the cantilever is long or when very high pressures are exerted behind the wall (see Figure 6-41). Counterforts, or intermediate traverse support bracing, are designed and built at intervals along the wall to reduce

the design forces. Generally, counterfort walls are economical for wall heights more than 20 feet, but are rarely used to protect homes.

6.3.1.2. Floodwall Site Visit

Detailed information must be obtained about the site and existing structure to make decisions and calculations concerning the design of a floodwall. The designer should use the guidance presented in this chapter, where detailed information and checklists for site visits are presented. Key information to collect includes the low point of elevation, topographic and utilities surveys, hazard determinations, local building requirements, and homeowner preferences. Once the designer has developed the low point of entry and site and utility survey information, a conceptual design of the proposed floodwall can be discussed with the homeowner. This discussion should cover the following:

- Site flood history and damages
- Strategies to protect structure openings and walls with a floodwall and floodwall closure
- Evidence of seepage/cracking in building foundation walls indicating hydrostatic pressure on the foundation
- Use of a floodwall to relieve hydrostatic pressure on the foundation and other exterior walls
- Floodwall options and conceptual designs that provide necessary flood protection (obtain consensus on the preferred size, location, and features of the proposed floodwall)
- Utilities requiring adjustment or floodproofing because of the floodwall
- Predicted disruptions during construction and impacts to home access

The floodwall designer should be aware that construction of a floodwall may not reduce the hydrostatic pressures against the below grade foundation of the building. Seepage beneath the floodwall and the natural capillary action of the soil layer may result in a water level inside the floodwall that is equal to or above grade. This condition is worsened by increased depth of flooding outside the floodwall and increased flood duration. Unless this condition is relieved, the effectiveness of the floodwall may be compromised (Figure 6-46).



Note

Determination of an appropriate distance from the structure for the floodwall is a function of the depth of the foundation and the soil type. The deeper the lowest level of the structure, the farther away the floodwall should be located.

It is important that the designer check the ability of the existing foundation to withstand saturated soil pressures that would develop under this condition. Formulas necessary for this determination are provided in Chapter 3.

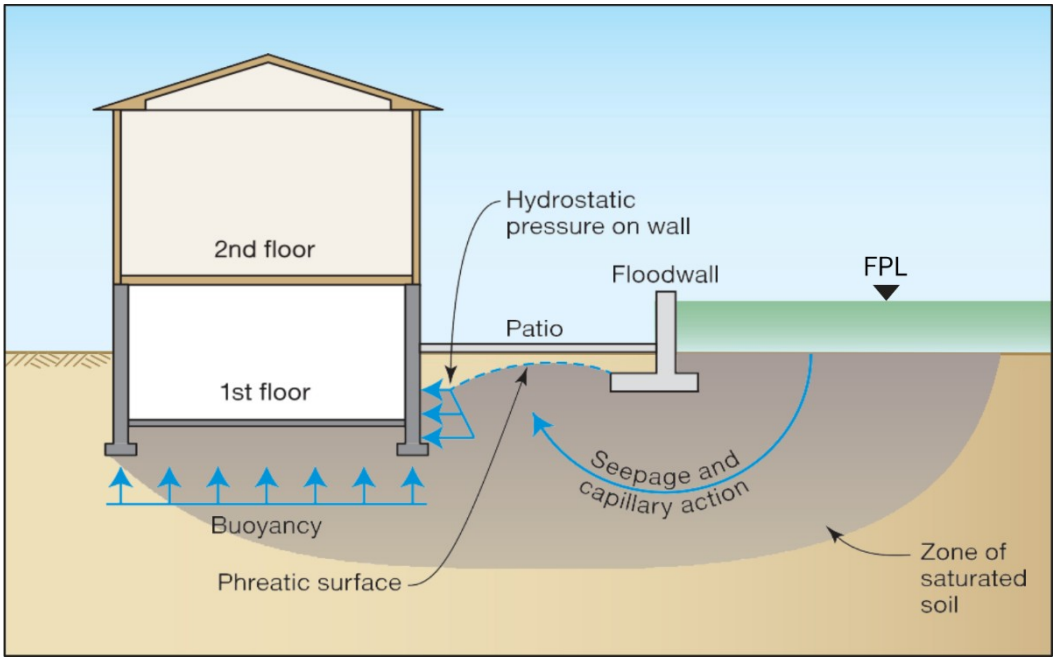


Figure 6-46. Seepage underneath a floodwall

The condition can be relieved by installation of foundation drainage (drainage tile and sump pump) at the footing level and/or by extending the distance from the foundation to the floodwall. Seepage pressures can also be decreased by placing backfill against the floodwall to extend the point where floodwaters submerge the soil, but the effectiveness of this measure depends on the relative characteristics of the soils in the foundation and the backfill. Foundation drains and sump pump measures are presented in Section 6.2.2.

Computation of the spacing required to address this challenge is a complicated process that should be performed by an experienced geotechnical engineer. The change in phreatic surface impacts increasing the distance between the foundation and the floodwall, or use of a foundation drain and sump pump system (Figure 6-47). The phreatic surface represents the surface of the water table at or below ground level.

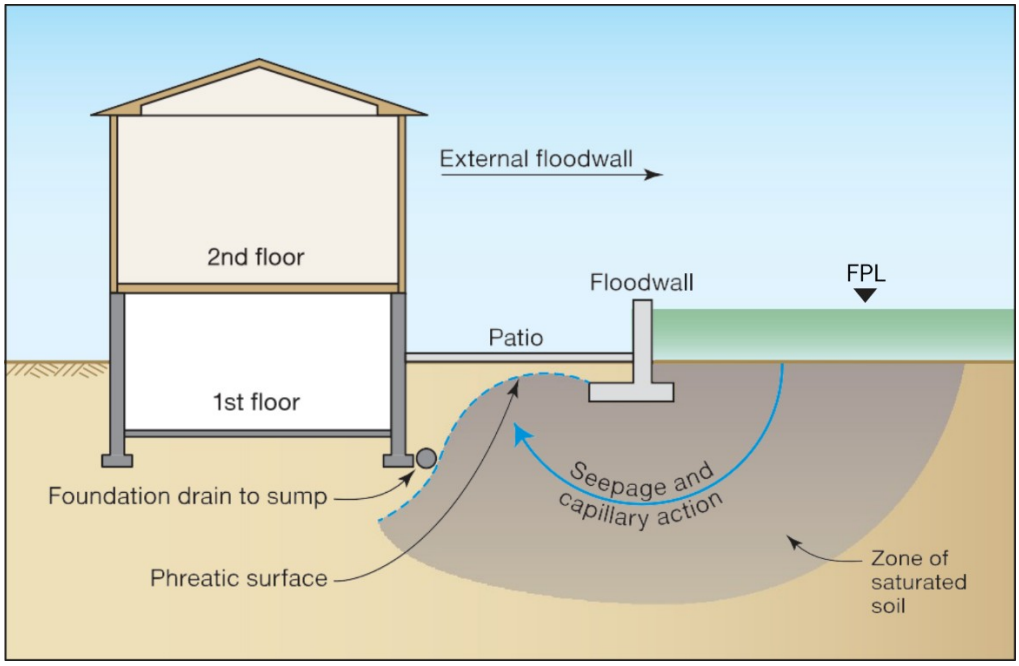


Figure 6-47. Reducing phreatic surface influence by increasing distance from foundation to floodwall and adding foundation drain

6.3.1.3. Floodwall Design Approaches

Detailed Floodwall Design Approach

The design of floodwalls consists of the proper selection and sizing of the floodwall and the specification of any necessary drainage systems; waterproof materials to stop seepage and leakage; and miscellaneous details to meet site and homeowner preferences for patios, steps, wall facings, and support of other overhead structures (posts and columns). The dimensions and forces associated with a floodwall are shown in Figure 6-48. This section introduces designers to the detailed design process for a floodwall provided in Appendix F (see Note), which consists of the following eight steps:

- Step 1: Determine wall height and footing depth.
- Step 2: Assume dimensions.
- Step 3: Calculate forces.
- Step 4: Calculate factor of safety against sliding.
- Step 5: Calculate the factor of safety against overturning.
- Step 6: Calculate eccentricity.
- Step 7: Calculate soil pressures.
- Step 8: Select reinforcing steel.

Note

Refer to Appendix F, Section F.1 for additional details regarding the eight-step design process, including a process flow chart, details, and equations to complete each step.

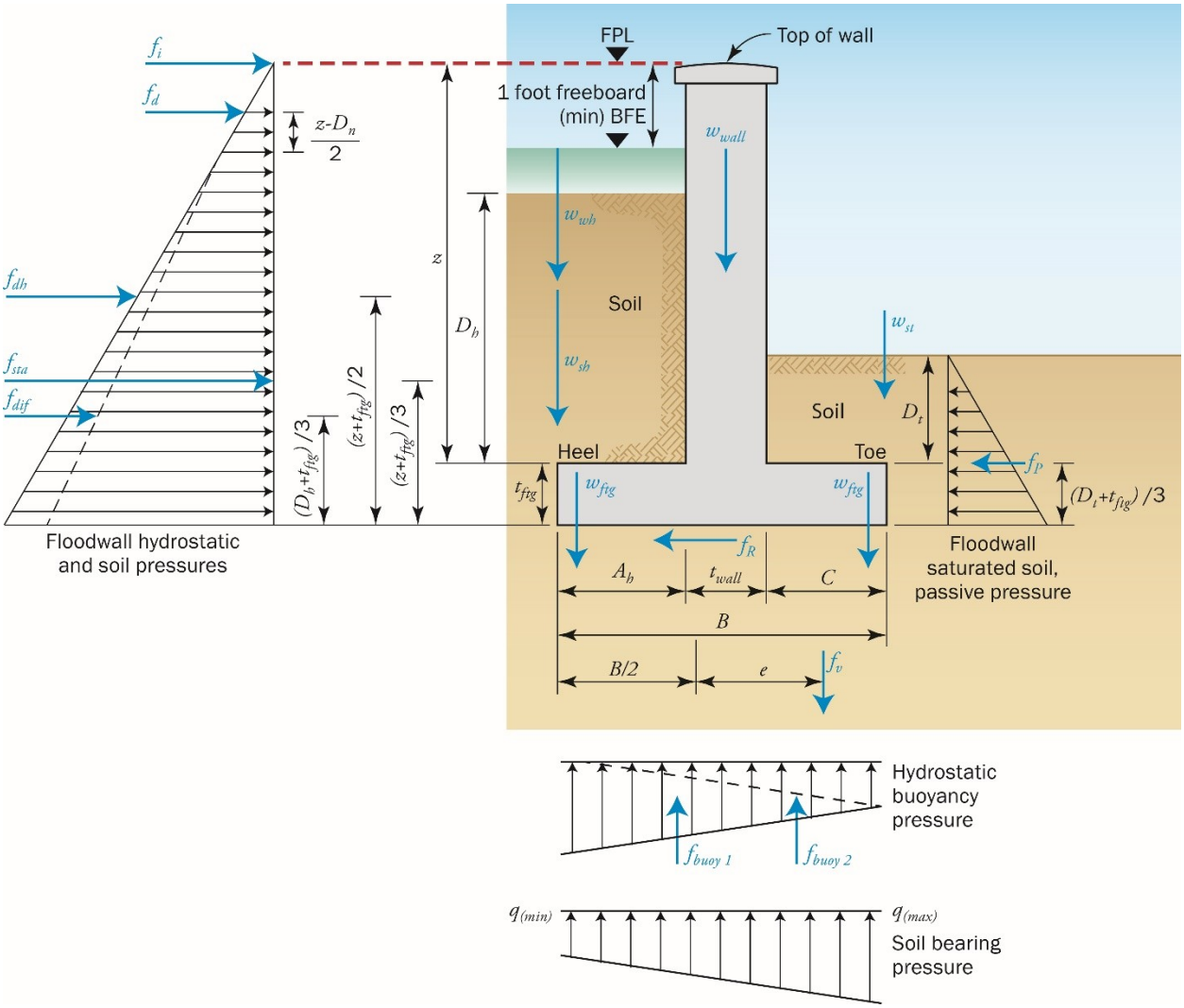


Figure 6-48. Typical dimensions and forces acting on a floodwall

Simplified Floodwall Design Approach

In contrast to the detailed floodwall design approach outlined in the previous section, Table 6-1 presents general factors used to develop a simplified, standardized approach to floodwall design. If the soil conditions at the site in question do not reflect the assumed conditions below, the standard criteria approach cannot be utilized, and the detailed design process presented in Section 6.3.1.3 and Appendix F must be used.

Based on the stability requirements (assuming no cohesion), footing dimensions for various wall heights, footing depths, and two different soil types have been calculated. The calculation results are shown in Tables 6-2 and 6-3. The designer can use the following tables to specify floodwall/footing dimensions required for heights up to six feet, which reflect flooding levels from one to four feet (including a minimum of three feet of soil over the footing). Flooding levels can be computed as $(z - D_t)$. It is important to note that these dimensions are very conservative, and the designer may be able to reduce the dimensions.

In these calculations, the following assumptions have been made:

- Wall and footing are concrete
- Wall thickness (t_{wall}) = 1.0 foot
- Footing thickness (t_{ftg}) = 1.0 foot
- Minimal debris impact potential
- Minimal velocity (<5 feet per second)
- Reinforcing consists of #4 steel bars on 12-inch centers in both the wall and footing

Note

This simplified approach uses assumed site conditions. The designer should be aware that the previous process is normally used in the design of most floodwalls. However, this design process can be shortened for floodwalls of less than three feet in height by assuming certain site-specific soil conditions and design parameters. Tables 6-2 and 6-3 show typical floodwall design sizes and reinforcement schemes that would be applicable in certain situations. The designer should be aware that, unless assumptions and standard design criteria are met, the complete design process for the floodwall should be performed.

Table 6-1. Assumed Soil Factors for Simplified Floodwall Design

Unified Soil Classification System Soil Type	Allowable Bearing Pressure (lb/ft^2)	k_p, Passive Soil Pressure Coefficient	C_f, Friction Factor	Equivalent Fluid Pressure for Saturated Soil	F_{soil}, Unit Weight of Soil, (lb/ft^3)
Clean, dense sand and gravel, GW, GP, SW, and SP	2,000	3.70	0.55	75	120
Dirty sand and gravel of restricted permeability, GM, GM-GP, SM, and SM-SP	2,000	3.00	0.45	77	115

Table 6-2. Typical Floodwall Dimensions for Clean, Dense Sand and Gravel Soil Types (GW, GP, SW, SP)

Height of Floodwall* z (ft)	Depth of Soil on Water* Side D_h (ft)	Depth of Soil on Water* Side D_t (ft)	Base Width* B (ft)	Heel Width* A_t (ft)	Toe Width C (ft)
3.0	2.0	2.0	2.5	1.0	0.5
4.0	2.0	2.0	4.5	2.5	1.0
4.0	3.0	2.0	4.0	2.0	1.0
4.0	3.0	3.0	4.5	2.5	1.0
5.0	2.0	2.0	6.5	3.5	2.0
5.0	3.0	2.0	6.0	3.5	1.5
5.0	4.0	2.0	5.5	3.0	1.5
5.0	3.0	3.0	4.5	2.5	1.0
5.0	4.0	3.0	4.0	2.5	0.5
6.0	2.0	2.0	9.0	6.5	1.5
6.0	3.0	3.0	7.0	3.5	2.5
6.0	4.0	3.0	6.5	3.5	2.0
6.0	3.0	2.0	8.0	5.0	2.0
6.0	5.0	2.0	7.0	4.0	1.5
6.0	5.0	3.0	6.0	3.5	1.5

* See Figure 6-48

Table 6-3. Typical Floodwall Dimensions for Dirty Sand and Gravel of Restricted Permeability Soil Types (GM, GM-GP, SM, SM-SP)

Height of Floodwall* z (ft)	Depth of Soil on Water* Side D_h (ft)	Depth of Soil on Water* Side D_t (ft)	Base Width* B (ft)	Heel Width* A_t (ft)	Toe Width C (ft)
3.0	2.0	2.0	2.5	1.0	0.5
4.0	2.0	2.0	5.0	2.5	1.0
4.0	3.0	2.0	4.5	2.5	1.0
4.0	3.0	3.0	4.0	2.0	1.0
5.0	2.0	2.0	8.0	5.5	1.5
5.0	3.0	2.0	7.5	5.5	1.0
5.0	4.0	2.0	7.0	5.5	0.5
5.0	3.0	3.0	5.5	3.0	1.5
5.0	4.0	3.0	5.0	3.0	1.5
6.0	3.0	3.0	8.0	5.0	2.0
6.0	4.0	3.0	7.0	4.0	2.0
6.0	5.0	3.0	6.5	4.0	1.5

* See Figure 6-48

6.3.1.4. Floodwall Components and Appurtenances

Floodwall components include drainage systems, stair details, wall facings, patios, existing structure connections (sealants), existing structure support (posts and columns), and closure details. The local building code may dictate standards for design and construction of floodwall elements.

Floodwall Closures

Many of the principles discussed earlier in Dry Floodproofing Section 6.2 apply to floodwall closure design. Watertight closures must be provided for all access openings, such as driveways, stairs, and ramps. Seals should be provided for all utility penetrations. Figure 6-49 shows typical floodwall closures. Structural analysis for closure design should follow the procedures previously outlined for shield design. Refer to Appendix F for specific floodwall closure design details (see Note).

Note

Refer to **Appendix F, Section F.2** for additional details regarding floodwall closure design, including figures, details and equations to address the various design issues.

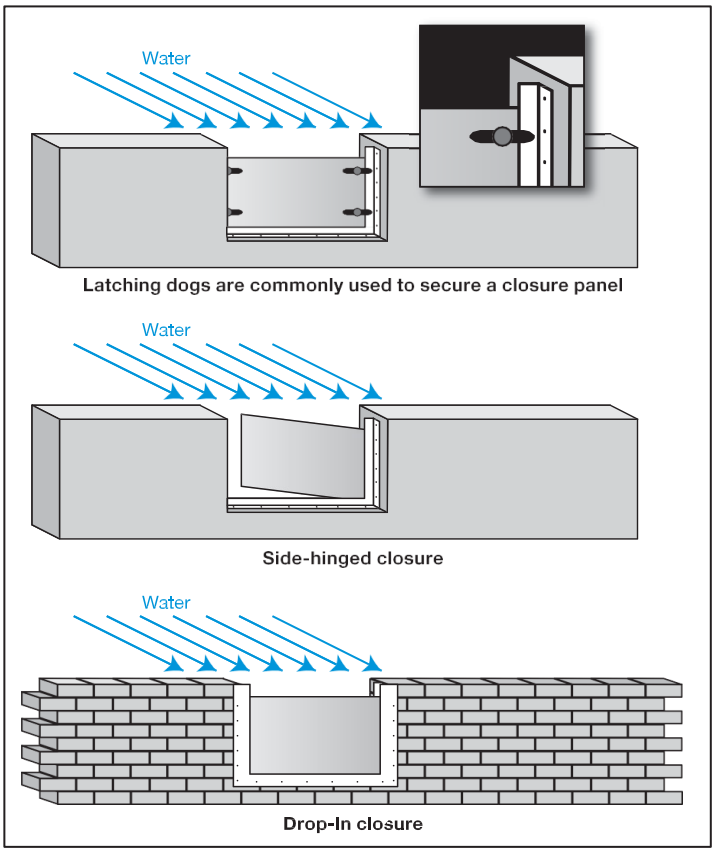


Figure 6-49. Typical floodwall closures

The type of closure used depends primarily on the size of the opening that needs to be protected. This will determine the type of material to be used and how the closure is to be installed and operated.

Longer and larger closures, such as for a driveway, must be able to withstand significant flood forces and should be made of more substantial materials, such as hinged steel plate or stop logs (Figure 6-50), protected against rust and corrosion. A heavy aluminum plate may also be used, although it will likely need to be reinforced. In either case, due to the weight of the closure, it is recommended that hinges be used to swing the closure into place. Hinging can be located along the bottom so the closure lies flat when not in use, or it can be placed along one side, so the closure can fold back out of the way.

For normal passage openings (Figure 6-51), aluminum is the most common material used. It is lightweight, allowing for easy fabrication and transport, and resistant to corrosion. Aluminum can buckle under heavy water pressure, so additional reinforcement may be required.



Figure 6-50. Example of larger floodwall closure for driveway (photo used with permission courtesy of Floodproofing.com)



Figure 6-51. Example of smaller floodwall closure (circled in red)

Exterior grade plywood is also commonly used for smaller openings. It is inexpensive and easily fabricated. However, over time, plywood is subject to decay, warping if not properly stored, and can fail under relatively low flood forces. Plywood will usually require significant reinforcement, such as a timber (2x4) frame or metal frame.

Aluminum and plywood are light enough for temporary closures that can be stored in a safe location and installed when floodwaters threaten. There are many different arrangements that can be used to

install movable closures. Common closure devices include “drop-in” shields that fit into a special slot arrangement and “bolt-on” shields affixed over an opening. There are several types of hardware that can be used to secure a closure, such as T-bolts, wing nuts on anchored bolts, or latching dogs.

It is essential that closures are watertight by use of a gasket. Neoprene and rubber are commonly used, but there are several other available materials that perform equally as well.

The successful performance of closure systems also requires that closures are firmly secured against the protected openings. Although the hydrostatic pressure of water may help hold the closure in place, floodwater surges can result in negative pressure that can pull off an improperly installed closure.

The closure material must be of sufficient strength and thickness to resist bending and deflection failures. The ability of a specific material to withstand bending stresses may be substantially different from its ability to withstand deflection stresses. Therefore, to provide for an adequate factor of safety, the required closure thickness should be calculated twice: for bending stresses and deflection stresses. The resulting thicknesses should be compared, and the larger value specified in the final closure design. Refer to Appendix F for equations and design details for making this determination.



Warning

Orientation of Openings: It is highly recommended that openings in floodwalls and berms not be placed on the upstream side. Closures should not be used on upstream sides where impact loads are expected.

Closure plates of plywood are limited to short spans and low water heights. It should also be noted that most plywood will deteriorate when exposed to high moisture. Therefore, plywood closure plates should be periodically examined and replaced.

Drainage Systems

When designing a floodwall system, designers must verify that the system will not flood adjacent properties blocking normal drainage. Specific information and local requirements can be obtained from the local zoning commission, building inspector, or water management agency. Before finalizing the design, designers should consult local building codes, floodplain and/or stormwater management ordinances, zoning ordinances, or property covenants that may prohibit or restrict floodwalls.

The flood protection design should be developed to divert floodwater and normal rainfall away from the structure. By directing the floodwater and rainfall away from the structure, designers can minimize potential erosion, scour, impacts, and water ponding. Typical design provisions include:

- Re-grading the site

- Sloping applications
- Drainage system(s)

Re-grading the site basically involves contouring. The surface can be contoured to improve the drainage and minimize floodwater turbulence. Ground covers or grasses, especially those with fibrous root systems, can be effective in holding soil against erosion and scour effects of floodwaters.

Sloping applications include providing positive drainage for engineered applications such as patios, sidewalks, and driveways. The material is slightly inclined, typically at a 1% to 2% grade, to an area designed for collection, which includes inlets, ditches, or an existing storm drainpipe system. Figure 6-52 and Figure 6-53 show two patio drainage options, and Figure 6-54 shows a floor drain section typically used to provide positive drainage for patio areas enclosed by floodwalls. These configurations can also be used with sump and sump pump installations.

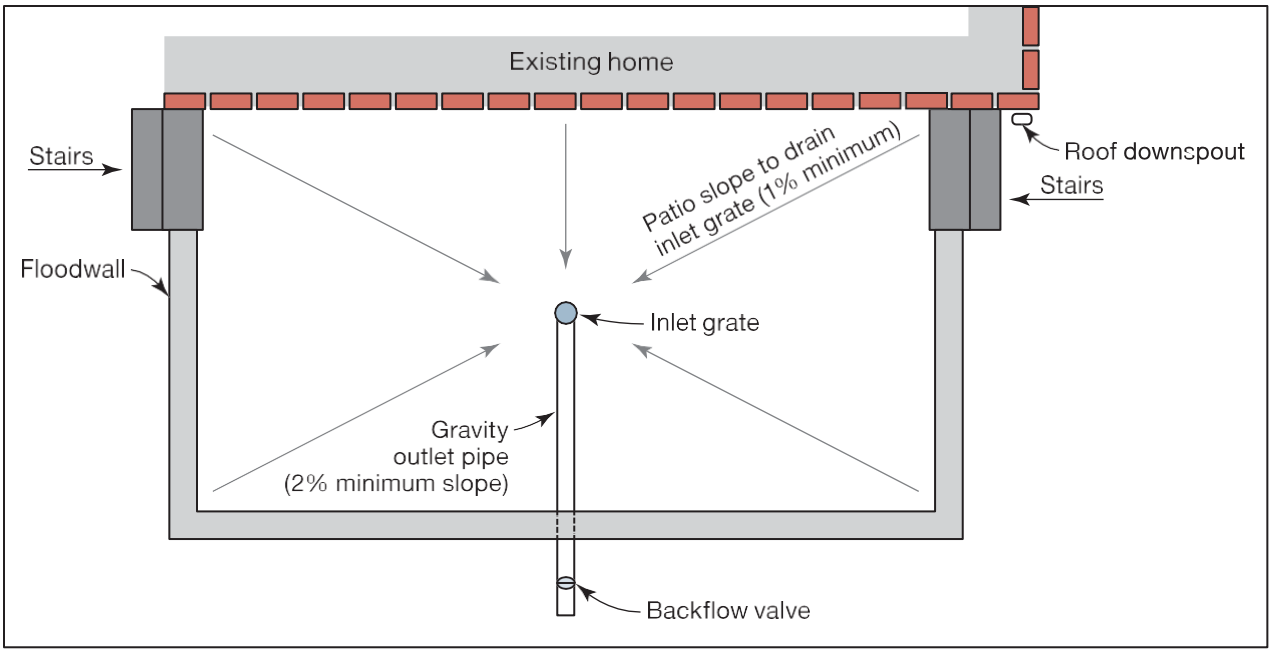


Figure 6-52. Sample patio drainage to an outlet

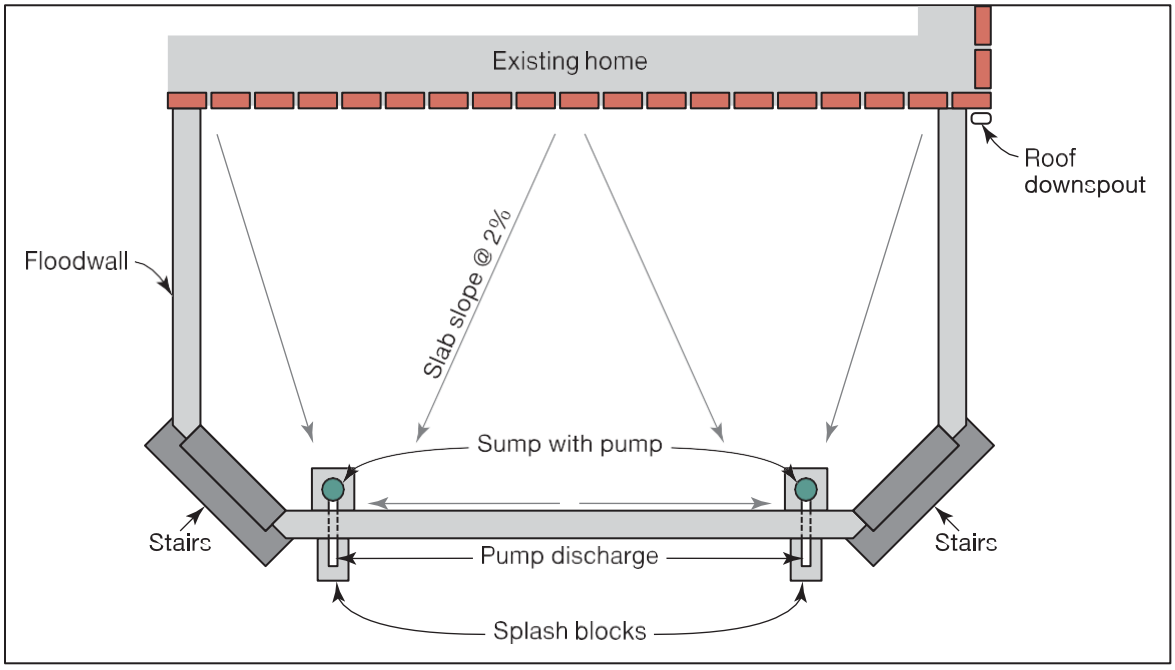


Figure 6-53. Sample patio drainage to a sump

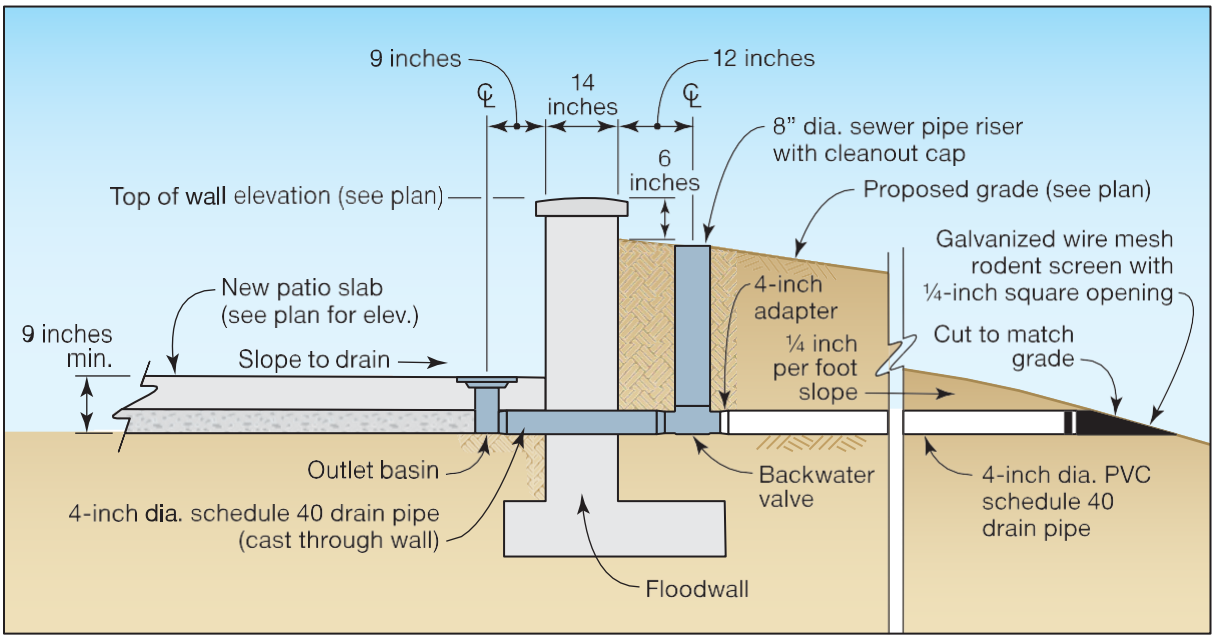


Figure 6-54. Typical gravity floor drain

Drainage systems are a series of pipes that collect and route interior drainage to a designated outfall. Usually, the drainage operation is underground and works through a gravity process. When grading and sloping will not allow the gravity system to function, provisions for a pumping method, such as a sump pump, should be made. Information on the design of sumps and sump pump applications is provided in Dry Floodproofing Section 6.2.

In its simplified form, a gutter and downspout outlet, which can be found on almost all houses, is a type of storm drainage system. Provisions for the downspout outfall should also be noted in the site drainage design.

Included in drainage system components are backflow valves. Sometimes referred to as a check valve, backflow valves are a type of valve that allows water to flow one way but automatically closes when water attempts to flow in the opposite direction. Figure 6-55 shows a typical floodwall with a check valve for gravity drainage. The elevation of the drain outlet should be as high as possible to delay activating the backflow valve, while maintaining a minimum of 2% slope on the drainpipe.

The success of gravity drainage systems requires that floodwater reach its maximum height after rainfall at the site has lessened or stopped. Therefore, when the backflow valve is activated, little or no water will accumulate on the patio slab (usually after a rainstorm). However, should this condition not exist, the use of a sump pump and/or design of runoff storage within the enclosed area should be provided.

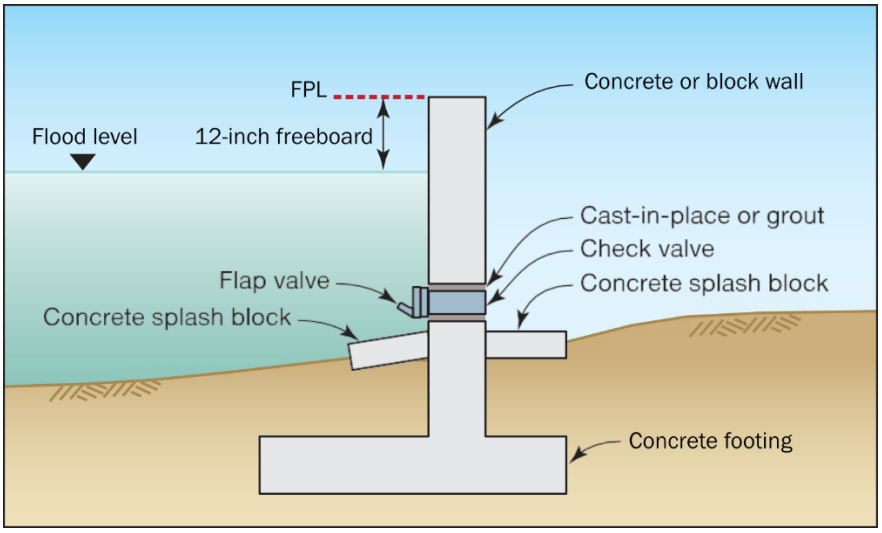


Figure 6-55. Typical floodwall with check valve

Seepage and Leakage Control

Floodwalls should be designed and constructed to minimize seepage and leakage during the design flood. Without proper design and construction, floodwalls are susceptible to seepage through the wall, seepage under the wall, leakage between the wall and residence, and leakage through any floodwall opening.

Seepage Through the Floodwall

Expansion and construction joints shall be constructed with appropriate water stops and joint sealing materials. To prevent excess seepage at the tension zones, the maximum deflection of any structural floor slab or exterior wall shall not exceed 1/500 of its shorter span. Figure 6-56 illustrates the use of water stops to prevent seepage through a floodwall.

Seepage Under the Floodwall

The floodwall design may also include the use of impervious barriers or cutoffs under the structure to decrease potential for development of full hydrostatic pressures and related seepage. Cutoffs must be connected to the impervious membrane of the building walls to effectively operate.

To meet these requirements, it may be necessary to provide impervious cutoffs to prevent seepage beneath the floodwall. This requirement is critical for structures designed for highly pervious foundation materials. It may also be necessary to construct a drainage system parallel to the interior base of the floodwall to collect seepage through or under the structure and normal surface runoff from the watershed. All seepage and storm drainage should be diverted to an appropriate number of sumps or gravity drains or pumped to the floodwater side of the structure. Normal surface runoff (during non-flood conditions) must also be considered in the drainage system.

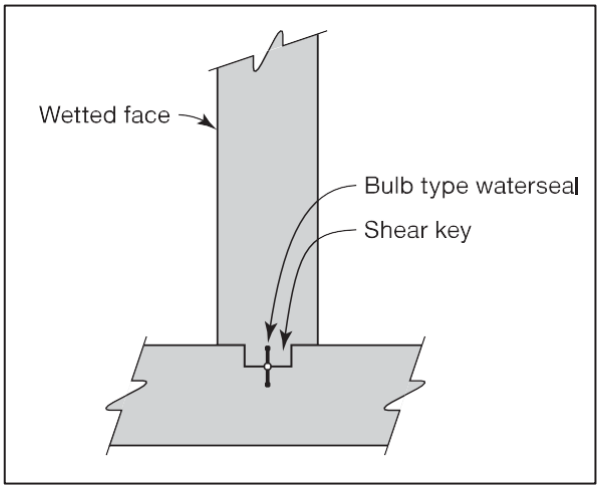


Figure 6-56. Water stop

Leakage Between the Floodwall and Residence

The connection between the existing house wall and the floodwall is normally not a fixed connection, because the floodwall footing is not structurally tied to the house foundation footing. A gap or expansion joint may exist between the two structures that creates the potential for leakage. It should be filled with a waterproof material that will work during seasonal freeze-thaw cycles.

One alternative is to use a 1/2-inch bituminous expansion material, 1/2-inch high-density caulking (Figure 6-57, top), and a bulb type water seal (Figure 6-57, bottom).

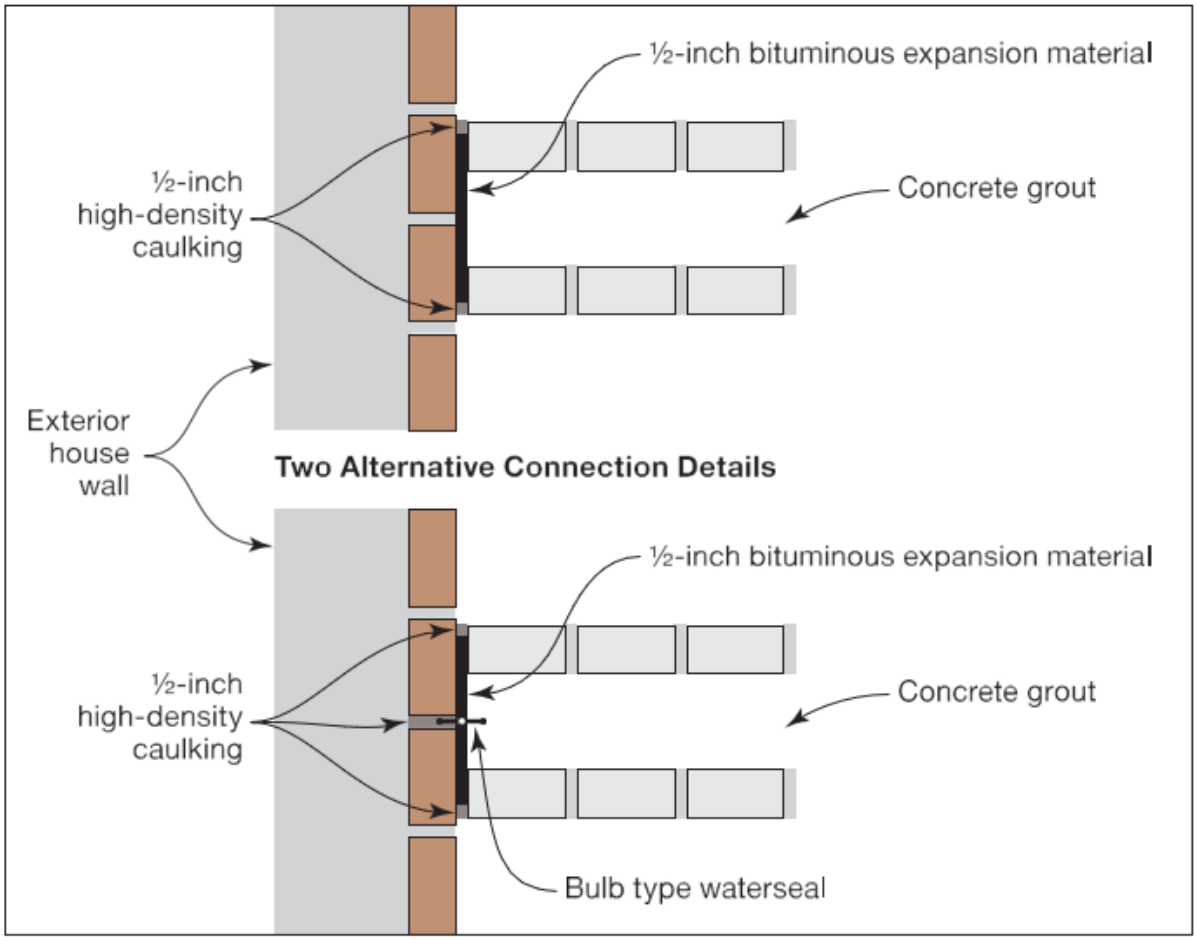


Figure 6-57. Floodwall to house connections: Top connection uses high-density caulking

Note

The effectiveness of house floodproofing can be increased by placing fill against the house to keep floodwaters from coming into direct contact with the structure.

Architectural Details

Floodwalls can be constructed in a variety of designs and materials. By considering the individual house design, topography, and construction materials, along with some imagination, designers can design floodwalls that provide a level of flood protection and enhance the appearance of the house.

Floodwalls can be a challenge to landscape or to blend into the terrain. By using natural topography and employing various types of floodproofing techniques, such as waterproofing, sealants, or decorative bricks or blocks, a floodwall can blend in with the house and landscape and serve as a privacy fence or by outlining a patio or garden area. The two most common applications of cosmetic facing of a floodwall are brick facing (see Figure 6-38) and decorative block facing.

A typical floodwall design can incorporate a patio, which is enclosed by the floodwall. A concrete slab-on-grade or decorative paving can be installed between the house and floodwall to create an attractive and useful feature. The slab-on-grade or pavers can serve four functional purposes:

- Patio area for the homeowner
- Additional bracing for the floodwall
- Positive drainage away from the building towards drainage collection points
- Impervious barrier inside the floodwall to reduce infiltration of water into the soil adjacent to the structure

The patio floor or slab-on-grade is set four inches below the door openings to provide water storage to accommodate rainfall and roof-gutter spillage that may occur after the floodwaters have reached the elevation. A backflow valve on the patio drain may be included. The concrete slab is sloped to a floor drain (or drains) which discharge, if the existing grade allows, through a gravity pipe or sump pump. In addition to designing patio applications, a qualified design professional can develop architectural and structural modifications that will accommodate existing/future decks or roof overhangs. These supports can bear on the floodwall's cap, provided additional structural modifications to the floodwall and foundations are furnished to sustain the increased load from above (Figure 6-58).

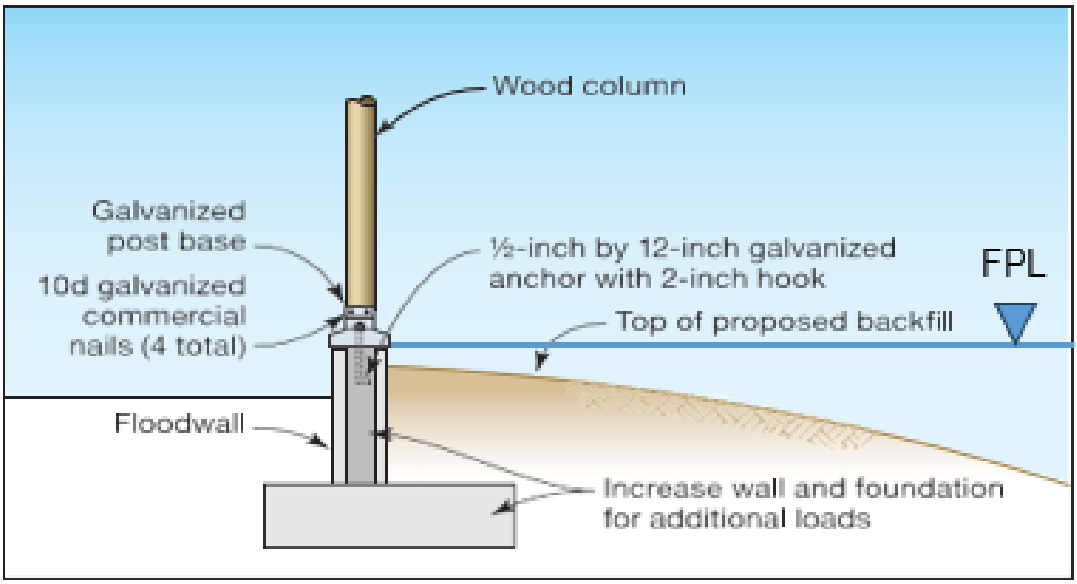


Figure 6-58. Floodwall supporting columns

Residential access requirements, such as driveways, sidewalks, doors, and other entrances, will need to be examined during the design. These entrances may create gaps in the floodwall. Every effort should be made to design passages that extend over the top of the wall and not through it. A stile stairway over a floodwall provides access while not creating an opening in the floodwall.

The stile is a series of steps up and over the floodwall and to the designed grades, which provides access but eliminates the need for a floodwall gap and provides permanent flood protection. A

typical step detail is shown in Figure 6-59. Note that handrails, railings, stair treads, and other safety features must be incorporated into the stile stairway consistent with local building codes.

In addition to the floodwall's architectural features, the entire area can be finished with landscaping features such as planter boxes, trees, and shrubs. Vegetative cover and stone aggregate can also be used to enhance the flood protection and to prevent erosion and scour. A qualified landscape architect should be consulted when selecting material coverage for a particular area. Roots, foliage, leaves, and even growth patterns of trees and shrubs should inform the selection of landscaping materials.

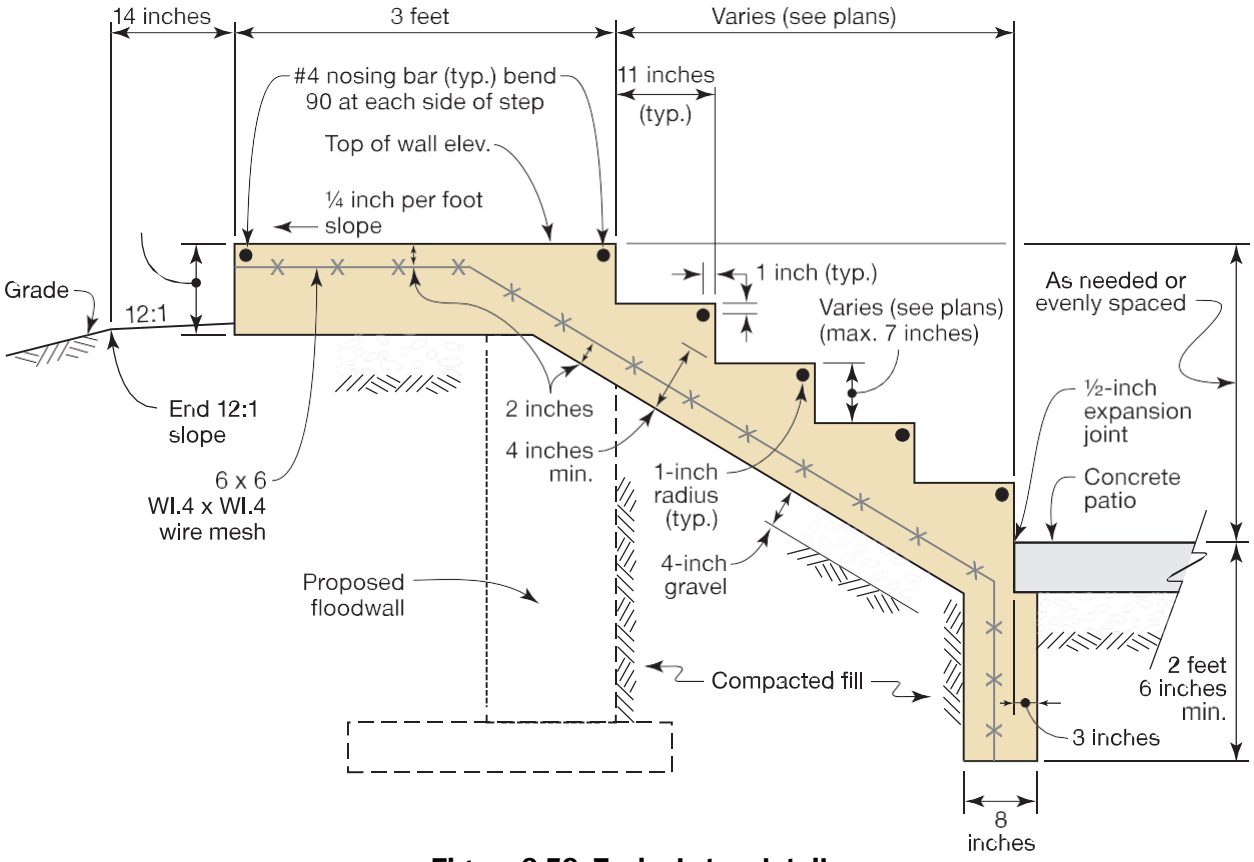


Figure 6-59. Typical step detail

6.3.1.5. Floodwall Inspection and Maintenance

During construction of a floodwall, periodic inspections should be conducted to ensure that the flood protection measure has been built per the original design. As a minimum, the designer, owner, or owner's representative should inspect and observe the following improvements:

- Confirm adequate slope drainage, including drainpipes, patio, and grading outside the floodwall.
- Confirm that floodwall foundation was prepared consistent with plans and specifications.

- Confirm that sealants, waterproofing, and caulking were applied per the manufacturer's installation requirements.
- Confirm that the sump pump is operational.
- Check sample brick or decorative block (before installation) for patterns or match to existing features.
- Confirm that a maintenance checklist was developed that includes the manufacturer's recommendations for passive flood protection applications, sealants, drains, etc.

Once the floodwall has been built, a maintenance schedule should be followed to ensure the system will remain operational during floods. Floodwalls should be inspected annually for structural integrity. The visual investigation should include a checklist and photographic log of:

- Date of inspection
- General floodwall observations involving wall cracking (length, width, locations), deteriorated mortar joints, misalignments, chipping, etc.
- Sealant observation, including displacement, cracking, and leakage
- General site characteristics, including water ponding/leakage, drain(s), and drainage and site landscaping
- Operation of the sump pump, generator/battery, and installation of any closures
- Drain and backflow valve testing



Note

Landscaping inside and hanging over a protected area may generate organic debris that could clog drains. Plants should be selected that do not result in clogged drains from falling leaves or fruit.

Additionally, the entire flood protection system should be inspected after a flood. A complete observation, including a photographic record, should be developed and may also include:

- Damages associated with impacts and flood
- Excessive erosion and scour damage
- Floodwater marks
- Functional analysis regarding the flood protection system

The following Floodwall Inspection Worksheet (Figure 6-60) can be used to record observations during the annual and post-flood inspections.

Floodwall Inspection Worksheet

Owner Name:_____ Prepared By:_____

Address: _____ Date: _____

Property Location: _____

Floodwall Component	Yes	No	Observations
Cracking in wall			
Mortar joint separation			
Wall misalignment			
Miscellaneous chipping and spalling			
Possible leakage spots			
Sealant displacement			
Water ponding			
Drains functional			
Sump pump operational			
Landscaping			

Sketch area:

General observations and summary:

Figure 6-60. Floodwall Inspection Worksheet

6.3.1.6 Deployable Floodwalls

Deployable floodwalls may be installed where construction of conventional floodwalls or berms is not acceptable because of related impacts on accessibility, cost, or aesthetics. Numerous deployable floodwalls are available. Figure 6-61 shows moveable floodwalls in storage, and Figure 6-62 shows the location in which these floodwalls would be deployed.



Figure 6-61. Moveable floodwalls in storage that can be deployed by filling baffles with water



Figure 6-62. The location where the moveable floodwalls shown in Figure 6-61 would be deployed

6.3.2. BERMS

A berm is a ridge or barrier constructed of compacted low permeability soil to prevent, divert, or direct water away from the protected area. Berms are smaller than levees and are used to protect individual structures, whereas levees protect large areas and communities from flooding. Berms are more commonly used than floodwalls for protecting single or limited numbers of residential buildings (Figure 6-63). Given berm land requirements and cost, berms are a less commonly used residential

flood mitigation measure than many of the other retrofitting options presented in this publication. The following sections provide important design and construction considerations for berms.



Figure 6-63. Residential berm during flooding

Warning

A settled height of six feet is the maximum elevation recommended for an individual residential berm.

Warning

Berms not specifically designed or engineered are not guaranteed to be effective for their intended purpose. The stability and ability to control or redirect water flow may be compromised due to the lack of formal analysis and design. Additionally, unforeseen subsurface conditions, such as variations in soil composition, groundwater level, or hidden obstructions, may exist and adversely affect the berm's functionality and structural integrity. It is recommended that a qualified professional engineer be consulted to assess site conditions and provide appropriate design guidance.

6.3.2.1. Berm Site Visit

Certain conditions must exist before berms can be considered a viable retrofitting option. The questions that should be asked before proceeding any further are listed below.

- Is the site topography appropriate for a berm?
    - A significant portion of the cost associated with berm construction is dependent on required fill material. If the topography around the home is such that only one or two sides of the structure need to be protected, a berm may be economical.
- Is a suitable low permeability soil fill material readily available?
    - Clayey soils, such as a CH, CL, or SC, are required in the construction of water retarding structures to eliminate concerns of seepage and stability. CH, CL, and SC are defined in the ASTM International (ASTM) *Standard Practice for Classification of Soils for Engineering Purposes (Unified Soil Classification System)* Designation D2487-17 (ASTM, 2025).
- Do local, State, or Federal laws, regulations, or ordinances restrict or prevent construction of a berm?
    - Has coordination with local, State, and Federal officials been arranged? This may be necessary to determine if the berm retrofitting option is permissible. Certain criteria prohibit construction within a FEMA-designated floodway, the channel of a river or other land areas adjacent to a watercourse that are needed to discharge the base flood during a storm, a wetland area, or a sensitive habitat.
- Will the berm alter, impede, or redirect the natural flow of floodwaters?
- Have previous calculations from Chapter 4 to determine both the depth and velocity of flood flows around the structure in question been checked? This should be done to ensure that the berm will not result in increased flood hazards. Also, in many cases, the local floodplain administrator may require an analysis of the proposed modification to the floodplain.
- Will flood velocities allow for use of a berm?
- Do the flood velocities along the water side of the berm embankment exceed eight feet per second? If so, the cost of protecting against the scour will most likely dictate the use of a different retrofitting method.

Warning

If the assumptions listed in this chapter are not applicable to the site being considered, an experienced design professional should be consulted, or another retrofitting approach considered.

Berm designers should be aware that berm construction may not reduce the hydrostatic pressures against a below grade foundation. Seepage underneath a berm and the natural capillarity of the soil layer may result in a water level inside the protected area that is equal to or above grade. This condition is worsened by increased depth of flooding outside the berm and increased flood duration. Unless this condition is relieved, berm effectiveness may be compromised. This condition, which involves the intersection of the phreatic line with the foundation, is illustrated in Figure 6-46 and Figure 6-47.

It is important that designers check the ability of the existing foundation to withstand saturated soil pressures that would develop under this condition. Computations necessary for this determination are provided in Chapter 3.

The condition can be relieved by installation of foundation drainage (drainage tile and sump pump) at the footing level, and/or by extending the distance from the foundation to the berm. The land side seepage pressures can also be decreased by placing backfill against the flood side of the levee to extend the point where floodwaters submerge the soil away from the structure, but the effectiveness of this measure depends on the relative characteristics of the soil. The design of foundation drainage and sump pumps is presented in Section 6.2. An experienced geotechnical engineer should compute required spacing.

6.3.2.2. Standard Levee Design Criteria Applicable to Berms

Because berms are like levees, elements of U.S. Army Corps of Engineers levee design criteria can be applied as a best practice. The following guidelines were developed for berms to provide a conservative design while eliminating several steps in the US Army Corps of Engineers design process, thereby minimizing the design cost. These guidelines pertain to the design and construction of berms with a maximum settled height of six feet. Techniques of slope stability analysis and calculation of seepage forces are not addressed. The recommended side slopes have been selected based on experience to satisfy requirements for stability, seepage control, and maintenance. The shear strength of suitable impervious soils compacted to at least 95% of the Standard Laboratory density, as determined by ASTM Standard D698-12, *Standard Test Methods for Laboratory Compaction Characteristics of Soil Using Standard Effort* (ASTM, 2021), will be adequate to ensure stability of berms, without the need for laboratory or field testing or calculation of safety factors.

Note

Berms and levees are defined by the National Flood Insurance Program as follows:

A **berm** is a type of free-standing barrier used for flood protection. Specifically, berms are earthen structures, typically constructed from local compacted fill, for the purpose of stopping or diverting floodwater from reaching a building or structure. Unlike levees, berms do not protect entire communities from flooding and have no impact on Flood Insurance Rate Maps or National Flood Insurance Program flood insurance rates.

A **levee** is a man-made earthen embankment built with sound engineering to contain, control, or divert water flow, reducing flood risk from temporary flooding. Unlike berms, levees can protect entire communities from flooding and can be evaluated for certification in accordance with specific standards established by the U.S. Army Corps of Engineers. Levees that are certified for accreditation by FEMA can be mapped in Flood Insurance Rate Maps and can impact National Flood Insurance Program flood insurance rates.

The minimum requirements for crest width and side slopes are defined below. In combination with the toe drainage trench and the cutoff effect provided by the backfilling of the inspection trench, these minimum requirements will provide sufficient control of seepage, and do not require complex analyses for short duration low-level flooding. Flatter land side slopes are recommended for a berm constructed on a sand foundation to provide a lower seepage gradient because a sand foundation is more susceptible to seepage failure than a clay foundation.

Note

These design recommendations—as illustrated in Figure 6-64, for a typical residential berm are conservative. Alternative parameters for a specific site may be developed by an engineer qualified in levee design.

Maximum Settled Berm Height of Six Feet: This is a practical limit placed due to available space and material costs.

Minimum Berm Crest Width of Five Feet: This is required to minimize seepage concerns and allow for ease of construction and maintenance.

Berm Floodwater Side Slope of One Vertical on 2.5 Horizontal: This is required to minimize the erosion and scour potential, provide adequate stability under all conditions (including rapid drawdown situations), and facilitate maintenance such as mowing.

Berm Land Side Slope: The land side slope may vary, based on the soil type used in the berm. If the berm material is clay, a land side slope of one vertical to three horizontal is acceptable. If the levee

material is sand, a flatter slope of one vertical to five horizontal is recommended to provide a lower seepage gradient.

One Foot of Freeboard: This is a best practice to provide a margin of safety against overtopping and allow for the effects of wave and wind action. These forces create an additional threat by raising the height of the floodwaters.

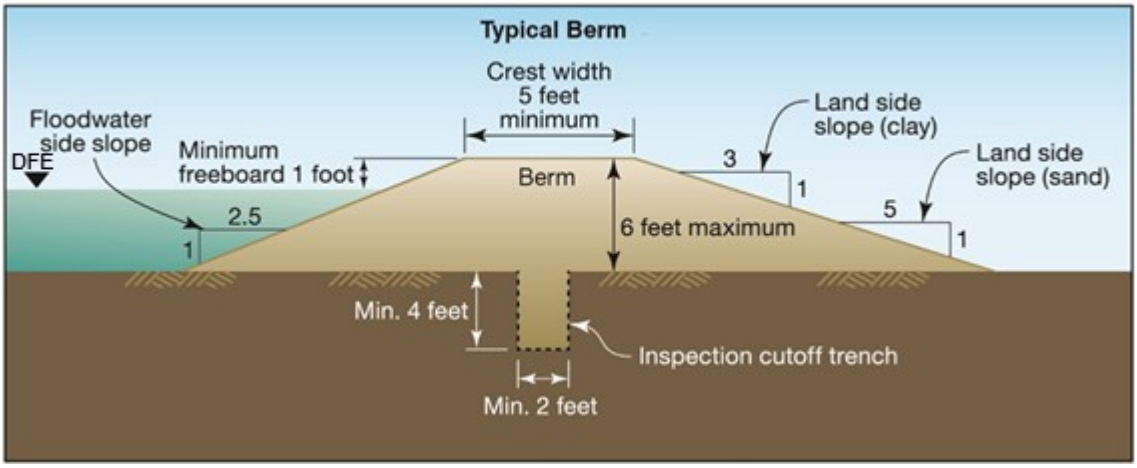


Figure 6-64. Typical residential berm

6.3.2.3. Berm Inspection Trench

Because of the importance of the foundation soil characteristics, excavation of an inspection trench is required to ensure the effectiveness of the berm. The minimum dimensions of the inspection trench are shown in Figure 6-64. The inspection trench, which shall run the length of and be located beneath the center of the proposed berm to provide the designer with critical information to be used in the subsequent steps of the design process. The excavation of an inspection trench is fundamental to the assumptions made for the rest of the design process. The inspection trench will accomplish the following objectives:

- **Locate Utility Lines That Cross Under the Berm**: Once identified, these must be further excavated and backfilled with a compacted impervious material to prevent development of a seepage path beneath the berm.

- **Provide "Cutoff" for Foundation Seepage**: The trench itself will be backfilled with a highly impervious soil, such as a CH, CL, or SC, as previously referenced, to create an additional buffer against levee foundation seepage.

- **Identify Berm Foundation Soil Type**: The construction of the inspection trench should provide the designer with a suitable sample to identify the foundation soil type using the ASTM Unified Soil Classification System. This variable will further direct the design of the levee.

- **Clay Foundation**: If, after inspection, it is determined that the in-situ foundation material is composed of a clay soil, as defined by ASTM D2487, a land side slope of 1 vertical on 3 horizontals should be used.
- **Sandy Foundation**: If, after inspection, it is determined that the in-situ foundation is composed of a sandy soil, as defined by ASTM D2487, a land side slope of 1 vertical on 5 horizontals should be utilized.

Warning

Duration of flooding is a critical consideration in the design of a berm. The longer the duration of flooding (i.e., the longer floodwaters are in contact with the berm), the greater the potential for seepage, and the greater the need for seepage control measures such as cutoffs, drainage toes, and impervious cores.

6.3.2.4. Berm Seepage Concerns

Two types of seepage must be considered in the design of a residential berm: foundation seepage and embankment seepage. The amount of seepage will be directly related to the type and density of soils in both the foundation and the embankment of the berm. While the installation and backfilling of the inspection trench with impervious material will help reduce concerns of foundation seepage, further steps must be taken to minimize any embankment seepage for berms between three and six feet in height.

Warning

If inspection determines that the foundation consists of a deep deposit of sand or gravel that will permit seepage under the shallow inspection trench, a deeper cutoff trench is necessary, especially if the protected structure has a basement founded on sand or gravel as defined by ASTM D2487. This scenario may make the use of a berm uneconomical.

The inclusion of a drainage toe for a berm of varying height will be limited to those areas with a height greater than three feet. If the berm height varies due to the natural topography, a drainage toe will only be necessary for those portions of the berm that have a height greater than three feet.

The major reason for the inclusion of these measures is to relieve the pressure of seepage through or under the berm so that piping may be avoided. Piping is the creation of a flow path for water through or under a soil structure, such as a levee, dam, or other embankment, resulting in a pipe-like channel carrying water through or under the structure. Piping can lead to failure. Piping becomes a more serious problem as the permeability of the foundation soil increases.

The drainage toe should be sized as shown in Figure 6-65 and should be filled with sand conforming to the gradation of standard concrete sand as defined by ASTM standards.

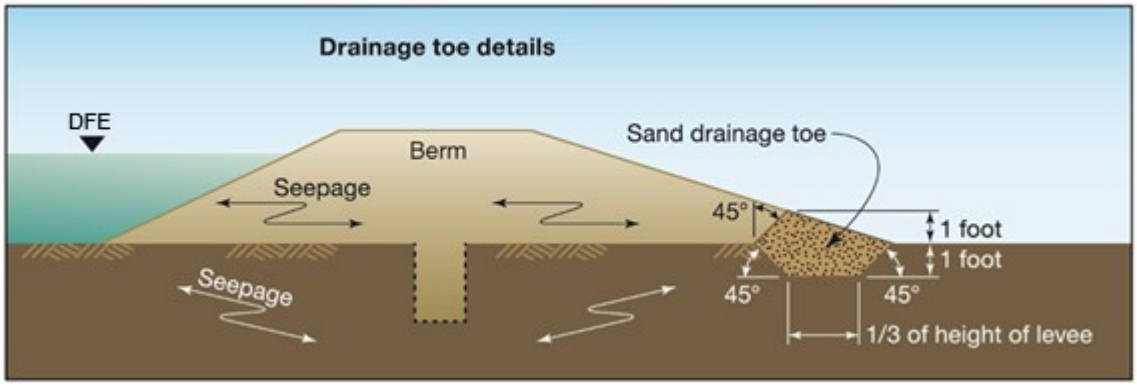


Figure 6-65. Drainage toe details

Note

Long duration flooding may negatively impact the ability of the drainage toe and inspection trench to control the seepage through and under the berm.

6.3.2.5. Berm Scour and Drainage Concerns

Scouring/Berm Slope Protection

The floodwater side of the berm embankment, to be effective, may require protection from erosion caused by excessive flow velocities. For flow velocities of up to three feet per second, a vegetatively stabilized or sodded embankment will generally provide adequate erosion protection. Some vegetative covers, such as Bermuda grass, Kentucky bluegrass, and tall fescue, provide erosion protection from velocities of up to five feet per second. The grasses should be those that are suitable for the local climate. An alternative or supplement to a vegetative cover is the use of a stone protection layer. The layer should be placed on the entire floodwater face of the berm and be sized in accordance with Table 6-4.

Table 6-4. Stone Protection Layer Guidance

Velocities Against Slope (ft/sec)	*Minimum Diameter or Stone (inches)*
< 2	0.5
< 5	2.0
< 8	9.0

Source: Design And Construction Of Levees (USACE, 2000)

Interior Drainage

Constructing a berm around a house should not only keep floodwaters out but also act to keep seepage and rainfall inside the protected area unless interior drainage techniques are utilized. One method of draining water that collects from rain and from seepage through and under a berm is to install drainpipes that extend through the berm, as shown in Figure 6-66. While this will allow for drainage by gravity, it is critical the drains equipped with flap gates on the river side of the levee, which close to prevent flow of floodwaters through the pipe. If these flap gates are not provided, then rising floodwaters will enter through these drainage pipes, resulting in flooding behind the berm system. The flap gates will open automatically when interior floodwaters rise above exterior floodwaters.



Cross Reference

Guidance on estimating interior drainage quantities is presented in Chapter 3.

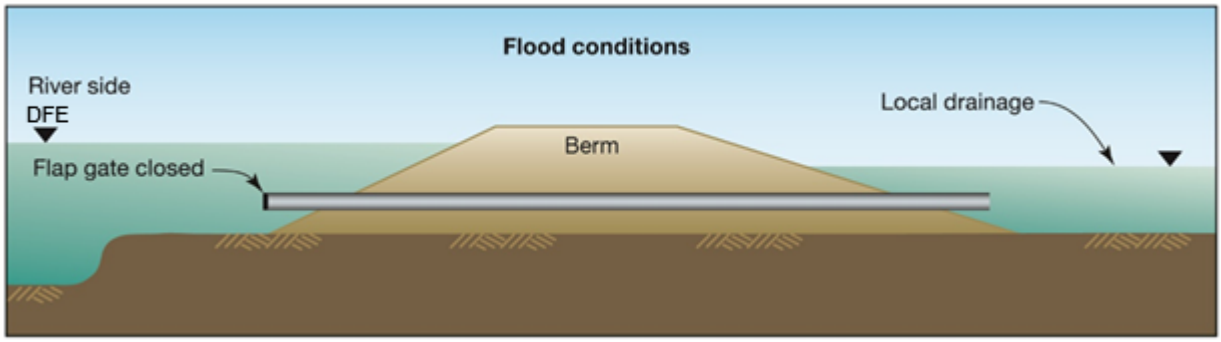


Figure 6-66. Drainpipe extending through berm

To ensure that water from precipitation or seepage within a protected area is removed during flooding, a sump pump should be installed in the lowest area encompassed by the berm. All interior drainage measures should lead to this pump, which will discharge the flow up and over the berm. The sump pump should have an independent power source so that it will remain in operation should there be an interruption of electrical power, a common event during a flood.

An alternative to the use of a sump pump (for minor storms) is the creation of an interior storage area that will detain all interior flow until the floodwaters can recede (see Figure 6-67). Typically, the storage area is sized for the 2- or 10-year recurrence interval event.

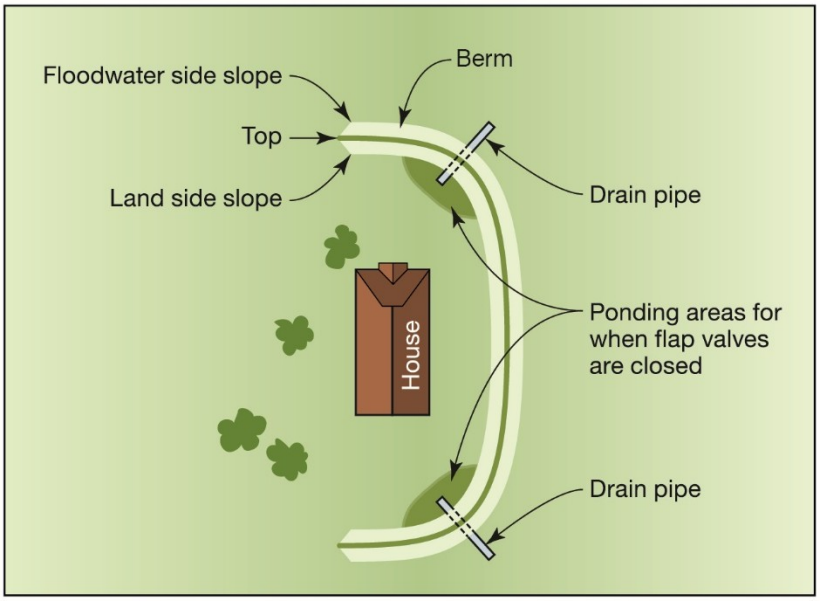


Figure 6-67. Interior storage area

6.3.2.6. Berm Construction Considerations

Berm Soil Suitability

Most types of soils are suitable for constructing residential berms. The exceptions are very wet, fine-grained, or highly organic soils, classified as OL, MH, CH, and OH. The most appropriate soils are those with a high clay content, which are highly impervious. Highly expansive clays should also be avoided because of potential cracking due to shrinkage.

Compaction Recommendations

As the berm is constructed, it should be built up in layers, or lifts, each of which should be individually compacted. Each lift should be no more than six inches deep before compaction (Figure 6-68). Compaction to at least 95% of standard laboratory density should be performed at or near optimum moisture content with pneumatic-tired rollers, sheep foot rollers, or other acceptable powered compaction equipment. In some situations, certain types of farm equipment can affect the needed compaction.

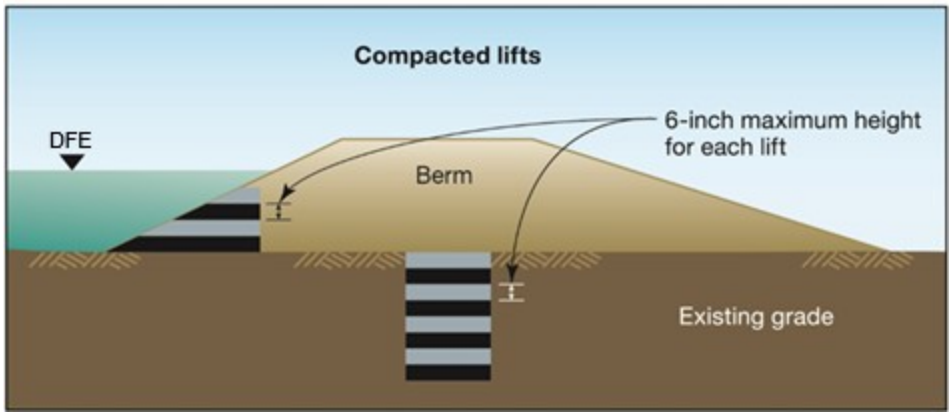


Figure 6-68. Compacted lifts

Settlement Allowance

The berm should be constructed at least 5% higher than the height desired to allow for soil settlement.

Note

Settlement allowances vary by geographic region and geologic conditions. Therefore, a 5% allowance may not be applicable in all situations. Consult a registered design professional, the State or local floodplain management or other appropriate official for further information.

Borrow Area Restrictions

A principal concern for the construction of the berm is the availability of suitable fill material for construction. Caution should be taken as to the location of the fill borrow area. This guidance recommends as a general rule to avoid utilizing a borrow area within 40 feet of the landward toe of the berm.

Access Across Berm

The complete encirclement of a structure with a berm can create access problems not only for the homeowner but also for emergency vehicles. If the berm is low enough, additional fill material can be added to provide a flat slope in one area for a vehicle access ramp running over the berm (Figure 6-69). Care should be taken to prohibit high volumes of traffic across the berm, which could result in the formation of ruts or the wearing away of the vegetative cover, in addition to potential increased crest settlement over time.

If it is necessary to have a gap in the berm, this can be closed during flooding with a gate or closure structure. Additional details are provided in Section 6-2. It should be noted that the use of a closure structure requires human intervention. If the structure in question is susceptible to flood hazards

with little or no warning time, or if human intervention cannot be guaranteed, the use of a closure is not recommended.

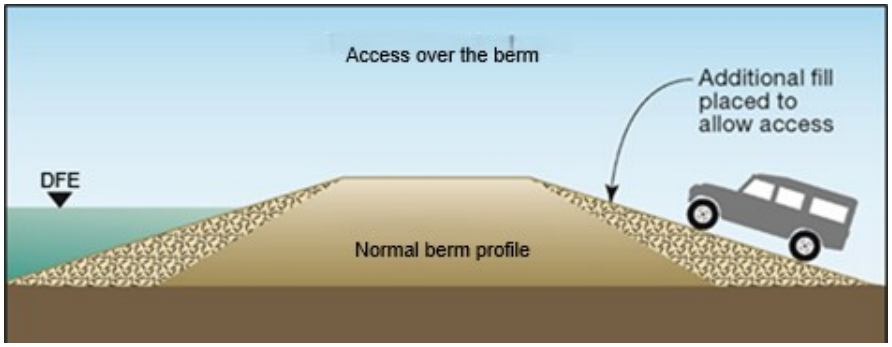


Figure 6-69. Access over the berm

6.3.2.7. Berm Inspection and Maintenance

Berm maintenance should include keeping the vegetation in good condition and avoiding or eliminating any trees or bushes, with their associated root systems, from being on or near the berm. Over time, these roots introduce vulnerabilities to the berm and can result in its failure. In addition, animal burrows should be immediately repaired and measures taken to prevent them from re-occurring. Both of these conditions can create openings or weak paths in the berm through which surface water and seepage can follow, enlarging the openings over time and ultimately causing a potential pipe failure. Planting of trees and bushes on the berm should either not be permitted by any regulatory authority involved with the berm project or avoided because the root systems could provide paths seepage of water based on the reasons given above.

Any berm design should include a good growth of sod on the top and slopes to protect against erosion by wind, water, and traffic, and to provide a pleasing appearance. Regular mowing, along with visual inspection several times a year, should identify critical maintenance issues.

To prepare for the construction of a berm, all ground vegetation and topsoil should be removed over the full footprint of the berm. If sod and topsoil are present, they should be set aside and saved for surfacing the berm when it is finished.

6.4. Summary: Floodproofing and Flood Barrier Techniques

A Floodproofing and Flood Barrier Assessment Worksheet, shown in Figure 6-70, can be used to select the best wet floodproofing, dry floodproofing, and/or flood barrier measures for your project.

Floodproofing and Flood Barriers Assessment Worksheet			
Owner Name:		Preparer	
Address:		Date:	
Property Details:			
Floodproofing and Flood Barrier Measures			
Floodproofing		**Flood Barriers**	
Dry Floodproofing	Wet Floodproofing	Floodwall	Berm
Discussion Questions		**Responses to Discussion Questions**	
1. After reviewing the project information and retrofitting matrices, which floodproofing or flood barrier option is best suited for the homeowner?			
2. What is the nature of the flood source (i.e., riverine or coastal) and the associated impacts on the building (i.e., flood depth, duration, velocity, debris)?			
3. If the building is protected to 2 ft above BFE, what is the anticipated floodproofing/flood barrier design height?			
4. Is the building constructed with reinforced concrete or reinforced masonry walls? Are the interior finishes constructed of flood damage-resistant materials?			
5. Does the building have space below the first floor that could be retrofitted with hydrostatic openings?			
6. Can the building structure be protected from flooding using sealants, shields, and an interior drainage system? What is the existing foundation type?			
7. Would the proposed solution require more than 12 hours of warning time to allow for human intervention to deploy the retrofit measures? How would the building occupants be warned of imminent flood danger?			
8. What building utility systems and equipment must be elevated or protected in place?			
9. Are the site soils low permeability? Is the lot size, availability of borrow material, and topography suitable for constructing a levee?			
10. Are there any other issues that need to be considered prior to selecting floodproofing or flood barriers as a final option?			
FINAL OPTION DETERMINATION		**Floodproofing**	**Flood Barriers**
Purpose:	The purpose of the Floodproofing and Flood Barriers Assessment Worksheet is to develop a final technical assessment of floodproofing and flood barrier measures to determine what option(s) are the most feasible and recommended for final analysis.		

Figure 6-70. Floodproofing and Flood Barrier Assessment Worksheet

6.5. Case Study Exercise 7 – Floodproofing and Flood Barrier Assessment

Use Floodproofing and Flood Barrier Assessment Worksheet (Figure 6-70) to assess floodproofing and relocation techniques for one of the two case study buildings (see Note).

Note

Case Study A was not considered for Exercise 7 because the assessment of flood retrofits for Mr. Brook in previous exercises did not indicate any options for floodproofing or flood barriers. Therefore, the Elevation and Relocation Assessment Worksheet is not applicable for Case Study A.

Case Study B – Exercise 7: Residential Retrofit Outside of the Floodplain using Floodwalls or Dry Floodproofing

Mr. Smith used the Floodproofing and Flood Barriers Assessment Worksheet, as shown in Figure CSB-15, to select between the options of dry floodproofing, wet floodproofing, floodwall, and berm. His responses revealed that he prefers a floodwall when compared to a dry floodproofing option. This would allow him to forgo elevating his HVAC and going through an engineering assessment regarding the ability of the existing slab-on-grade to resist buoyancy. He felt the unknowns regarding the potential disruption to his property for dry floodproofing construction were not worth the investment. Alternatively, Mr. Smith thought the perimeter wall of the property needed an upgrade and saw the value of the enhancement as better for protecting the building from future flooding. Despite the local flood warning system, Mr. Smith does not want to rely on human intervention for the floodwall to protect his property. He has decided that a self-closing (passive) flood barrier be provided at floodwall openings, at the driveway gate, and pedestrian entrance. These barriers will be stored in the ground and rise into position without electricity, power, or human intervention. The floodwall retrofit will help reduce risk for his property from unexpected floods.

Floodproofing and Flood Barriers Assessment Worksheet			
Owner Name:	John Smith	Preparer	JJS-MH
Address:	2908 Valley Drive	Date:	7/6/2026
Property Details:	Case Study B		

Floodproofing and Flood Barrier Measures			
Floodproofing		Flood Barriers	
Dry Floodproofing	Wet Floodproofing	Floodwall	Berm

Discussion Questions	Responses to Discussion Questions
1. After reviewing the project information and retrofitting matrices, which floodproofing or flood barrier option is best suited for the homeowner?	Floodwall
2. What is the nature of the flood source (i.e., riverine or coastal) and the associated impacts on the building (i.e., flood depth, duration, velocity, debris)?	Riverine. Designed to resist 3 ft of flood depth at the building which is approximately 5 ft at the floodwall.
3. If the building is protected to 2 ft above BFE, what is the anticipated floodproofing/flood barrier design height?	(BFE + 2 ft) = (0 ft + 2 ft) = 2 ft
4. Is the building constructed with reinforced concrete or reinforced masonry walls? Are the interior finishes constructed of flood damage-resistant materials?	Reinforced masonry walls. No.
5. Does the building have space below the first floor that could be retrofitted with hydrostatic openings?	No.
6. Can the building structure be protected from flooding using sealants, shields, and an interior drainage system? What is the existing foundation type?	Yes. Slab on grade with spread footings.
7. Would the proposed solution require more than 12 hours of warning time to allow for human intervention to deploy the retrofit measures? How would the building occupants be warned of imminent flood danger?	No. Local flood warning system.
8. What building utility systems and equipment must be elevated or protected in place?	HVAC compressor.
9. Are the site soils low permeability? Is the lot size, availability of borrow material, and topography suitable for constructing a berm?	Yes. No.
10. Are there any other issues that need to be considered prior to selecting floodproofing or flood barriers as a final option?	Passive flood gate at the main entrance.

FINAL OPTION DETERMINATION	Floodproofing	Flood Barriers
	Dry Floodproofing	Floodwall

Purpose:	The purpose of the Floodproofing and Flood Barriers Assessment Worksheet is to develop a final technical assessment of floodproofing and flood barrier measures to determine what option(s) are the most feasible and recommended for final analysis.

Figure CSB-15. Floodproofing and Flood Barrier Assessment Worksheet for The Valley Apartments

Chapter 7. Cost-Effectiveness and Alternative Selection

After evaluating the retrofit options in Chapters 5 and 6, most homeowners are left with two or three feasible alternatives. The remaining alternatives can be evaluated for cost-effectiveness and other factors to select the retrofit measure that best meets the homeowner's technical, practical, aesthetic, and financial needs. Chapter 7 provides an understanding of the cost-effectiveness of residential retrofit projects. Cost-effectiveness evaluation processes and other factors for final retrofitting selection are outlined.

7.1. Cost-Effectiveness

Everyone, from property owners to the Federal government, seeks cost-effective investments. "Cost-effective" means that the benefits of the investments outweigh the total cost. Since government funds are limited, FEMA regulations and other Federal agencies require that federally funded hazard mitigation projects be cost-effective. To evaluate cost-effectiveness, a project's total net benefits are divided by its total project cost, resulting in a project benefit-cost ratio, as shown in Equation 7-1. A project is cost-effective when the benefit-cost ratio is greater than or equal to 1.0, indicating the benefits are sufficient to justify the costs.



EQUATION 7-1: BENEFIT–COST RATIO

$$BCR = \frac{Project\ Benefits}{Project\ Costs}$$

Where:

BCR = benefit-cost ratio

$Project\ Benefits$ = total project net benefits

$Project\ Costs$ = total project cost

This section will cover cost-effectiveness based on benefit-cost analysis concepts consistent with the current FEMA approach, mirrored by other federal agencies that evaluate flood retrofitting and other hazard mitigation projects.

Determining the benefit-cost ratio for a residential flood retrofit project requires the following data:

- Flood hazard risk (Section 7.1.1)
- Project costs (Section 7.1.2)
- Project benefits (Section 7.1.3)

Cross Reference

Additional information on FEMA Benefit-Cost Analysis software and associated policy guidance can be found on FEMA's Benefit-Cost Analysis webpage: https://www.fema.gov/grants/tools/benefit-cost-analysis. Users are also encouraged to contact their State Hazard Mitigation Officer for information on state and local government funding that can help fund cost-effective residential flood retrofit projects.

7.1.1. RISK

Risk is defined by the expected probability and frequency of the hazard occurring, people and property exposed to the hazard, and potential consequences. To estimate future damages (and the benefits of avoiding them), probabilities of future event occurrence must be considered. The probabilities of future events are very important factors when determining whether a proposed retrofit project is cost-effective. The benefits of avoiding flood damage for a building vulnerable to a 10% annual chance of flooding (i.e., located in the 10-year floodplain) will be enormously greater than the benefits of avoiding flood damage for an identical building with a 0.001% annual chance of flooding (i.e., located in the 1,000-year floodplain). In addition to future flood probability, it is important to consider the damage and other consequences associated with a future flood event on a building. Estimated flood damage for a one-story building built on a slab on grade foundation will usually be greater than damage from the same flood on a multi-story building built on an elevated foundation. Damage sustained by buildings exposed to flood hazards includes site damage, structural and nonstructural building damage, destruction or impairment of utility equipment, and damage to or loss of contents. This damage, along with loss of building function, is avoided if buildings are located away from flood hazard areas and/or built to exceed minimum flood protection levels and/or Design Flood Elevation requirements.

Many property owners lack awareness of the true hazards that threaten their property or may not fully understand the risks they assume, often well into the future, due to decisions they make regarding their property. Property owners should understand how the choices they make potentially reduce the risk of damage from future natural hazard events. Risk communication is critical to help better understand risks to residential (and other) properties. One common misperception is that the 1% annual chance flood, or 100-year flood, means that there is only a 1% chance of ever being flooded; a risk they are willing to assume. In reality, the 100-year flood means there is a 1% chance of a flood that equals or exceeds the 100-year flood event elevation occurring *annually.* Another misperception is that the 100-year flood can only happen roughly once every 100 years. Unfortunately, these misperceptions result in a gross underestimation of flood risk. During a typical 30-year mortgage, a residential building in the Special Flood Hazard Area has a 26% chance of being subjected to flooding that equals or exceeds the 1% annual chance flood and a 6% chance of being subjected to a 0.2% annual chance (500-year flood).

It is important to find methods to communicate natural hazard risks for a property location and how those risks may be addressed through retrofitting. The best available information should be examined, including FEMA Flood Insurance Rate Maps, records of historical flooding, and advice from state, local, and other experts who can evaluate flood risks.



Note

The most cost-effective residential flood retrofitting measures address the highest possible flood risk at the lowest project cost.

7.1.2. DETERMINING PROJECT COSTS

There are two types of project cost estimates:

- **Professionally provided** cost estimates are created by building contractors or other experienced professionals familiar with detailed, line-item budgets eligible for reimbursement through Federal mitigation grants.
- **User developed** cost estimates are provided by the property owner, or state, local, tribal, and territorial government officials if professionals are not available to provide a detailed cost estimate. These are typically developed based on local knowledge or using national average unit cost guides such as RSMeans, with adjustments for local costs.

In either case, developing a retrofitting project cost estimate includes the following six steps:

1. **Estimate pre-construction or non-construction costs:** The first step in the cost estimation process is to estimate costs of required work prior to construction. Examples of such pre-construction or non-construction costs include surveys to prepare site plans and Elevation Certificates, fees for building permits, or site preparation.
2. **Estimate construction costs:** The second step in the process is to estimate the project construction costs based on an itemized breakdown of labor and material costs for each project task. This is typically the largest cost of a residential flood retrofit project.
3. **Estimate ancillary costs:** The next step is to determine ancillary costs, e.g., those associated with design fees, contractor mark-ups, and inspections.
4. **Estimate annual maintenance costs:** The fourth step is to estimate annual maintenance costs associated with the proposed retrofit project. Residential retrofit projects' annual maintenance costs include additional annual costs of activities necessary to support the proposed retrofit elements to function properly throughout their useful life, such as replacing gaskets on flood shields.
5. **Adjust estimate to account for timing and data currency:** The next step is to review the retrofit cost estimate to ensure it reflects current costs and anticipated changes in current costs through the anticipated construction completion date.

6. **Review and confirm cost estimate:** The final step of cost estimation is a review of the total cost estimate to ensure all costs to prepare, construct, and maintain the project are included, and reflect accurate, current local costs.



Note

The project cost used in a benefit-cost analysis is a life-cycle cost that represents the full investment required over the useful life of the retrofitting project. This life-cycle cost may include costs that would not be considered eligible for reimbursement under most Federal hazard mitigation grant programs, such as annual maintenance costs.



Note

Construction costs of residential elevation and relocation projects presented in Chapter 5 are typically higher than floodproofing and flood barrier project costs discussed in Chapter 6. The annual maintenance costs of floodproofing and flood barrier projects (active mitigation) tend to be significantly higher than the annual maintenance costs of elevation and relocation projects (passive mitigation).

7.1.3. ESTIMATING PROJECT BENEFITS

The benefits considered in a residential retrofitting project are the future damages or losses that would be avoided if the proposed project is constructed. Benefits cannot be precisely estimated because the number and severity of future flood events are unknown. As a result, benefits are estimated based on historic (actual) or expected (hypothetical) flood events of various magnitudes. Benefits for residential flood retrofit projects typically fall into the following categories:

- **Building** benefits reflect avoided damage to the structure and its associated and applicable building utility systems are typically estimated using a depth damage function and the building replacement value or historical damage records (e.g., flood insurance claim data); as floodwaters rise, more damage occurs to the structure.

- **Contents** benefits reflect avoided damages to the contents within a building and are typically estimated using a depth damage function and the contents value or historical damage records (e.g., flood insurance claim data).

- **Displacement benefits** reflect the avoided costs incurred when occupants of a residence are displaced to temporary housing due to a flood event. Displacement occurs when damage to a structure is sufficiently severe that the structure cannot be repaired with occupants in place or local officials condemn the property, prohibiting occupation.

- **Loss of Business or Rental Income** benefits reflect the impact that may occur if damages are severe enough to close a business, estimated using the net income lost during the closure.
- **Other** benefits reflect avoided damages that have not been previously estimated. Examples of other benefits may include debris removal costs and emergency preparedness costs, such as sandbagging.



Note

A depth damage function is the estimate of direct damage to the building based on a depth of flooding calculated as the percent damage to structures. Depth damage functions are compiled from a variety of sources, including FEMA and U.S. Army Corps of Engineers. Depth damage functions typically vary based on the building type (i.e., one-story versus two-story), foundation (i.e., open versus closed), and occupancy type (i.e., residential versus commercial). Table 7-1 provides a summary of generic residential Depth damage functions developed by the U.S. Army Corps of Engineers Institute for Water Resources and used by FEMA and other agencies to estimate riverine flood damages to residential structures.

The calculation of project benefits entails estimating the present value of the sum of the expected annual damages over the useful life. Elements include:

- Probabilities of various levels of flooding events and associated damages
- Useful lifetime of the mitigation project
- The time value of money

Table 7-1. U.S. Army Corps of Engineers Generic Residential Depth Damage Functions

Building Type	Depth Above Lowest Floor Elevation (Feet)	Structure Depth Damage Function (%)	Contents Depth Damage Function (%)	Displacement Depth Damage Function (Days)
1-story residential no basement	-2.0	0.0%	0.0%	0
1-story residential no basement	-1.0	2.5%	2.4%	0
1-story residential no basement	0.0	13.4%	8.1%	0
1-story residential no basement	1.0	23.3%	13.3%	45
1-story residential no basement	2.0	32.1%	17.9%	90
1-story residential no basement	3.0	40.1%	22.0%	135
1-story residential no basement	4.0	47.1%	25.7%	180

Building Type	Depth Above Lowest Floor Elevation (Feet)	Structure Depth Damage Function (%)	Contents Depth Damage Function (%)	Displacement Depth Damage Function (Days)
1-story residential no basement	5.0	53.2%	28.8%	225
1-story residential no basement	6.0	58.6%	31.5%	270
1-story residential no basement	7.0	63.2%	33.8%	315
1-story residential no basement	8.0	67.2%	35.7%	360
1-story residential no basement	9.0	70.5%	37.2%	405
1-story residential no basement	10.0	73.2%	38.4%	450
1-story residential no basement	11.0	75.4%	39.2%	495
1-story residential no basement	12.0	77.2%	39.7%	540
1-story residential no basement	13.0	78.5%	40.0%	585
1-story residential no basement	14.0	79.5%	40.0%	630
1-story residential with basement	-2.0	13.8%	10.5%	0
1-story residential with basement	-1.0	19.4%	13.2%	0
1-story residential with basement	0.0	25.5%	16.0%	0
1-story residential with basement	1.0	32.0%	18.9%	45
1-story residential with basement	2.0	38.7%	21.8%	90
1-story residential with basement	3.0	45.5%	24.7%	135
1-story residential with basement	4.0	52.2%	27.4%	180
1-story residential with basement	5.0	58.6%	30.0%	225
1-story residential with basement	6.0	64.5%	32.4%	270
1-story residential with basement	7.0	69.8%	34.5%	315
1-story residential with basement	8.0	74.2%	36.3%	360
1-story residential with basement	9.0	77.7%	37.7%	405
1-story residential with basement	10.0	80.1%	38.6%	450
1-story residential with basement	11.0	81.1%	39.1%	495
1-story residential with basement	12.0	81.1%	39.1%	540

Building Type	Depth Above Lowest Floor Elevation (Feet)	Structure Depth Damage Function (%)	Contents Depth Damage Function (%)	Displacement Depth Damage Function (Days)
1-story residential with basement	13.0	81.1%	39.1%	585
1-story residential with basement	14.0	81.1%	39.1%	630
2- or 3-story residential no basement	-2.0	0.0%	0.0%	0
2- or 3-story residential no basement	-1.0	3.0%	1.0%	0
2- or 3-story residential no basement	0.0	9.3%	5.0%	0
2- or 3-story residential no basement	1.0	15.2%	8.7%	45
2- or 3-story residential no basement	2.0	20.9%	12.2%	90
2- or 3-story residential no basement	3.0	26.3%	15.5%	135
2- or 3-story residential no basement	4.0	31.4%	18.5%	180
2- or 3-story residential no basement	5.0	36.2%	21.3%	225
2- or 3-story residential no basement	6.0	40.7%	23.9%	270
2- or 3-story residential no basement	7.0	44.9%	26.3%	315
2- or 3-story residential no basement	8.0	48.8%	28.4%	360
2- or 3-story residential no basement	9.0	52.4%	30.3%	405
2- or 3-story residential no basement	10.0	55.7%	32.0%	450
2- or 3-story residential no basement	11.0	58.7%	33.4%	495
2- or 3-story residential no basement	12.0	61.4%	34.7%	540
2- or 3-story residential no basement	13.0	63.8%	35.6%	585
2- or 3-story residential no basement	14.0	65.9%	36.4%	630
2- or 3-story residential with basement	-2.0	10.2%	8.4%	0
2- or 3-story residential with basement	-1.0	13.9%	10.1%	0
2- or 3-story residential with basement	0.0	17.9%	11.9%	0
2- or 3-story residential with basement	1.0	22.3%	13.8%	45
2- or 3-story residential with basement	2.0	27.0%	15.7%	90
2- or 3-story residential with basement	3.0	31.9%	17.7%	135

Building Type	Depth Above Lowest Floor Elevation (Feet)	Structure Depth Damage Function (%)	Contents Depth Damage Function (%)	Displacement Depth Damage Function (Days)
2- or 3-story residential with basement	4.0	36.9%	19.8%	180
2- or 3-story residential with basement	5.0	41.9%	22.0%	225
2- or 3-story residential with basement	6.0	46.9%	24.3%	270
2- or 3-story residential with basement	7.0	51.8%	26.7%	315
2- or 3-story residential with basement	8.0	56.4%	29.1%	360
2- or 3-story residential with basement	9.0	60.8%	31.7%	405
2- or 3-story residential with basement	10.0	64.8%	34.4%	450
2- or 3-story residential with basement	11.0	68.4%	37.2%	495
2- or 3-story residential with basement	12.0	71.4%	40.0%	540
2- or 3-story residential with basement	13.0	73.7%	43.0%	585
2- or 3-story residential with basement	14.0	75.4%	46.1%	630

Some helpful terms to consider when estimating benefits are:

- ***Expected annual damages*** expected over the life of the structure or useful life of the mitigation project. “Expected annual” does not mean that these damages will occur every year.
- ***Scenario damages*** indicate estimated damages resulting from a single flood of a specified depth at the building under evaluation. For example, the scenario damages for a 3-foot flood are the expected damages and losses each time a 3-foot flood occurs at the specific site. Scenario damages do not depend on the probability of floods at that location.
- ***Historic damages*** are based on actual recorded damages (such as flood insurance claim payouts as opposed to estimated damages) and are associated with a flood frequency to help estimate the probability of occurrence.

The scenario (or historic) damages and the expected annual damages before mitigation provide a complete picture of the vulnerability of the building to flood damage prior to mitigation. Expected annual damages are usually much smaller than scenario or historical damages because they are multiplied by the probabilities of occurrence. A building with high expected annual damages has high scenario damages and high flood probabilities. If expected annual damages are high, then there will be high potential benefits in avoiding such damages. Damages after mitigation depend on the effectiveness of the mitigation measure in avoiding damages. The expected annual damages and

losses after mitigation also depend on the degree of flood risk at the site under evaluation. For some mitigation projects, such as acquisition, the scenario damages before mitigation are eliminated, and expected annual losses after mitigation will be zero. For other mitigation projects, such as elevation or flood barriers, scenario damages and expected annual losses after mitigation will be lower than before mitigation, but there is always some residual risk of future flooding, so the after mitigation damages cannot be zero.

The expected annual benefit for a project is calculated using Equation 7-2.

EQUATION 7-2: EXPECTED ANNUAL BENEFIT

$$EAB = EAD_{Before\ Mitigation} - EAD_{After\ Mitigation}$$

Where:

EAB = Expected annual benefit

$EAD_{Before\ Mitigation}$= Expected annual damages before mitigation

$EAD_{After\ Mitigation}$= Expected annual damages after mitigation

To compare the future benefits to the current cost of the proposed mitigation project in the benefit-cost ratio (Equation 7-1), a discount rate is applied over the life of the project to calculate the net present value of the expected annual benefits. For FEMA-funded mitigation projects, the Office of Management and Budget sets the discount rate. Equation 7-3 shows how to calculate the project benefits using the annual discount rate.

EQUATION 7-3: PROJECT BENEFITS

$$B = EAB\left[\frac{1-(1+r)^{-T}}{r}\right]$$

Where:

B = project benefits

EAB = total expected annual net benefit

r = annual discount rate used to determine net present value of benefits

T = estimated time the project will be effective, known as the Project Useful Life; see Table 7-2 for a summary of FEMA Standard Project Useful Life values for residential retrofits

Note

In Equation 7-3, the combined effect of the discount rate (r) and the project useful life (T) is the present value coefficient. Elevation, relocation, and flood barrier projects tend to have longer project useful lifetimes than floodproofing projects; so, the present value coefficient tends to be higher and results in higher project benefits. When the discount rate is higher, the present value coefficient is lower, resulting in lower project benefits for all project types.

Table 7-2. FEMA Standard Project Useful Life Values for Residential Retrofits

Residential Retrofit Project Type	FEMA Standard Project Useful Life
Structural Elevation or Elevation Alternatives	30 years
Relocation	100 years
Dry or Wet Floodproofing	15 years
Floodwall or Flood Berm	50 years

A Benefit-Cost Analysis Determination Worksheet is provided in Figure 7-1 on the next page for use with various residential flood retrofit projects covered in Chapters 5 and 6. This worksheet can be used in conjunction with other data to determine the benefit-cost ratio for the two or three most promising retrofitting alternatives.

Benefit-Cost Analysis (BCA) Determination Worksheet

Owner Name:		**Preparer**	
Address:		**Date:**	
Property Details:			

Determine the Retrofit Project Costs

Retrofit Measure: _____

H = Flood Design Height = _____ ft (determined based on previous design calculations)

T = Project Useful Life = _____ years (taken from FEMA P-259 Table 7-2)

r = Discount Rate = _____ *% (Discount Rate set by OMB Circular A-94)*

PVC = Present Value Coefficient = $[1 - (1 + r)^{-T}]/r$ = _____ (taken from FEMA P-259 Equation 7-3)

Base Cost = _____ (develop based on FEMA P-259 Section 7.1.2 Steps 1-4 and Step 6)

O&M Cost = (Base Cost) x (Annual O&M %) x PVC = _____ (develop based on FEMA P-259 Section 7.1.2 Step 5)

Project Costs = *Base Cost + O&M Cost* =

Estimate Expected Annnal Damages Before Mitigation (*EAD Before*)

Residential Building Details:

Number of Stories = _____ (choose between 1 and 3) **Building Area:** _____ square feet

Foundation Type = _____ (choose between basement, crawlspace, piers, piles, or grade slab)

Flood Zone = _____ *Assume riverine or non-Coastal A Zone unless noted otherwise*

USACE Generic Residential Depth-Damage Functon (DDF) = _____ (see FEMA P-259 Table 7-1)

Building Replacement Value (BRV) = _____ (unit cost in dollars per square foot)

Total Building Value = _____ (based on Building Area x BRV)

Total Contents Value = 100% Total Building Value (assumed for all USACE General Residential DDFs)

Number of Occupants = _____ *(based on tax records or U.S. Census average household size rounded to whole number)*

Meals Rate = _____ *(unit cost in dollars per day based on FY2025 GSA Per Diem Rates for CONUS)*

Lodging Rate = _____ *(unit cost in dollars per day night on FY2025 GSA Per Diem Rates for CONUS)*

Displacement Cost = _____ *(unit cost in dollars per day based on ([Number of Occupants x Meals Rate) + Lodging Rate])*

Complete the following matrix of flood damages for up to four flood event recurrence intervals

Flood Event RI (years)	**Depth Above Lowest Floor** (ft)	**Event Damages and Losses** ($)				**EAD = Damage/RI** ($/year)
		Structure	**Contents**	**Displcmt**	**Total**	
10						
50						
100						
500						

Expected Annual Damages Before Mitigation, EAD Before = _____ *per year*

Approximate Expected Annnal Damages After Mitigation (*EAD After*)

Retrofit Measure: _____

Use adjacent table, Post-Retrofit Appoxmations by Retrofit Measure, to estimate Flood Damages After Mitigation

Flood Event RI (years)	**Post-Event Damage** ($)	**EAD = Damage/RI** ($/year)
10		
50		
100		
500		

Post-Retrofit Approximations by Retrofit Measure

Retrofit Measure	**Project Effective-ness**	**Reduced Minimum RI Flood**	**Reduced Design RI Flood**
Elevation	High	100%	90%
Relocation	Highest	100%	100%
Wet Floodprooofing	Moderate	50%	25%
Dry Floodproofing	Moderate	100%	0%
Flood Barriers	Moderate	100%	0%

Expected Annual Damages After Mitigation, EAD After = _____ *per year*

Determine the Project Benefits

Expected Annual Benefit, *EAB* = *EAD Before* - *EAD After* = _____ *per year* (from FEMA P-259 Equation 7-2)

Project Benefits = *EAB x PVC* = _____

Determine the Benefit-Cost Ratio, BCR

***BCR* = (Project Benefits)/(Project Costs) =** (from FEMA P-259 Equation 7-1)

Figure 7-1. Benefit-Cost Analysis Determination Worksheet

7.2. Case Study Exercise 8 – Benefit-Cost Analysis Review of Alternatives

Use the Benefit-Cost Analysis Determination Worksheet (Figure 7-1) to estimate retrofit project benefits and costs of the most promising techniques for the Case Study A and B buildings. Refer to Appendix A for Case Study A supporting documentation and Appendix B for Case Study B supporting documentation.

Case Study A – Exercise 8: Residential Retrofit in Riverine Floodplain Using Relocation or Elevation

Mr. and Mrs. Doe used Benefit-Cost Analysis Determination Worksheet and associated Benefit-Cost Analysis and project guidance to assess the cost-effectiveness of the two flood retrofit options of elevation on perimeter foundation walls and relocation, as shown in CSA-18 and CSA-19, respectively, which helped the determine the more cost-effective option. (Mr. and Mrs. Doe ultimately decided against using wet floodproofing as a retrofit method because of the challenges associated with cleanup and the residual risk depending on how the retrofit is implemented for a finished floor that is more than 5 feet below the Design Flood Elevation.) The results indicated that elevation on a perimeter foundation wall would achieve a Benefit-Cost Ratio greater than 1.0. Elevation on perimeter foundation walls was the most cost-effective, with the highest Benefit-Cost Ratio of 1.04, followed by relocation with the lower Benefit-Cost Ratio of 0.59.

Benefit-Cost Analysis (BCA) Determination Worksheet

Owner Name:	**John and Jane Doe**	**Preparer**	**JJS-MH**
Address:	**55 Cedar River Road**	**Date:**	**7/6/2026**
Property Details:	**Case Study A**		

Determine the Retrofit Project Costs

Retrofit Measure: Elevation on Perimeter Foundation Wall

H = Flood Design Height = **7.6** ft (determined based on previous design calculations)

T = Project Useful Life = **30** years (taken from FEMA P-259 Table 7-2)

r = Discount Rate = **7.0** *% (Discount Rate set by OMB Circular A-94)*

PVC = Present Value Coefficient = $[1 - (1 + r)^{-T}]/r$ = **12.41** (taken from FEMA P-259 Equation 7-3)

Base Cost = **$196,000** (develop based on FEMA P-259 Section 7.1.2 Steps 1-4 and Step 6)

O&M Cost = (Base Cost) x (Annual O&M %) x PVC = **$0** (develop based on FEMA P-259 Section 7.1.2 Step 5)

Project Costs = *Base Cost + O&M Cost* = **$196,000**

Estimate Expected Annnal Damages Before Mitigation (EAD_{Before})

Residential Building Details:

Number of Stories = **1.0** (choose between 1 and 3) **Building Area:** **1,600** square feet

Foundation Type = **Crawlspace** (choose between basement, crawlspace, piers, piles, or grade slab)

Flood Zone = **AE (Riverine)** *Assume riverine or non-Coastal A Zone unless noted otherwise*

USACE Generic Residential Depth-Damage Functon (DDF) = **1-story with basement** (see FEMA P-259 Table 7-1)

Building Replacement Value (BRV) = **$145** (unit cost in dollars per square foot)

Total Building Value = **$232,000** (based on Building Area x BRV)

Total Contents Value = *100% Total Building Value (assumed for all USACE General Residential DDFs)*

Number of Occupants = **3** *(based on tax records or U.S. Census average household size rounded to whole number)*

Meals Rate = **$68** *(unit cost in dollars per day based on FY2025 GSA Per Diem Rates for CONUS)*

Lodging Rate = **$110** *(unit cost in dollars per day night on FY2025 GSA Per Diem Rates for CONUS)*

Displacement Cost = **$314** *(unit cost in dollars per day based on ([Number of Occupants x Meals Rate) + Lodging Rate])*

Complete the following matrix of flood damages for up to four flood event recurrence intervals

Flood Event RI (years)	**Depth Above Lowest Floor** (ft)	**Event Damages and Losses** ($)				**EAD = Damage/RI** ($/year)
		Structure	**Contents**	**Displcmt**	**Total**	
10	**0.8**	**$62,858**	**$39,440**	**$0**	**$102,298**	**$10,230**
50	**2.1**	**$95,396**	**$53,737**	**$28,260**	**$177,393**	**$3,548**
100	**3.6**	**$112,158**	**$60,886**	**$42,390**	**$215,433**	**$2,154**
500	**5.6**	**$144,449**	**$73,950**	**$70,650**	**$289,049**	**$578**

Expected Annual Damages Before Mitigation, EAD_{Before} = **$16,510** *per year*

Approximate Expected Annnal Damages After Mitigation (EAD_{After})

Retrofit Measure: Elevation on Perimeter Foundation Wall

Use adjacent table, Post-Retrofit Appoxmations by Retrofit Measure, to estimate Flood Damages After Mitigation

Flood Event RI (years)	**Post-Event Damage** ($)	**EAD = Damage/RI** ($/year)
10	**$0**	**$0**
50	**$0**	**$0**
100	**$0**	**$0**
500	**$28,905**	**$58**

Expected Annual Damages After Mitigation, EAD_{After} = **$58** *per year*

Post-Retrofit Approximations by Retrofit Measure

Retrofit Measure	**Project Effective-ness**	**Reduced Minimum RI Flood**	**Reduced Design RI Flood**
Elevation	High	100%	90%
Relocation	Highest	100%	100%
Wet Floodprooofing	Moderate	50%	25%
Dry Floodproofing	Moderate	100%	0%
Flood Barriers	Moderate	100%	0%

Determine the Project Benefits

Expected Annual Benefit, *EAB* = $EAD_{Before} - EAD_{After}$ = **$16,452** *per year* (from FEMA P-259 Equation 7-2)

Project Benefits = *EAB x PVC* = **$204,156**

Determine the Benefit-Cost Ratio, BCR

***BCR* = (Project Benefits)/(Project Costs) =** **1.04 > 1.0 OK** (from FEMA P-259 Equation 7-1)

Figure CSA-18. Benefit-Cost Analysis Determination Worksheet for elevation on perimeter foundation walls at the Doe house

Benefit-Cost Analysis (BCA) Determination Worksheet

Owner Name:	**John and Jane Doe**	**Preparer**	**JJS-MH**
Address:	**55 Cedar River Road**	**Date:**	**7/6/2026**
Property Details:	**Case Study A**		

Determine the Retrofit Project Costs

Retrofit Measure: Relocation

H = Flood Design Height = **7.6** ft (determined based on previous design calculations)

T = Project Useful Life = **100** years (taken from FEMA P-259 Table 7-2)

r = Discount Rate = **7.0** *% (Discount Rate set by OMB Circular A-94)*

PVC = Present Value Coefficient = $[1 - (1 + r)^{-T}]/r$ = **14.27** (taken from FEMA P-259 Equation 7-3)

Base Cost = **$400,000** (develop based on FEMA P-259 Section 7.1.2 Steps 1-4 and Step 6)

O&M Cost = (Base Cost) x (Annual O&M %) x PVC = **$0** (develop based on FEMA P-259 Section 7.1.2 Step 5)

Project Costs = *Base Cost + O&M Cost* = **$400,000**

Estimate Expected Annnal Damages Before Mitigation (EAD_{Before})

Residential Building Details:

Number of Stories = **1.0** (choose between 1 and 3) **Building Area:** **1,600** square feet

Foundation Type = **Crawlspace** (choose between basement, crawlspace, piers, piles, or grade slab)

Flood Zone = **AE (Riverine)** *Assume riverine or non-Coastal A Zone unless noted otherwise*

USACE Generic Residential Depth-Damage Functon (DDF) = **1-story with basement** (see FEMA P-259 Table 7-1)

Building Replacement Value (BRV) = **$145** (unit cost in dollars per square foot)

Total Building Value = **$232,000** (based on Building Area x BRV)

Total Contents Value = 100% Total Building Value (assumed for all USACE General Residential DDFs)

Number of Occupants = **3** *(based on tax records or U.S. Census average household size rounded to whole number)*

Meals Rate = **$68** *(unit cost in dollars per day based on FY2025 GSA Per Diem Rates for CONUS)*

Lodging Rate = **$110** *(unit cost in dollars per day night on FY2025 GSA Per Diem Rates for CONUS)*

Displacement Cost = **$314** *(unit cost in dollars per day based on ([Number of Occupants x Meals Rate) + Lodging Rate])*

Complete the following matrix of flood damages for up to four flood event recurrence intervals

Flood Event RI (years)	**Depth Above Lowest Floor** (ft)	**Event Damages and Losses** ($)				**EAD = Damage/RI** ($/year)
		Structure	**Contents**	**Displcmt**	**Total**	
10	**0.8**	**$62,858**	**$39,440**	**$0**	**$102,298**	**$10,230**
50	**2.1**	**$95,396**	**$53,737**	**$28,260**	**$177,393**	**$3,548**
100	**3.6**	**$112,158**	**$60,886**	**$42,390**	**$215,433**	**$2,154**
500	**5.6**	**$144,449**	**$73,950**	**$70,650**	**$289,049**	**$578**

Expected Annual Damages Before Mitigation, EAD_{Before} = **$16,510** *per year*

Approximate Expected Annnal Damages After Mitigation (EAD_{After})

Retrofit Measure: Relocation

Use adjacent table, Post-Retrofit Appoxmations by Retrofit Measure, to estimate Flood Damages After Mitigation

Flood Event RI (years)	**Post-Event Damage** ($)	**EAD = Damage/RI** ($/year)
10	**$0**	**$0**
50	**$0**	**$0**
100	**$0**	**$0**
500	**$0**	**$0**

Post-Retrofit Approximations by Retrofit Measure

Retrofit Measure	**Project Effective-ness**	**Reduced Minimum RI Flood**	**Reduced Design RI Flood**
Elevation	High	100%	90%
Relocation	Highest	100%	100%
Wet Floodprooofing	Moderate	50%	25%
Dry Floodproofing	Moderate	100%	0%
Flood Barriers	Moderate	100%	0%

Expected Annual Damages After Mitigation, EAD_{After} = **$0** *per year*

Determine the Project Benefits

Expected Annual Benefit, *EAB* = $EAD_{Before} - EAD_{After}$ = **$16,510** *per year* (from FEMA P-259 Equation 7-2)

Project Benefits = *EAB x PVC* = **$235,586**

Determine the Benefit-Cost Ratio, BCR

***BCR* = (Project Benefits)/(Project Costs) =** **0.59 < 1.0 NG** (from FEMA P-259 Equation 7-1)

Figure CSA-19. Benefit-Cost Analysis Determination Worksheet for relocation at the Doe house

Case Study B – Exercise 8: Residential Retrofit Outside of the Floodplain Using Floodwalls or Dry Floodproofing

The Valley Apartments used the Benefit-Cost Analysis Determination Worksheet and associated Benefit-Cost Analysis and project guidance to assess the cost-effectiveness of the three flood retrofit options of dry floodproofing, wet floodproofing, and floodwall, as shown in Figures CSB-16, CSB-17, and CSB-18, respectively, which helped determine the most cost-effective option. The results indicated that the floodwall achieved a Benefit-Cost Ratio greater than 1.0. However, relatively speaking, the floodwall was the most cost-effective with the highest Benefit-Cost Ratio of 1.09, followed by dry floodproofing with a Benefit-Cost Ratio of 0.80, and finally wet floodproofing with the lowest Benefit-Cost Ratio of 0.52.

Benefit-Cost Analysis (BCA) Determination Worksheet

Owner Name:	**John Smith**	**Preparer**	**JJS-MH**
Address:	**2908 Valley Drive**	**Date:**	**7/6/2026**
Property Details:	**Case Study B**		

Determine the Retrofit Project Costs

Retrofit Measure: **Dry Floodproofing**

H = Flood Design Height = **0.0** ft (determined based on previous design calculations)

T = Project Useful Life = **15** years (taken from FEMA P-259 Table 7-2)

r = Discount Rate = **7.0** *% (Discount Rate set by OMB Circular A-94)*

PVC = Present Value Coefficient = $[1 - (1 + r)^{-T}]/r$ = **9.11** (taken from FEMA P-259 Equation 7-3)

Base Cost = **$250,000** (develop based on FEMA P-259 Section 7.1.2 Steps 1-4 and Step 6)

O&M Cost = (Base Cost) x (Annual O&M %) x PVC = **$113,849** (develop based on FEMA P-259 Section 7.1.2 Step 5)

Project Costs = *Base Cost + O&M Cost* = **$363,849**

Estimate Expected Annnal Damages Before Mitigation (EAD_{Before})

Residential Building Details:

Number of Stories = **2.0** (choose between 1 and 3) **Building Area:** **10,000** square feet

Foundation Type = **Grade Slab** (choose between basement, crawlspace, piers, piles, or grade slab)

Flood Zone = **Outside Floodplain** *Assume riverine or non-Coastal A Zone unless noted otherwise*

USACE Generic Residential Depth-Damage Functon (DDF) = **2- or 3-story no basement** (see FEMA P-259 Table 7-1)

Building Replacement Value (BRV) = **N/A** (unit cost in dollars per square foot)

Total Building Value = **N/A** (based on Building Area x BRV)

Total Contents Value = 100% Total Building Value (assumed for all USACE General Residential DDFs)

Number of Occupants = **N/A** *(based on tax records or U.S. Census average household size rounded to whole number)*

Meals Rate = **N/A** *(unit cost in dollars per day based on FY2025 GSA Per Diem Rates for CONUS)*

Lodging Rate = **N/A** *(unit cost in dollars per day night on FY2025 GSA Per Diem Rates for CONUS)*

Displacement Cost = **N/A** *(unit cost in dollars per day based on ([Number of Occupants x Meals Rate) + Lodging Rate])*

Complete the following matrix of flood damages for up to four flood event recurrence intervals

Flood Event RI (years)	Depth Above Lowest Floor (ft)	Event Damages and Losses ($)				EAD = Damage/RI ($/year)
		Structure	Contents	Displcmt	Total	
10	**0.5**	-	-	-	**$46,000**	**$4,600**
13	**0.8**	-	-	-	**$83,000**	**$6,225**
20	**1.3**	-	-	-	**$235,000**	**$11,750**
40	**2.0**	-	-	-	**$370,000**	**$9,250**

Expected Annual Damages Before Mitigation, EAD_{Before} = **$31,825** *per year*

Approximate Expected Annnal Damages After Mitigation (EAD_{After})

Retrofit Measure: **Dry Floodproofing**

Use adjacent table, Post-Retrofit Appoxmations by Retrofit Measure, to estimate Flood Damages After Mitigation

Flood Event RI (years)	Post-Event Damage ($)	EAD = Damage/RI ($/year)
10	**$0**	**$0**
13	**$0**	**$0**
20	**$0**	**$0**
40	**$0**	**$0**

Post-Retrofit Approximations by Retrofit Measure

Retrofit Measure	Project Effective-ness	Reduced Minimum RI Flood	Reduced Design RI Flood
Elevation	High	100%	90%
Relocation	Highest	100%	100%
Wet Floodprooofing	Moderate	50%	25%
Dry Floodproofing	Moderate	100%	0%
Flood Barriers	Moderate	100%	0%

Expected Annual Damages After Mitigation, EAD_{After} = **$0** *per year*

Determine the Project Benefits

Expected Annual Benefit, *EAB* = EAD_{Before} - EAD_{After} = **$31,825** *per year* (from FEMA P-259 Equation 7-2)

Project Benefits = *EAB x PVC* = **$289,859**

Determine the Benefit-Cost Ratio, BCR

***BCR* = (Project Benefits)/(Project Costs) =** **0.80 < 1.0 NG** (from FEMA P-259 Equation 7-1)

Figure CSB-16. Benefit-Cost Analysis Determination Worksheet for dry floodproofing at The Valley Apartments

Benefit-Cost Analysis (BCA) Determination Worksheet

Owner Name:	**John Smith**	**Preparer**	**JJS-MH**
Address:	**2908 Valley Drive**	**Date:**	**7/6/2026**
Property Details:	**Case Study B**		

Determine the Retrofit Project Costs

Retrofit Measure: Wet Floodproofing

H = Flood Design Height = **3.0** ft (determined based on previous design calculations)

T = Project Useful Life = **15** years (taken from FEMA P-259 Table 7-2)

r = Discount Rate = **7.0** *% (Discount Rate set by OMB Circular A-94)*

PVC = Present Value Coefficient = $[1 - (1 + r)^{-T}]/r$ = **9.11** (taken from FEMA P-259 Equation 7-3)

Base Cost = **$225,000** (develop based on FEMA P-259 Section 7.1.2 Steps 1-4 and Step 6)

O&M Cost = (Base Cost) x (Annual O&M %) x PVC = **$51,232** (develop based on FEMA P-259 Section 7.1.2 Step 5)

Project Costs = *Base Cost + O&M Cost* = **$276,232**

Estimate Expected Annnal Damages Before Mitigation (EAD_{Before})

Residential Building Details:

Number of Stories = **2.0** (choose between 1 and 3) **Building Area:** **10,000** square feet

Foundation Type = **Grade Slab** (choose between basement, crawlspace, piers, piles, or grade slab)

Flood Zone = **Outside Floodplain** *Assume riverine or non-Coastal A Zone unless noted otherwise*

USACE Generic Residential Depth-Damage Functon (DDF) = **2- or 3-story no basement** (see FEMA P-259 Table 7-1)

Building Replacement Value (BRV) = **N/A** (unit cost in dollars per square foot)

Total Building Value = **N/A** (based on Building Area x BRV)

Total Contents Value = 100% Total Building Value (assumed for all USACE General Residential DDFs)

Number of Occupants = **N/A** *(based on tax records or U.S. Census average household size rounded to whole number)*

Meals Rate = **N/A** *(unit cost in dollars per day based on FY2025 GSA Per Diem Rates for CONUS)*

Lodging Rate = **N/A** *(unit cost in dollars per day night on FY2025 GSA Per Diem Rates for CONUS)*

Displacement Cost = **N/A** *(unit cost in dollars per day based on ([Number of Occupants x Meals Rate) + Lodging Rate])*

Complete the following matrix of flood damages for up to four flood event recurrence intervals

Flood Event RI (years)	Depth Above Lowest Floor (ft)	Event Damages and Losses ($)				EAD = Damage/RI ($/year)
		Structure	Contents	Displcmt	Total	
10	**0.5**	-	-	-	**$46,000**	**$4,600**
13	**0.8**	-	-	-	**$83,000**	**$6,225**
20	**1.3**	-	-	-	**$235,000**	**$11,750**
40	**2.0**	-	-	-	**$370,000**	**$9,250**

Expected Annual Damages Before Mitigation, EAD_{Before} = **$31,825** *per year*

Approximate Expected Annnal Damages After Mitigation (EAD_{After})

Retrofit Measure: Wet Floodproofing

Use adjacent table, Post-Retrofit Appoxmations by Retrofit Measure, to estimate Flood Damages After Mitigation

Flood Event RI (years)	Post-Event Damage ($)	EAD = Damage/RI ($/year)
10	**$23,000**	**$2,300**
13	**$41,500**	**$3,113**
20	**$117,500**	**$5,875**
40	**$185,000**	**$4,625**

Post-Retrofit Approximations by Retrofit Measure

Retrofit Measure	Project Effective-ness	Reduced Minimum RI Flood	Reduced Design RI Flood
Elevation	High	100%	90%
Relocation	Highest	100%	100%
Wet Floodprooofing	Moderate	50%	25%
Dry Floodproofing	Moderate	100%	0%
Flood Barriers	Moderate	100%	0%

Expected Annual Damages After Mitigation, EAD_{After} = **$15,913** *per year*

Determine the Project Benefits

Expected Annual Benefit, *EAB* = EAD_{Before} - EAD_{After} = **$15,913** *per year* (from FEMA P-259 Equation 7-2)

Project Benefits = *EAB x PVC* = **$144,930**

Determine the Benefit-Cost Ratio, BCR

***BCR* = (Project Benefits)/(Project Costs) =** **0.52 < 1.0 NG** (from FEMA P-259 Equation 7-1)

Figure CSB-17. Benefit-Cost Analysis Determination Worksheet for wet floodproofing at The Valley Apartments

Benefit-Cost Analysis (BCA) Determination Worksheet

Owner Name:	John Smith	Preparer	JJS-MH
Address:	2908 Valley Drive	Date:	7/6/2026
Property Details:	Case Study B		

Determine the Retrofit Project Costs

Retrofit Measure: Floodwall

H = Flood Design Height = **5.0** ft (determined based on previous design calculations)

T = Project Useful Life = **50** years (taken from FEMA P-259 Table 7-2)

r = Discount Rate = **7.0** *% (Discount Rate set by OMB Circular A-94)*

PVC = Present Value Coefficient = $[1 - (1 + r)^{-T}]/r$ = **13.80** (taken from FEMA P-259 Equation 7-3)

Base Cost = **$300,000** (develop based on FEMA P-259 Section 7.1.2 Steps 1-4 and Step 6)

O&M Cost = (Base Cost) x (Annual O&M %) x PVC = **$103,506** (develop based on FEMA P-259 Section 7.1.2 Step 5)

Project Costs = *Base Cost + O&M Cost* = **$403,506**

Estimate Expected Annnal Damages Before Mitigation (EAD_{Before})

Residential Building Details:

Number of Stories = **2.0** (choose between 1 and 3) **Building Area:** **10,000** square feet

Foundation Type = **Grade Slab** (choose between basement, crawlspace, piers, piles, or grade slab)

Flood Zone = **Outside Floodplain**

USACE Generic Residential Depth-Damage Functon (DDF) = **2- or 3-story no basement** (see FEMA P-259 Table 7-1)

Building Replacement Value (BRV) = **N/A** (unit cost in dollars per square foot)

Total Building Value = **N/A** (based on Building Area x BRV)

Total Contents Value = 100% Total Building Value (assumed for all USACE General Residential DDFs)

Number of Occupants = **N/A** *(based on tax records or U.S. Census average household size rounded to whole number)*

Meals Rate = **N/A** *(unit cost in dollars per day based on FY2025 GSA Per Diem Rates for CONUS)*

Lodging Rate = **N/A** *(unit cost in dollars per day night on FY2025 GSA Per Diem Rates for CONUS)*

Displacement Cost = **N/A** *(unit cost in dollars per day based on ([Number of Occupants x Meals Rate) = Lodging Rate])*

Complete the following matrix of flood damages for up to four flood event recurrence intervals

Flood Event RI (years)	Depth (feet)	Event Damages and Losses ($)				EAD = Damage/RI ($/year)
		Structure	Contents	Displcmt	Total	
10	**0.50**	-	-	-	**$46,000**	**$4,600**
13	**0.83**	-	-	-	**$83,000**	**$6,225**
20	**1.25**	-	-	-	**$235,000**	**$11,750**
40	**2.00**	-	-	-	**$370,000**	**$9,250**

Expected Annual Damages Before Mitigation, EAD_{Before} = **$31,825** *per year*

Approximate Expected Annnal Damages After Mitigation (EAD_{After})

Retrofit Measure: Floodwall

Use adjacent table, Post-Retrofit Appoxmations by Retrofit Measure, to estimate Flood Damages After Mitigation

Flood Event RI (years)	Post-Event Damage ($)	EAD = Damage/RI ($/year)
10	**$0**	**$0**
13	**$0**	**$0**
20	**$0**	**$0**
40	**$0**	**$0**

Post-Retrofit Approximations by Retrofit Measure

Retrofit Measure	Project Effective-ness	Reduced Minimum RI Flood	Reduced Design RI Flood
Elevation	High	100%	90%
Relocation	Highest	100%	100%
Wet Floodprooofing	Moderate	50%	25%
Dry Floodproofing	Moderate	100%	0%
Flood Barriers	Moderate	100%	0%

Expected Annual Damages After Mitigation, EAD_{After} = **$0** *per year*

Determine the Project Benefits

Expected Annual Benefit, *EAB* = $EAD_{Before} - EAD_{After}$ = **$31,825** *per year* (from FEMA P-259 Equation 7-2)

Project Benefits = *EAB x PVC* = **$439,209**

Determine the Benefit-Cost Ratio, BCR

***BCR* = (Project Benefits)/(Project Costs) =** **1.09 > 1.0 OK** (from FEMA P-259 Equation 7-1)

Figure CSB-18. Benefit-Cost Analysis Determination Worksheet for floodwall at The Valley Apartments

7.3. Alternative Selection Factors

In addition to cost-effectiveness (Section 7.1), the following alternative selection factors can be used to assess proposed residential retrofit projects:

- Regulatory compliance (Section 7.3.1)
- Homeowner preferences (Section 7.3.2)
- Flood, Site and Building Characteristics (Section 7.3.3)
- Technical Feasibility (Section 7.3.4)
- Project Cost (Section 7.3.5)

Each of these alternative selection factors will be briefly discussed in the sections that follow.

7.3.1. REGULATORY COMPLIANCE

Residential retrofit projects must comply with applicable federal, state, and local regulations, including National Flood Insurance Program regulations, building codes, and standards. Retrofit projects that do not comply with all applicable regulations, including local zoning and permitting requirements, cannot be considered for further analysis.

Cross Reference

Detailed information on federal regulatory requirements can be found in Section 2.1, with additional information on community regulations and permitting in Section 2.5. Additionally, property owners considering a flood retrofit project should contact their local building official and floodplain manager for an understanding of state and local regulations and permitting requirements.

7.3.2. HOMEOWNER PREFERENCES

Homeowner preferences when selecting retrofitting alternatives include aesthetics, cost, risk concerns, as well as accessibility and future home resale value. Since the homeowner is responsible for operating and maintaining the selected retrofit alternative, homeowner preferences and concerns should be addressed as part of the design process to ensure that the project is successful at reducing risk.

Cross Reference

Detailed information on homeowner preferences and concerns can be found in Section 2.6.1 and includes the Preliminary Homeowner Retrofitting Preference Matrix (Figure 2-4).

7.3.3. FLOOD, SITE, AND BUILDING CHARACTERISTICS

An understanding of flooding, site, and building characteristics is critical for the initial assessment of residential retrofitting alternatives. For example, if a home is at risk from design flood depths greater than six feet above grade, then the most likely retrofitting alternatives would be elevation or relocation.

Cross Reference

Detailed information on flood, site and building characteristics can be found in Section 2.8 and includes the Retrofitting Screen Matrices with Instructions for Flood Characteristics (Figures 2-10 and 2-11), Site Characteristics (Figures 2-14 and 2-15), and Building Characteristics (Figures 2-17 and 2-18).

7.3.4. TECHNICAL FEASIBILITY

Designing a technically feasible retrofitting alternative requires the following actions:

- Consideration of gravity loads and all flood and non-flood hazard forces acting on the structure
- Review of the geotechnical parameters of the site's soils
- Analysis of load combinations and global design checks
- Understanding the detailed requirements and limitations of elevation, relocation, floodproofing, and flood barriers

Retrofitting alternatives must be technically feasible to be considered for final selection.

Cross Reference

Additional information on technical feasibility can be found throughout Chapters 3 through 6. Specific references include:

- Hydrostatic, Hydrodynamic, and Debris Impact Force Combination Worksheets in Figures 3-5, 3-7 and 3-8.
- Hazard Risk Assessment Matrix for Non-Flood Hazards with Instructions in Figure 3-16.
- Geotechnical Considerations Matrix with Instructions in Figures 3-17 and 3-18.
- Load Combinations Worksheet with Instructions in Figures 4-10 and 4-11.
- Elevation and Relocation Assessment Matrix in Figure 5-50.
- Floodproofing and Flood Barriers Assessment Matrix in Figure 6-70.

7.3.5. PROJECT COST

Project cost is usually the primary consideration for most property owners in choosing a retrofit option. In some situations, the owner may choose a retrofitting alternative that provides less protection and is less cost-effective than other alternatives because it is the only affordable option. The project cost estimation process is discussed in Section 7.1.2 as part of the cost-effectiveness determination process.



Cross Reference

Information on the relative costs of retrofit projects can be found in Tables 2-3 through 2-7 of Section 2.6.5 and Table 5-1 in Section 5.2.4. Additionally, property owners considering a flood retrofit project are encouraged to contact two or more experienced, reputable (i.e., licensed, bonded, insured) contractors in their area for itemized project proposals and cost estimates.

7.4. Selecting the Final Retrofit Alternative

7.4.1. RANKING ALTERNATIVE SELECTION FACTORS

For the most promising/preferred retrofit alternatives, the Alternative Selection Factors listed in the previous section (i.e., Regulatory Compliance, Homeowner Preferences; Flood, Site and Building Characteristics; Technical Feasibility; Project Cost; and Cost-Effectiveness) can be ranked using a preference ranking alternative (Likert) scale of 1-5:

- 5 = High, indicating the most preferable
- 4 = Medium-High, indicating preferable
- 3 = Medium, indicating moderately preferable
- 2 = Medium-Low, indicating less preferable
- 1 = Low, indicating the least preferable

Once the Alternative Selection Factors are ranked using the preference ranking scale, each of the factors can be adjusted to increase or decrease their relative importance using Importance Factors. Alternative Selection Factors that are more important to the homeowner can be assigned Importance Factors greater than 1.0; while factors less important to the homeowner can be assigned Importance Factors less than 1.0. In some cases, where the homeowner may not want to consider a particular Alternative Selection Factor, that factor can be assigned an Importance Factor of zero (0). In instances where the homeowner has no preferences, each Alternative Selection Factor can be assigned the same Importance Factor of 1.0.

After the Alternative Selection Factors are ranked and Importance Factors are assigned for a preferred retrofit alternative, a Total Preference Ranking Score can be computed by multiplying each Alternative Selection Factor ranking by its respective Importance Factor and adding up the results. Once completed for all the preferred retrofit alternatives, the Total Preference Ranking Score for each alternative can be compared, and the alternative with the highest score can be recommended for final selection and construction.

A Preference Ranking Alternative Worksheet that illustrates these concepts is provided in Figure 7-2.

Preference Ranking Alternative Worksheet							
Owner Name:						**Preparer:**	
Address:						**Date:**	
Property Details:							
	Alternative Selection Factors						**Total Preference Ranking Score**
	Regulatory Compliance	**Homeowner Preferences**	**Flood, Site and Building Characteristics**	**Technical Feasibility**	**Project Cost**	**Cost-Effectiveness**	
	Importance Factor	**Importance Factor**	**Importance Factor**	**Importance Factor**	**Importance Factor**	**Importance Factor**	
Preferred Retrofit Alternatives							
Elevation on Perimeter Foundation Walls							
Relocation							
Wet Floodproofing							
Purpose:	The purpose of the Preference Ranking Alternative Worksheet is to aid in the final selection of the retrofit measure from the top two or three alternatives.						
Instructions:	Step 1:	Review the Alternative Selection Factors and assign Importance Factors between 0.5 and 1.0 based on their relative importance to the homeowner, with highest Importance Factors set to 1.0, moderate Importance Factors set to 1.0, and lowest Importance Factors set to 0.5. If the homeowner does not want to consider a particular factor, then it can be assigned an Importance Factor of 0. If the homeowner has no specific preferences, then set all Alternative Selection Importance Factors equal to 1.0.					
	Step 2:	For each Preferred Retrofit Alternative, rank the Alternative Selection Factors from left to right (i.e., starting with Regulatory Compliance and ending with Cost-Effectiveness) using a preference scale of 1 to 5 as follows: 5 = High (most preferable of alternatives) 4 = Medium-High (more preferable of alternatives) 3 = Medium (moderately preferable of alternatives) 2 = Medium-High (less preferable of alternatives) 1 = Low (least preferable of alternatives) For Regulatory Compliance, if a Preferred Retrofit Alternative does not comply with the NFIP and/or local building codes/standards for the project location, then Regulatory Compliance should be scored as NF, and all other Alternative Selection Factors for that Preferred Alternative should be scored as zero (0). For Technical Feasibility, if a Preferred Retrofit Alternative cannot be designed to protect the building to the Design Flood Elevation, then Technical Fasibility should be scored as zero (0), but all other factors should be scored as indicated in the above guidance.					
	Step 3:	Once all Importance Factors are input (Step 1) and Alternative Selection Factors are ranked (Step 2), compute the Total Preference Ranking Score by multiplying each Alternative Selection Factor ranking by its Importance Factor, and summing the results for all other Selection Factors.					
Evaluation of Results:	The Preferred Retrofit Alternative with the highest Total Preference Ranking Score is the one recommended for final selection.						

Figure 7-2. Preference Ranking Alternative Worksheet

7.5. Case Study Exercise 9 – Final Retrofit Measure Selection

Use the results from the Case Study Introductions, Exercises 1 through 8, and the information in Section 7.3.1 to complete the Preference Ranking Alternative Worksheet (Figure 7-2) and determine the most promising retrofitting techniques for the Case Study A and B buildings.

Case Study A – Exercise 9: Residential Retrofit in Riverine Floodplain Using Relocation or Elevation

Mr. and Mrs. Doe's preferences for retrofitting are summarized in Figure CSA-20. Six selection factors of equal weight were used to rank the retrofit alternatives. The Does consistently scored Elevation on Perimeter Foundation Walls as moderately preferable to most preferred for each of the selection factors. This resulted in Mr. and Mrs. Doe's highest ranking score of 24 being associated with their most preferred option to elevate the existing home on new perimeter foundation walls versus relocation (21).

Along with elevating the house, Mr. and Mrs. Doe will also need to elevate their detached saferoom. Similar evaluations for the elevation of the house can be performed for the saferoom, as well, to ensure it is elevated to the same flood level and the foundation can withstand the proper loads.

Preference Ranking Alternative Worksheet							
Owner Name:	**John and Jane Doe**					**Preparer:**	**JJS-MH**
Address:	**55 Cedar River Road**					**Date:**	**7/6/2026**
Property Details:	**Case Study A**						
	Alternative Selection Factors						**Total Preference Ranking Score**
	Regulatory Compliance	**Homeowner Preferences**	**Flood, Site and Building Characteristics**	**Technical Feasibility**	**Project Cost**	**Cost-Effectiveness**	
	Importance Factor	**Importance Factor**	**Importance Factor**	**Importance Factor**	**Importance Factor**	**Importance Factor**	
Preferred Retrofit Alternatives	**1.0**	**1.0**	**1.0**	**1.0**	**1.0**	**1.0**	
Elevation on Perimeter Foundation Walls	**4**	**5**	**5**	**3**	**3**	**4**	**24**
Relocation	**4**	**5**	**4**	**5**	**1**	**2**	**21**
Purpose:	The purpose of the Preference Ranking Alternative Worksheet is to aid in the final selection of the retrofit measure from the top two or three alternatives.						
Instructions:	Step 1:	Review the Alternative Selection Factors and assign Importance Factors between 0.5 and 1.0 based on their relative importance to the homeowner, with highest Importance Factors set to 1.0, moderate Importance Factors set to 1.0, and lowest Importance Factors set to 0.5. If the homeowner does not want to consider a particular factor, then it can be assigned an Importance Factor of 0. If the homeowner has no specific preferences, then set all Alternative Selection Importance Factors equal to 1.0.					
	Step 2:	For each Preferred Retrofit Alternative, rank the Alternative Selection Factors from left to right (i.e., starting with Regulatory Compliance and ending with Cost-Effectiveness) using a preference scale of 1 to 5 as follows: 5 = High (most preferable of alternatives) 4 = Medium-High (more preferable of alternatives) 3 = Medium (moderately preferable of alternatives) 2 = Medium-High (less preferable of alternatives) 1 = Low (least preferable of alternatives) For Regulatory Compliance, if a Preferred Retrofit Alternative does not comply with the NFIP and/or local building codes/standards for the project location, then Regulatory Compliance should be scored as NF, and all other Alternative Selection Factors for that Preferred Alternative should be scored as zero (0). For Technical Feasibility, if a Preferred Retrofit Alternative cannot be designed to protect the building to the Design Flood Elevation, then Technical Fasibility should be scored as zero (0), but all other factors should be scored as indicated in the above guidance.					
	Step 3:	Once all Importance Factors are input (Step 1) and Alternative Selection Factors are ranked (Step 2), compute the Total Preference Ranking Score by multiplying each Alternative Selection Factor ranking by its Importance Factor, and summing the results for all other Selection Factors.					
Evaluation of Results:	The Preferred Retrofit Alternative with the highest Total Preference Ranking Score is the one recommended for final selection.						

Figure CSA-20. Preference Ranking Alternative Worksheet for the Doe house

Case Study B – Exercise 9: Residential Retrofit Outside of the Floodplain Using Floodwalls or Dry Floodproofing

Mr. Smith's preferences for retrofitting The Valley Apartments are summarized in Figure CSB-19. He scored the floodwall option (23) a little higher than dry floodproofing (21). Wet floodproofing (13) scored the lowest of the three options, as Mr. Smith recognized that his tenants did not find this option desirable. The berm option was not scored since that option was never desirable, given the amount of space it would require and the aesthetics that it would create as an anomaly within the community. Ultimately, the tipping points were his preference for a floodwall to replace the existing brick fence and the suitability of a floodwall to

protect the site with minimal disruptions during construction because of the flood, site, and building characteristics.

Preference Ranking Alternative Worksheet							
Owner Name:	**Atticus Finch**					**Preparer:**	**JJS-MH**
Address:	**2908 Valley Drive**					**Date:**	**7/6/2026**
Property Details:	**Case Study B**						
	Alternative Selection Factors						**Total Preference Ranking Score**
	Regulatory Compliance	**Homeowner Preferences**	**Flood, Site and Building Characteristics**	**Technical Feasibility**	**Project Cost**	**Cost-Effectiveness**	
	Importance Factor	**Importance Factor**	**Importance Factor**	**Importance Factor**	**Importance Factor**	**Importance Factor**	
Preferred Retrofit Alternatives	**1.0**	**1.0**	**1.0**	**1.0**	**1.0**	**1.0**	
Floodwall	**4**	**5**	**5**	**4**	**3**	**2**	**23**
Dry Floodproofing	**3**	**4**	**4**	**3**	**4**	**3**	**21**
Wet Floodproofing	**2**	**1**	**2**	**2**	**5**	**1**	**13**
Purpose:	The purpose of the Preference Ranking Alternative Worksheet is to aid in the final selection of the retrofit measure from the top two or three alternatives.						
Instructions:	Step 1:	Review the Alternative Selection Factors and assign Importance Factors between 0.5 and 1.0 based on their relative importance to the homeowner, with highest Importance Factors set to 1.0, moderate Importance Factors set to 1.0, and lowest Importance Factors set to 0.5. If the homeowner does not want to consider a particular factor, then it can be assigned an Importance Factor of 0. If the homeowner has no specific preferences, then set all Alternative Selection Importance Factors equal to 1.0.					
	Step 2:	For each Preferred Retrofit Alternative, rank the Alternative Selection Factors from left to right (i.e., starting with Regulatory Compliance and ending with Cost-Effectiveness) using a preference scale of 1 to 5 as follows: 5 = High (most preferable of alternatives) 4 = Medium-High (more preferable of alternatives) 3 = Medium (moderately preferable of alternatives) 2 = Medium-High (less preferable of alternatives) 1 = Low (least preferable of alternatives) For Regulatory Compliance, if a Preferred Retrofit Alternative does not comply with the NFIP and/or local building codes/standards for the project location, then Regulatory Compliance should be scored as NF, and all other Alternative Selection Factors for that Preferred Alternative should be scored as zero (0). For Technical Feasibility, if a Preferred Retrofit Alternative cannot be designed to protect the building to the Design Flood Elevation, then Technical Fasibility should be scored as zero (0), but all other factors should be scored as indicated in the above guidance.					
	Step 3:	Once all Importance Factors are input (Step 1) and Alternative Selection Factors are ranked (Step 2), compute the Total Preference Ranking Score by multiplying each Alternative Selection Factor ranking by its Importance Factor, and summing the results for all other Selection Factors.					
Evaluation of Results:	The Preferred Retrofit Alternative with the highest Total Preference Ranking Score is the one recommended for final selection.						

Figure CSB-19. Preference Ranking Alternative Worksheet for The Valley Apartments

Appendix A. Case Study A Supplemental Material

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A.1 Case Study A Background

This appendix provides supplemental material for Case Study A with extra guidance and detailed calculations. It offers considerations for the relocation of a structure and the elevation process. This appendix also shows calculations used to fill out the Computation Worksheets. Some of the calculations in Appendix A include the development of dead load weights, live loads, roof loads, snow loads, wind loads, and earthquake loads.

A.2 Case Study A Supplemental Information

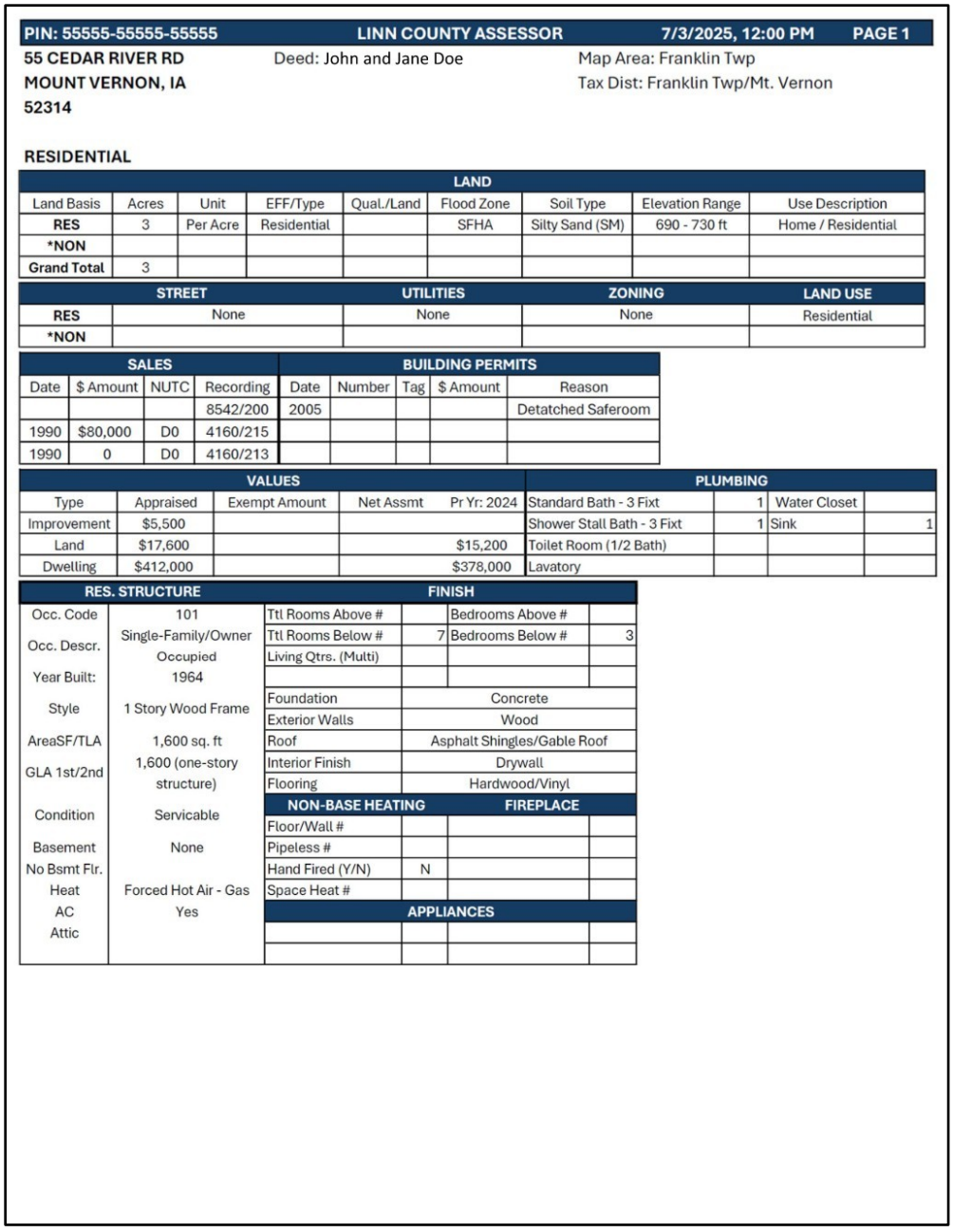
Building Value Assessment

An updated tax card is shown in Figure A-1, providing an alternate source to verify the building square footage data. The building replacement value of the Brook home is approximately $145.00 per square foot, based on real estate market cost estimating guides.

Elevation

Elevating the structure on existing foundations is also a viable retrofit option. The most practical way to accomplish this for the Brook house would be to demolish the existing grouted foundation walls and masonry piers down to the footings. New reinforced foundation walls and reinforced masonry piers can be designed and installed on existing footings to accommodate horizontal loads. Refer to Chapter 1, Figure 1-6 for the advantages and disadvantages of elevation. The elevation process would include:

- Designing the foundation walls and piers
- Disconnecting utilities
- Lifting the existing structure on hydraulic jacks
- Demolishing the foundation walls and piers down to the existing footings
- Constructing the new foundation walls and piers
- Installing flood openings
- Lowering the structure and securing it to the foundation walls and piers
- Reconnecting utilities
- Constructing new landings and stairs



PIN: 55555-55555-55555 | **LINN COUNTY ASSESSOR** | **7/3/2025, 12:00 PM** | **PAGE 1**

55 CEDAR RIVER RD
MOUNT VERNON, IA
52314

Deed: John and Jane Doe

Map Area: Franklin Twp
Tax Dist: Franklin Twp/Mt. Vernon

RESIDENTIAL

LAND

Land Basis	Acres	Unit	EFF/Type	Qual./Land	Flood Zone	Soil Type	Elevation Range	Use Description
RES	3	Per Acre	Residential		SFHA	Silty Sand (SM)	690 - 730 ft	Home / Residential
***NON**								
Grand Total	3							

STREET	UTILITIES	ZONING	LAND USE
RES	None	None	None	Residential
***NON**			

SALES

Date	$ Amount	NUTC	Recording
			8542/200
1990	$80,000	D0	4160/215
1990	0	D0	4160/213

BUILDING PERMITS

Date	Number	Tag	$ Amount	Reason
2005				Detatched Saferoom

VALUES

Type	Appraised	Exempt Amount	Net Assmt	Pr Yr: 2024
Improvement	$5,500			
Land	$17,600			$15,200
Dwelling	$412,000			$378,000

PLUMBING

Standard Bath - 3 Fixt	1	Water Closet	
Shower Stall Bath - 3 Fixt	1	Sink	1
Toilet Room (1/2 Bath)			
Lavatory			

RES. STRUCTURE

Occ. Code	101
Occ. Descr.	Single-Family/Owner Occupied
Year Built:	1964
Style	1 Story Wood Frame
AreaSF/TLA	1,600 sq. ft
GLA 1st/2nd	1,600 (one-story structure)
Condition	Servicable
Basement	None
No Bsmt Flr.	
Heat	Forced Hot Air - Gas
AC	Yes
Attic	

FINISH

Ttl Rooms Above #		Bedrooms Above #	
Ttl Rooms Below #	7	Bedrooms Below #	3
Living Qtrs. (Multi)			
Foundation	Concrete		
Exterior Walls	Wood		
Roof	Asphalt Shingles/Gable Roof		
Interior Finish	Drywall		
Flooring	Hardwood/Vinyl		

NON-BASE HEATING / **FIREPLACE**

Floor/Wall #			
Pipeless #			
Hand Fired (Y/N)	N		
Space Heat #			

APPLIANCES

Figure A-1. Doe house tax card

Relocation

The only way to nearly eliminate the flood risk to Mr. and Mrs. Doe's home is to move the entire structure out and well above, the Special Flood Hazard Area. It's important to note, upwards of 25% of National Flood Insurance Program claims payouts are to structures that are actually outside of the Special Flood Hazard Area. Because his tract is large with ample buildable space outside and well above the Special Flood Hazard Area, relocation is a good option. Figure 1-9 in Chapter 1 summarizes relocation advantages and disadvantages. The relocation process should include site

selection considerations as presented in the Special Note below; several of which apply to the Doe's home.



Note

Several factors influence the selection of a new site for the relocation of an entire structure. It should not only be less prone to flooding but access between the existing site and the new site will also need to be feasible. Access roads must exist or must be constructed that allow the home to be moved from the existing to the new site. Road width, slope, clearance to overhead utilities and the ability to support the house and moving equipment must be considered. Also, if required by the community, the new site will need to be accessible for firefighters and other emergency responders. Even when not required, firefighter and emergency responder access is desirable.

Utility location will also influence site selection. In areas served by municipal utilities, provisions for water, wastewater and stormwater should be considered. In rural areas that rely on private wells and waste disposal systems, the ability to drill potable water wells (to also support fire suppression) and to install waste disposal (septic) systems will affect site selection. For both urban and rural sites, access to electric and communication services affects site selection.

The relocation process will also include:

- Designing, excavating for, and constructing the new foundation;
- Lifting the existing structure;
- Transporting the structure from the original site to the new site;
- Lowering the structure and securing it onto the new foundation;
- Connecting utilities; and
- Removing the old foundation and restoring (e.g., replanting or reseeding) the existing site.

A.3 Detailed Load Calculations for the Doe House

Elevation

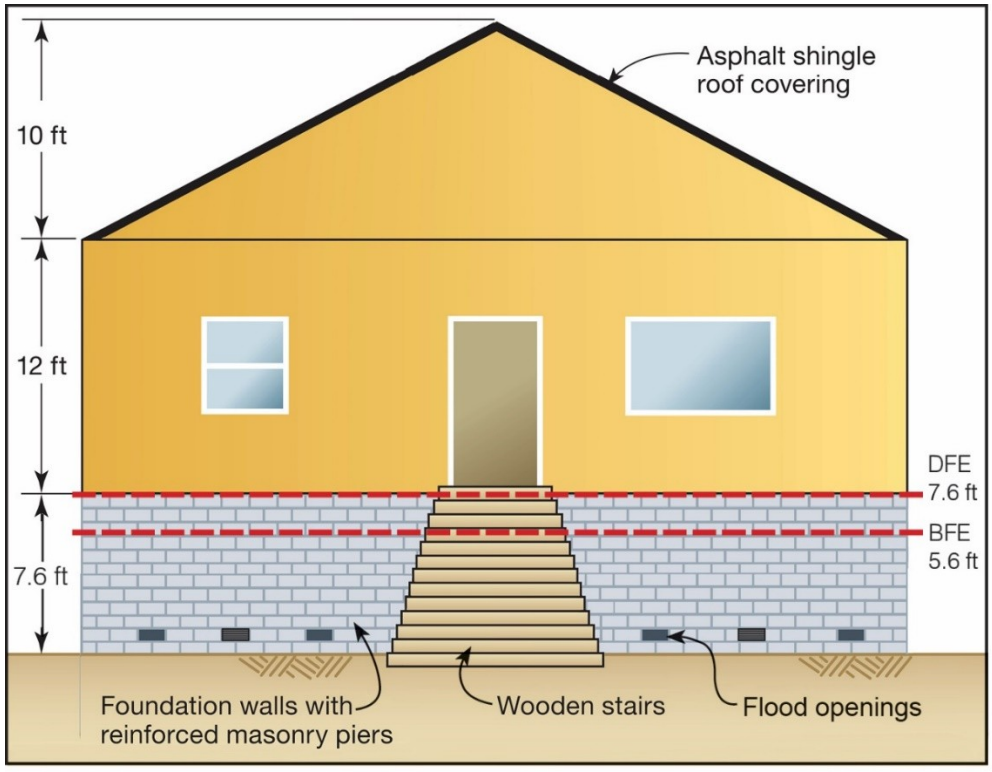


Figure A-2. The Doe house after elevation, including extended foundation walls and flood openings

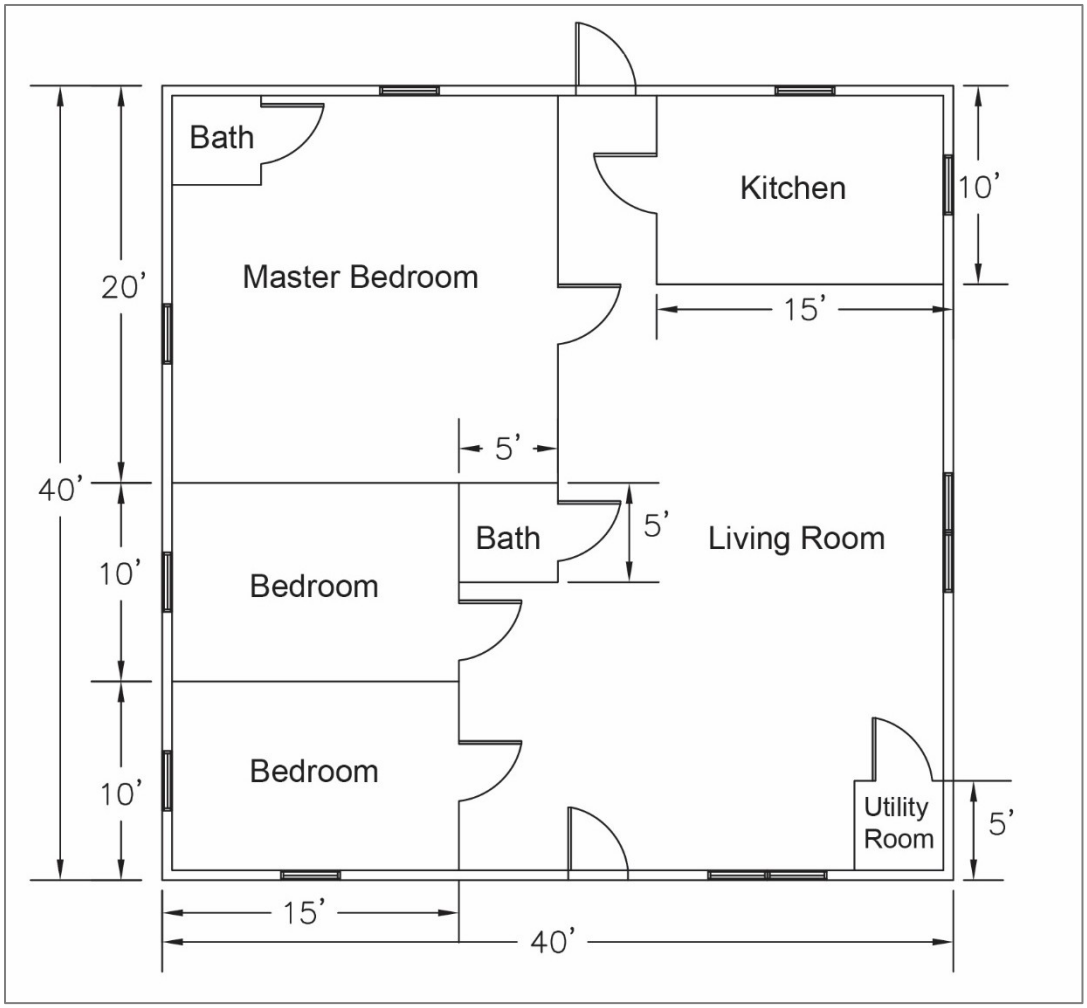


Figure A-3. The floor plan of the Doe house

Dead Loads

Dead load calculations are summarized in Tables A-1 and A-2 on the next page. The total dead load was calculated to be 302,794 lbs.

Live Loads

Live load calculations are summarized in Table A-3 on the next page. The total live load was calculated to be 64,000 lbs, with the total roof live load calculated to be 35,840 lbs.

Table A-1. Dead Loads Part 1 of 2 (Using Pounds/Square Feet)

Element	Area (ft^2)	Unit Weight (lb/ft^2)	Total Weight (lbs)
Exterior walls: drywall. 4 in. batt insulation, wood siding	(4)(40ft)(12ft)+ (2)(10ft)(40ft/2) = 2,320	11	25,520
Interior walls: wood stud, 2 in. x 4 in., 1/2 in. drywall	(12)(15+10+15+10+5+5+5+20+5+5 +10+15+5+5) = 1,560	8	12,480
Floor frame: wood-frame 2 x 10s with subflooring	(40ft)(40ft) = 1,600	10	16,000
Floor cover: hardwood	(40ft)(40ft) = 1,600	4	6,400
Ceiling: drywall and wood furring	(40ft)(40ft) = 1,600	4	6,400
Roof: rafters, sheathing, 10 in. batt insulation	(1.12)(1,600 ft^2) = 1,792	15	26,880
Roof cover: asphalt shingles	(1.12)(1,600 ft^2) = 1,792	2	3,584
TOTAL	**Over the 1,600 ft^2 structure**	**54**	**97,264**

Table A-2. Dead Loads Part 2 of 2 (Using Pounds/Cubic Feet)

Element	Volume (ft^3)	Unit Weight (lb/ft^3)	Total Weight (lbs)
Concrete Masonry Unit Walls	(160ft)(10.6ft)(0.67ft) = 1,136	75	85,200
Concrete Masonry Unit Piers	(12)(2ft)(2ft)(10.6ft) = 509	120	61,080
Concrete Footers	(160ft)(2ft)(1ft) + (12)(2.5ft)(2.5ft)(1ft) = 395	150	59,250
TOTAL			**205,530**

Total Dead Load = (97,264 + 205,530) = 302,794 lbs

Table A-3. Live Loads

Element	Live Load (lb/ft²)	Calculation
Live Load: Interior Floor Area	40	(1,600ft²)(40lb/ft²) = 64,000 lbs
Live Load: Roof	20	(1,792ft²)(20lb/ft²) = 35,840 lbs

Snow Loads

The local snow load is 51 lb/ft², per ASCE Hazard Tool at the specified location. The snow load acts on the horizontal projected area of the roof.

S = (51lb/ft²)(1,792ft²) = 91,392 lbs (vertical)

Wind Loads

Wind load calculations are summarized below and in Tables A.4 and A.5.

Wind Pressure

Mean Roof Height = 7.6-ft + 12-ft + 5-ft = 24.6-ft

Exposure Category C and z will be set to the mean roof height, h for this example.

Wind Pressure (q_z) = $0.00256K_hK_{zt}K_eV^2$

- V = 109 mph
- K_h = 0.94
- K_{zt} = 1.0
- K_e = 1.0

$q_z = 0.00256(0.94)(1.0)(1.0)(109^2)$

q_z = 28.6 psf

Lateral Wind Loads on the House:

To determine the overall lateral and uplift wind loads on the house, Chapter 27 of ASCE 7-22 Section 27.3 can be followed in detail. It provides specific pressure coefficients for each exterior building surface, along with internal pressure coefficients where appropriate for individual surface design, along with appropriate gust factors (G = 0.85 for houses) and wind directionality adjustment factors (K_d = 0.85 for overall loads on houses). Typically, the positive pressure on the windward walls can be varied with height to reflect the variation in wind speed with height, while the pressures on all the other surfaces are based on the reference velocity pressure at mean roof height. For houses, a

conservative order of magnitude can be estimated by simply using the reference pressure at mean roof height for all the wind load calculations ($q_h = q_z$ = 28.6 psf). The pressure coefficient for windward surfaces (ASCE 7-22 Figure 27.3-1) is +0.8. For leeward surfaces, the coefficient varies with the ratio of building length parallel to the wind direction, L, divided by the building width, B, perpendicular to the wind direction. For a square building, that ratio is 1.0, and the leeward pressure coefficient (ASCE 7-22 Figure 27.3-1) is -0.5. Positive coefficients indicate pressures that act towards the surface, and negative coefficients indicate pressures that act away from the building surface. To get the net lateral loads on the building when using a common reference design pressure (the pressure at mean roof height), the pressure on the leeward surface can be subtracted from the pressure on the windward surface [+0.8 – (-0.5)] = 1.3, and therefore C_p = 1.3. Note that for overall forces, internal pressures would cancel out, but for design of a particular exterior surface, the internal pressure would need to be considered.

The equation for calculating the net pressures across the building in this simplified approach is:

$P = q_h K_d G C_p$ = 28.6(0.85)(0.85)(1.3) = 26.9 psf

This pressure can be applied to all the vertical surfaces and will produce a reasonable but slightly conservative estimate for winds blowing against the gable end wall. It can also be used for the wall portions of the house when wind blows perpendicular to a sloped roof.

For winds blowing perpendicular to the sloped roof, a more accurate estimate of the net load on the roof portion of the house can be obtained by extracting the largest positive pressure coefficient on the windward roof surface and the appropriate leeward roof surface pressure coefficient based on the roof slope in ASCE 7-22 Figure 27.3-1. The house has a 6:12 roof slope (26.6 degrees), which corresponds to a windward roof positive pressure coefficient of +0.2 and a leeward roof negative pressure coefficient of -0.6. The net pressure coefficient for the roof when wind blows perpendicular to the sloped roof surface would be [+0.2 – (-0.6)] = +0.8 and therefore C_p = +0.8. The resulting pressure for the roof portion in this simplified approach is:

$P = q_h K_d G C_p$ = 28.6(0.85)(0.85)(0.8) = 16.5 psf

Table A-4. Lateral Wind Loads on with Gable End Facing Wind

Element	Area (ft^2)	Wind Pressure (lb/ft^2)	Wind Load (lbs)
Elevated Crawlspace Area	(7.6ft)(40ft) = 304	26.9	8,178
Exterior Wall Area	(12ft)(40ft) = 480	26.9	12,912
Gable End Portion of Wall	(0.5)(10ft)(40ft) = 200	26.9	5,380
TOTAL			**26,470**

Table A-5. Lateral Wind Loads on House with Wind Perpendicular to Roof Slope

Element	Area (ft^2)	Wind Pressure (lb/ft^2)	Wind Load (lbs)
Elevated Crawlspace Area	(7.6ft)(40ft) = 304	26.9	8,178
Exterior Wall Area	(12ft)(40ft) = 480	26.9	12,912
Complete Roof Area	(10ft)(40ft) = 400	16.5	6,600
TOTAL			**27,690**

During the design flood event, the wind load on the crawlspace is excluded, and the net lateral wind loads reduce by 8,178 lbs to 18,292 lbs and 19,512 lbs for winds blowing perpendicular to the gable end and perpendicular to the sloped roof, respectively. These reduced values were used when determining horizontal wind forces when horizontal flood loads are being applied.

Wind Uplift Load on Roof of House:

Wind uplift loads on the house arise from the roof uplift loads. The highest roof uplift loads specified in ASCE 7-22 for this house will occur when the wind is blowing parallel to the ridge (perpendicular to one of the gable ends). ASCE 7-22 specifies different coefficients according to distance from the windward edge of the roof, and the coefficients vary depending on the height to length ratio. Calculating the coefficients for the different roof zones and averaging over the roof surface produces an average uplift coefficient of C_{pn} = -0.76. This average number will be used to provide a reasonable estimate of the roof uplift load. The simplified method shown below is used to provide a representative uplift pressure on the roof and avoid detailed calculations that are better illustrated in a primarily wind retrofit publication. See ASCE 7-22 Chapter 27 and Figure 27.3.1 for more accurate and detailed formulas.

- Wind Uplift Pressure at Roof (pr) = $q_h K_d G C_{pn}$
- p_r = 28.6(0.85)(0.85)(-0.76)
- p_r = -15.7 psf
- Wind Loads on Vertical Projected Surface - Roof
  - Area (ft^2): (40ft)(40ft) = 1,600 ft^2
  - Wind Uplift Pressure (lb/ft^2): 15.7 lb/ft^2
  - Wind Uplift Load (lbs): 25,120 lbs

Seismic Loads

The seismic loads are assumed to be negligible for this location, which is in Seismic Design Category B.

A.4 Elevated Foundation Assessment

The extended perimeter foundations walls used for elevating Mr. and Mrs. Doe's house impose additional dead load on the existing footings that must be evaluated through a bearing capacity check. The silty sand soil at the site can support an ultimate bearing capacity of 4,000 psf. The calculation below shows the bearing area determined from the existing 2 feet wide wall footings and the twelve 2 feet by 2 feet interior pier footings.

$A_{bearing}$ (Bearing Area of Footings) = (4)(2ft)(40ft) – (4)(2ft)(2ft) + (12)(2ft)(2ft) = 352 ft^2

Maximum vertical load obtained from Load Combination 3a: (1.2D + S + L)

= 1.2(302,794) + 91,392 + 64,000 = 518,745 lbs

Maximum Vertical Load = 518,745 lbs

Actual Bearing = Maximum Vertical Load/$A_{bearing}$ = 518,745 lbs / 352 ft^2 = 1,474 psf

Ultimate Bearing Capacity = 4,000 psf

Since the Ultimate Bearing Capacity is greater than the Actual Bearing on the soil, the elevated foundation load on the existing footings is considered acceptable.



Note

This publication does not address the material checks that should be performed for the new perimeter foundation walls. Proper steel reinforcement should be designed for the grouted concrete masonry unit foundation walls so that the walls can resist the loads. In particular, the perimeter foundation walls should have sufficient capacity to resist the horizontal flood loads.

A.5 Cost-Effectiveness

This first step in assessing cost-effectiveness was to estimate the cost of elevating and relocating the Doe house. The results of the assessment are summarized below, based on the following information summarized in Table A-6:

Table A-6. Summary of Retrofit Costs for Doe House

Retrofit Option	Unit Cost ($/SF of building footprint)	Base Cost ($)	Annual O&M Costs (% Base Cost)	Present Value of O&M Costs ($)	Total Project Cost ($)
Elevation on perimeter foundation walls	$110/SF up to 4 ft; $10,000 for each additional ft	$196,000	0.5%	$14,246 (T = 30 yrs; R = 7.0%)	$208,161
Relocation	$250/SF	$400,000	0.0%	$0	$400,000

Next, the Does used the US Army Corps of Engineers Depth Damage Functions for a one-story with basement residence (assuming a crawlspace incurs damage similar to a basement within two feet of the finished floor) as shown in Table A-6 to estimate the 10-, 50-, 100-, and 500-year flood damages based on flood depths of 0.8, 2.1, 3.6, and 5.6.

Table A-7. Flood Depth Damage Functions estimated for Doe House

1-story residential with basement			
Depth Above FFE (feet)	Structure DDF %	Contents DDF %	Displace-ment Days
-2.0	13.8%	10.5%	0
-1.0	19.4%	13.2%	0
0.0	25.5%	16.0%	0
1.0	32.0%	18.9%	45
2.0	38.7%	21.8%	90
3.0	45.5%	24.7%	135
4.0	52.2%	27.4%	180
5.0	58.6%	30.0%	225
6.0	64.5%	32.4%	270
7.0	69.8%	34.5%	315
8.0	74.2%	36.3%	360
9.0	77.7%	37.7%	405
10.0	80.1%	38.6%	450
11.0	81.1%	39.1%	495
12.0	81.1%	39.1%	540
13.0	81.1%	39.1%	585
14.0	81.1%	39.1%	630



Note

The average flood depth in Table A-7 represents a range of plus or minus 0.5 feet; so a flood depth of 0.8 feet corresponds to a depth of 1.0 feet, while flood depths of 2.1 feet, 3.6 feet and 5.6 feet correspond to flood depths of 2.0, 4.0 and 6.0 feet, respectively.

Finally, Mr. and Mrs. Doe used Benefit Cost Analysis Determination Worksheet and associated Benefit Cost Analysis and project guidance to assess the cost-effectiveness of the three flood retrofit options of elevation and relocation as shown in Chapter 7, CSA-18, and CSA-19.

Appendix B. Case Study B Supplemental Material

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B.1 Case Study B Background

This appendix provides supplemental material for Case Study B through extra guidance and detailed calculations. This offers additional procedures to implement the construction of a floodwall or dry floodproofing. This appendix also shows calculations used to fill out the Computation Worksheets. Some of the calculations for dry floodproofing in Appendix B include the development dead load weights, live loads and roof loads, snow loads, wind loads, and earthquake loads.

B.2 Case Study B Supplemental Information

Floodwall

To protect the entire structure, a floodwall should be built around all four sides of the apartment building (Figure B-1). Refer to Chapter 1, Figure 1-16 for the advantages and disadvantages of floodwalls. This would involve:

- Selecting the site and extent of the floodwall, including distance from the structure
- Excavating for footings
- Installing reinforcing steel and pouring concrete
- Designing and installing a drainage system
- Designing and installing access points:
  - One set of stairs for pedestrian access
  - One pedestrian gate
  - Temporary barrier for vehicle access
- Backfilling

A simplified design process similar to that outlined in Chapter 5 for Soil Type SM-SP will achieve an above grade floodwall height of 5 feet, as shown in Figure B-2.

Special Note

One way to install an aesthetically pleasing floodwall is to build a brick facing facade. Figure 6-45 in Chapter 6 shows a detail of a brick-faced concrete floodwall. Refer to Chapter 6 for details on closures.

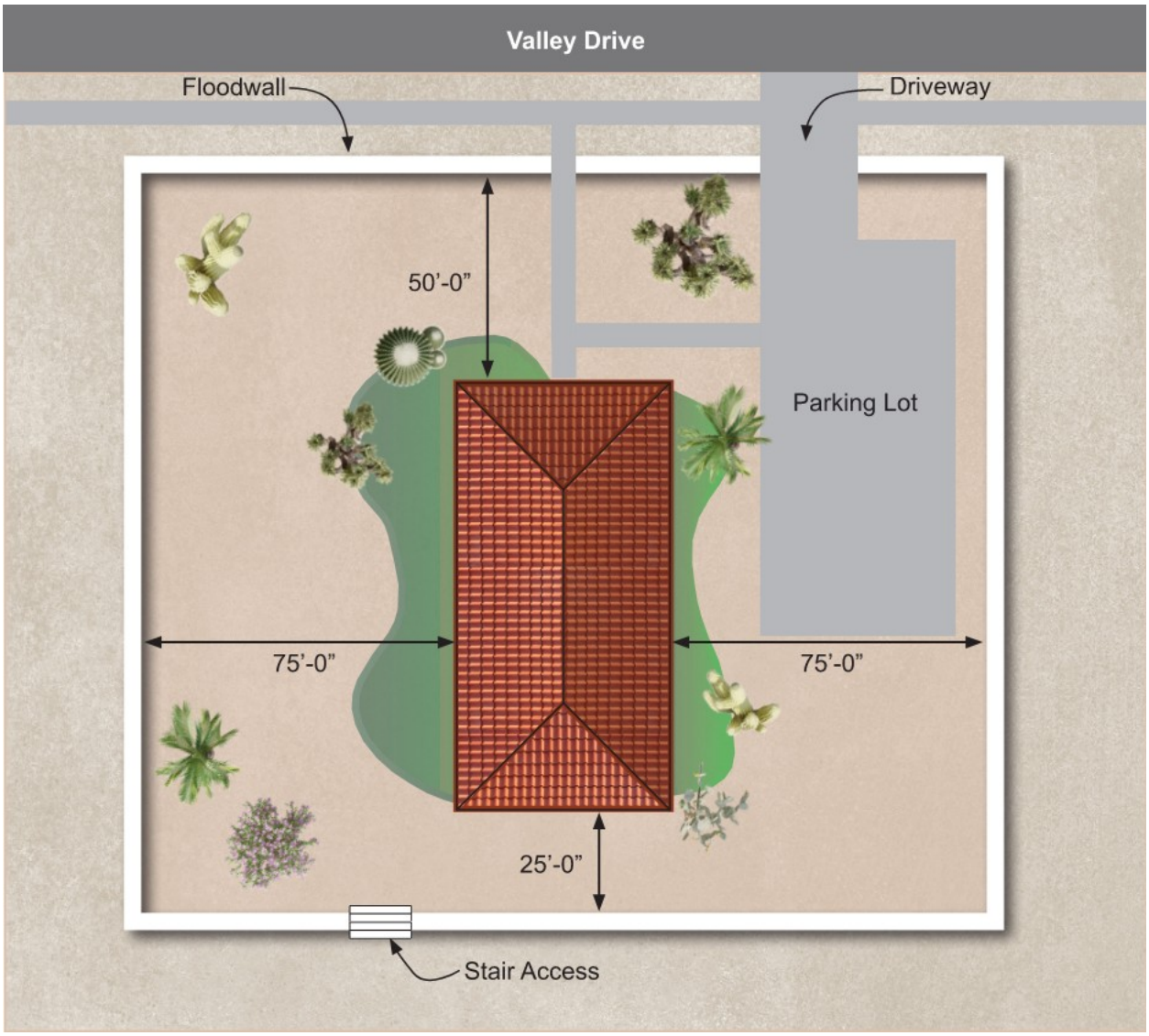


Figure B-1. Site plan for The Valley Apartments floodwall

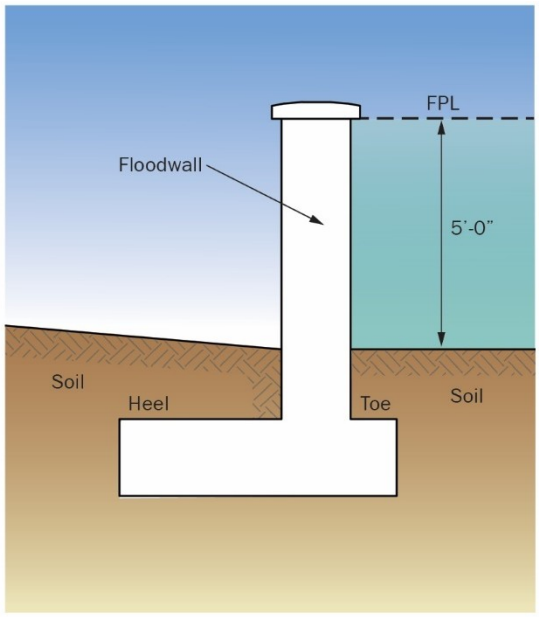


Figure B-2. Floodwall cross-section for The Valley Apartments

Dry Floodproofing

The purpose of dry floodproofing is to keep the water out of the flood protected area. Refer to Figure 1-11 in Chapter 1 for the advantages and disadvantages of dry floodproofing. For The Valley Apartments, this would involve:

- Constructing additional concrete floor topping, or cutoff foundation walls, or soil anchors to resist buoyancy.
- Investigating and confirming that the existing exterior reinforced masonry walls can resist the hydrostatic pressures.
- Applying a waterproof sealant to the exterior of the concrete masonry unit walls.
- Sealing all exterior wall penetrations and conduits.
- Installing metal flood shields over the two exterior doors.
- Providing a backflow valve for the sanitary sewer line.
- Installing a sump pump in the interior to remove any potential water seepage.

An elevation view of the front of the building using dry floodproofing is shown in Figure B-3.

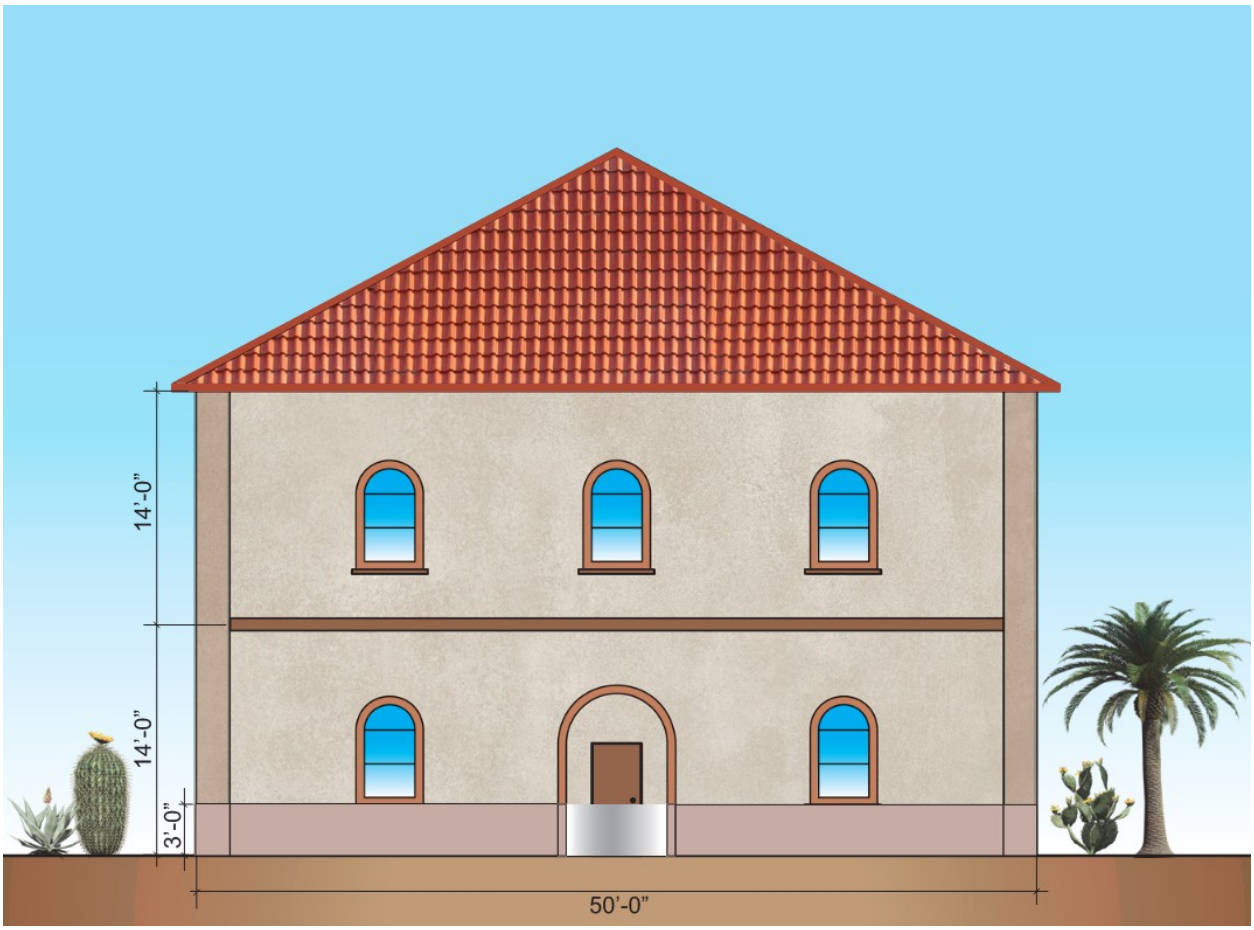


Figure B-3. Dry Floodproofing to Three Feet Above Grade for The Valley Apartments

B.3 The Valley Apartments Detailed Calculations

Dry Floodproofing

Dead Loads

Dead load calculations are summarized in Tables B-1 and B-2 on the next page. The total dead load was calculated to be 1,522,631 lbs.

Table B-1. Dead Loads Part 1 of 2 (Using Pounds/Square Feet)

Element	Area (ft^2)	Unit Weight (lb/ft^2)	Total Weight (lbs)
First floor: 4" concrete floor slab with floor tile	(50 ft)(100 ft) = 5,000	56	280,000
Exterior walls: 8" concrete masonry unit fully grouted for the bottom 4 feet and partially grouted elsewhere, furring strips with gypsum	(2)(50 ft + 100 ft)((14 ft)(2)+(1 ft)) - (5 ft)(4 ft)(30) - (2)(7 ft)(3 ft) = 8,058	58	467,364
Interior bearing walls: 8" concrete masonry unit partially grouted with furring strips and gypsum each face	(4)(14 ft)(45 ft)(2) = 5,040	58	292,320
Second floor frame: 2x12 joists at 16" o.c. with subflooring	(50 ft)(100 ft) = 5,000	10	50,000
Second floor cover: hardwood	(50 ft)(100 ft) = 5,000	4	20,000
Interior partition walls: 2x4 stud walls with gypsum	(410 ft)(14 ft) = 5,740	8	45,920
Roof: trusses, sheathing, underlayment	(1.12)(54 ft)(104 ft) = 6,290	12	75,479
Roof cover: clay tiles	(1.12)(54 ft)(104 ft) = 6,290	20	125,798
TOTAL	**Over the 5,000 ft^2 footprint**	**271**	**1,356,881**

Table B-2. Dead Loads Part 2 of 2 (Using Pounds/Cubic Feet)

Element	Volume (ft^3)	Unit Weight (lb/ft^3)	Total Weight (lbs)
Footings for exterior walls	(2.5ft)(1ft)(50ft+100ft)(2) - (2.5ft)(2.5ft)(1ft)(4) = 725	150	108,750
Footings for interior walls	(2ft)(1ft)(50ft-2.5ft)(4) = 380	150	57,000
TOTAL			**165,750**

Total Dead Load = (1,356,881 + 165,750) = 1,522,631 lbs

Live Loads

Live load calculations are summarized in Table B-3. The total live load was calculated to be 200,000 lbs, with the total roof live load calculated to be 125,800 lbs. The roof live load was determined based on the area of the roof including overhangs multiplied by 1.12 to account for the roof pitch.

Table B-3. Live Loads

Element	Live Load (lb/ft^2)	Calculation	Total Weight (lbs)
Live Load: Interior Floor Area	40	$(5{,}000 ft^2)(40 lb/ft^2)$ = 200,000 lbs	200,000
Live Load: Roof	20	$(6{,}290 ft^2)(20\ lb/ft^2)$ = 125,800 lbs	125,800

Snow Loads

The local snow load is 3 lb/ft^2, per ASCE Hazard Tool at the specified location, but the local jurisdiction allows for the snow load to be 0 lb/ft^2. The snow loads are considered negligible.

Wind Loads

Wind load calculations are summarized on the next page and in Tables B-4 and B-5.

Wind Pressure

Mean Roof Height = 2(14 ft) + 5 ft = 33 ft

Exposure Category B and z will be set to the mean roof height, h for this example.

Wind Pressure (q_z) = $0.00256 K_h K_{zt} K_e V^2$

- V = 102 mph
- K_h = 0.75
- K_{zt} = 1.0
- K_e = 1.0

$q_z = 0.00256(0.75)(1.0)(1.0)(102)^2$

q_z = 20 psf

Table B-4. Wind Loads on Horizontal Projected Surface

Element	Area (ft^2)	Wind Pressure (lb/ft^2)	Wind Load (lbs)
Exterior Wall Area	(28ft)(100ft) = 2,800	20	56,000
Vertical Roof Area	0,5(100ft+50ft)(10ft) = 750	20	15,000
TOTAL			**71,000**

During the design flood event, the wind load on the dry floodproofing is excluded, and the wind load reduces by (3ft)(100ft)(20lb/ft^2) = 6,000 lbs. These reduced values were used when determining horizontal wind forces when horizontal flood loads are being applied.

Wind Load on Vertical Project Surface

A conservative assumption for The Valley Apartments of a combined net pressure coefficient of -0.7 will be used for uplift on the entire vertical projected surface of the roof. Uplift at the roof overhangs using an external pressure coefficient of -0.7 will also be added to the uplift on the vertical projected surface of the roof. The simplified methods shown below are used to illustrate representative uplift pressures on the roof and avoid detailed calculations that are better illustrated in a primarily wind retrofit publication. See ASCE 7 for more accurate and detailed formulas.

Wind Uplift Pressure at Roof (p_r) = $GC_{pn}\, q_z$

- p_r = -0.7(20)
- p_r = -14 psf

Wind Uplift Pressure at Roof Overhang (po) = GCp qz

- p_o = -0.7(20)
- p_o = -14 psf

Table B-5. Wind Loads on Vertical Projected Surface and Roof Overhang

Element	Area (ft^2)	Wind Pressure (lb/ft^2)	Wind Load (lbs)
Roof	(54ft)(104ft) = 5,616	-14	-78,624
Roof Overhang	(104ft)(54ft)-(100ft)(50ft) = 616	-14	-8,624
TOTAL			**-87,248**

Seismic Loads

The seismic loads are assumed to be negligible for this location, which is in Seismic Design Category B.

B.4 Bearing Capacity Assessment

The silty clay at the site can support an ultimate bearing capacity of 3,000 psf. The calculation below shows the bearing area determined from the existing 2.5 feet wide perimeter wall footings and the 2 2 feet wide interior wall footings.

$A_{bearing}$ (Bearing Area of Footings) = (2.5ft)(50ft+100ft)(2) – (2.5ft)(2.5ft)(4) + (2ft)(50ft-2.5ft)(4) = 1,105 ft^2

Maximum Vertical Load = 2,228,438 lbs

Actual Bearing = Maximum Vertical Load/$A_{bearing}$ = 2,228,438 lbs / 1,105 ft^2 = 2,016 psf

Ultimate Bearing Capacity = 3,000 psf

Since the Ultimate Bearing Capacity is greater than the Actual Bearing on the soil, the elevated foundation load on the existing footings is considered acceptable.

B.5 Cost-Effectiveness

This first step in assessing cost-effectiveness was to estimate the cost of wet floodproofing, dry floodproofing, and floodwall construction for The Valley Apartments . The results of the assessment are summarized below, based on the following information summarized in Table B-6:

Table B-6. Summary of Retrofit Costs for The Valley Apartments

Retrofit Option	Unit Cost ($/SF of building footprint)	Base Cost ($)	Annual O&M Costs (% Base Cost)	Present Value of O&M Costs ($)	Total Project Cost ($)
Wet Floodproofing	$45/SF up to 4 ft; $5,000 per additional ft	$225,000	2.5%	$51,232 (T = 15 yrs; R = 7.0%)	$276,232
Dry Floodproofing	$50/SF for 3 ft height	$250,000	5.0%	$113,849 (T = 15 yrs; R = 7.0%)	$363,849

Retrofit Option	Unit Cost ($/SF of building footprint)	Base Cost ($)	Annual O&M Costs (% Base Cost)	Present Value of O&M Costs ($)	Total Project Cost ($)
Floodwall	$60/SF for 5 ft height above grade	$300,000	2.5%	$103,506 (T = 50 yrs; R = 7.0%)	$403,506

Next, the event recurrence intervals need to be approximated for the four flood events based on the year the structure was built (1985) and the magnitude of each damage event, as shown in Table B-7. Once the flood event recurrence intervals were estimated, the annualized damages could be determined by dividing the event damage by the event recurrence interval.

Table B-7. Flood event recurrence intervals approximated for The Valley Apartments

Event Magnitude ($)	Age of Structure (years)	Event Ranking (Highest to Lowest)	Approximate Event Recurrence Interval = (Structure Age /Event Ranking)	Annualized Event Damage ($/year)
$46,000	[(2025)-(1985)] = 40 years	4	(40/4) = 10 years	$4,600
$83,000		3	(40/3) = 13 years	$6,225
$235,000		2	(40/2) = 20 years	$11,750
$370,000		1	(40/1) = 40 years	$9,250

Finally, the Benefit Cost Analysis Determination Worksheet and associated Benefit Cost Analysis and project guidance were used to assess the cost-effectiveness of the three flood retrofit options of wet floodproofing, dry floodproofing, and floodwalls as shown in Chapter 7.

Appendix C. Case Study C (Island Construction)

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C.1 Case Study C Background

This case study examines a single-story residential island home owned by the Perez family located in the town of Barceloneta, Puerto Rico. The home is presently located in a Special Flood Hazard Area, but due to a recent flood event, flood insurance studies are being completed and it is anticipated that Flood Insurance Rate Maps in the municipality will be revised. Accordingly, it is expected that the Special Flood Hazard Area boundaries will increase. Flood velocities during the base flood are presently estimated to be two feet per second.



Note

The purpose of Case Study C is to provide residential retrofit options for typical island construction found in U.S. territories such as Puerto Rico, Guam, Commonwealth of the Northern Mariana Islands, and the U.S. Virgin Islands. Since residences on these islands are frequently subject to flooding, high winds, and other hazards, they are often constructed with reinforced concrete or reinforced masonry walls and, in many cases, a concrete flat roof; which can make these homes difficult to structurally elevate or relocate.

C.2 Description of Property and Historical Damage

The effective Flood Insurance Rate Map (panel 72000C0270J effective November 18, 2009) places the Perez home in a Zone AE with a Base Flood Elevation of 10.0 meters (32.8 feet) (Figure C-2). According to the flood profile (Figure C-3), flood elevations for the 10% annual chance exceedance (10-year) flood, the 2% annual chance exceedance (50-year) flood, the 1% annual chance exceedance (100-year) flood, and the 0.2%annual chance exceedance (500-year) flood are 27.9 feet (8.5 meters), 31.2 feet (9.5 meters), 32.8 feet (10.0 meters), and 36.7 feet (11.2 meters) respectively.

The home is a one-story, 1,100 square foot (102 square meters) four-bedroom, two-bath single-family home with an attached single-car carport and utility room (Figure C-1). The walls are constructed with 6-inch concrete masonry units. Floors are finished with mortar-set ceramic tiles in the kitchen, baths, and laundry room, and with terrazzo in the living room, hallway, and bedrooms. There is a concrete stoop at the front door with a single step.

The home was constructed in the mid-1960s, and the Perez family purchased it in 1998. Since that time, the home has flooded six times. In four of the six floods, flooding was limited to the carport and did not reach the living space. Two of the floods were more extreme, and floodwaters entered the living space. Water from the most extreme flood event reached two feet (0.6 meters) deep in the house and nearly three feet (0.8 meters) deep in the carport. The worst flood caused extensive damage to the interior space and displaced the homeowners and their family for six weeks while repairs were made.



Figure C-1. The Perez house front elevation and floor plan

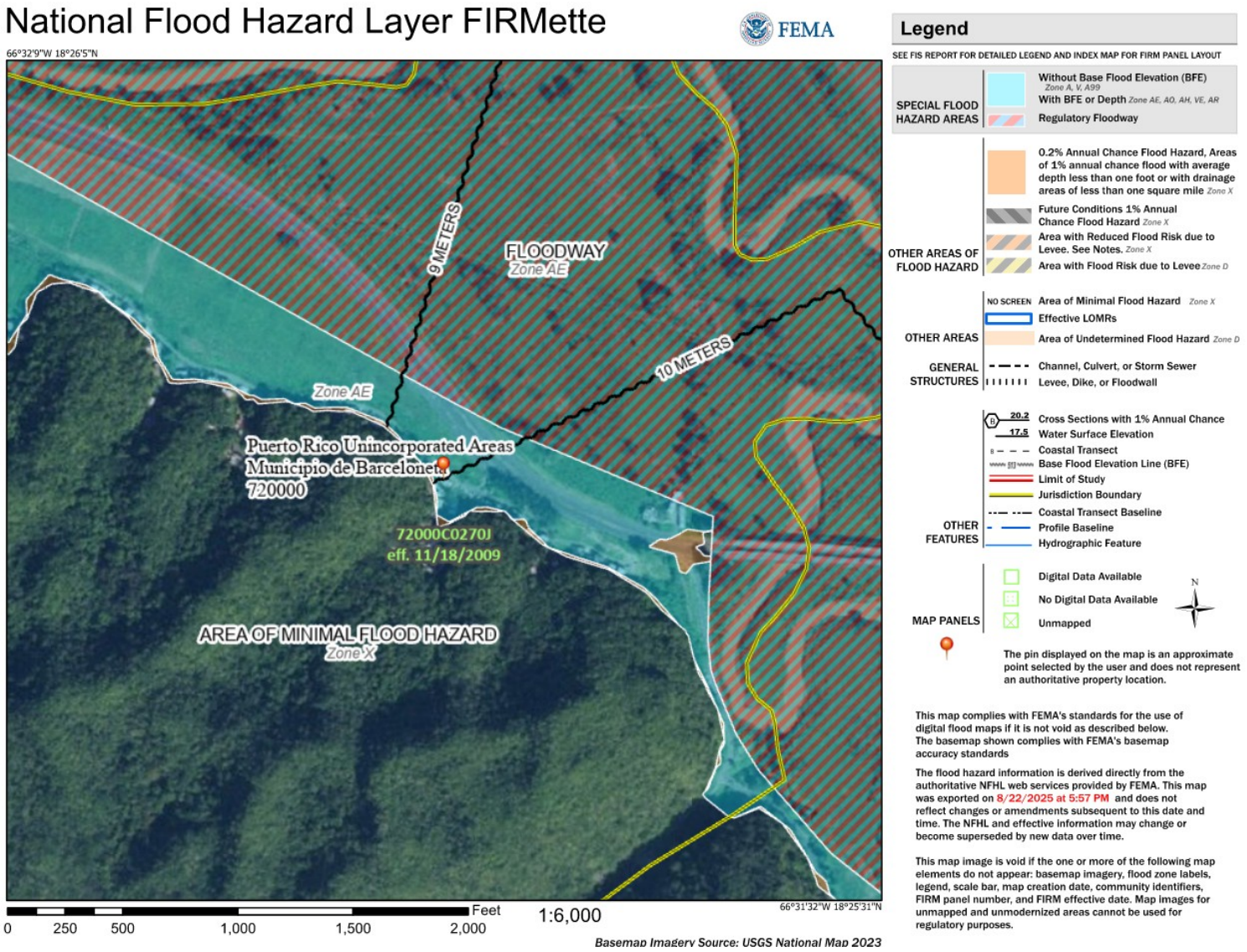


Figure C-2. FIRMette showing the location of the Perez home using the red pin taken from the FEMA-National Flood Hazard Layer viewer (https://hazards-fema.maps.arcgis.com/)

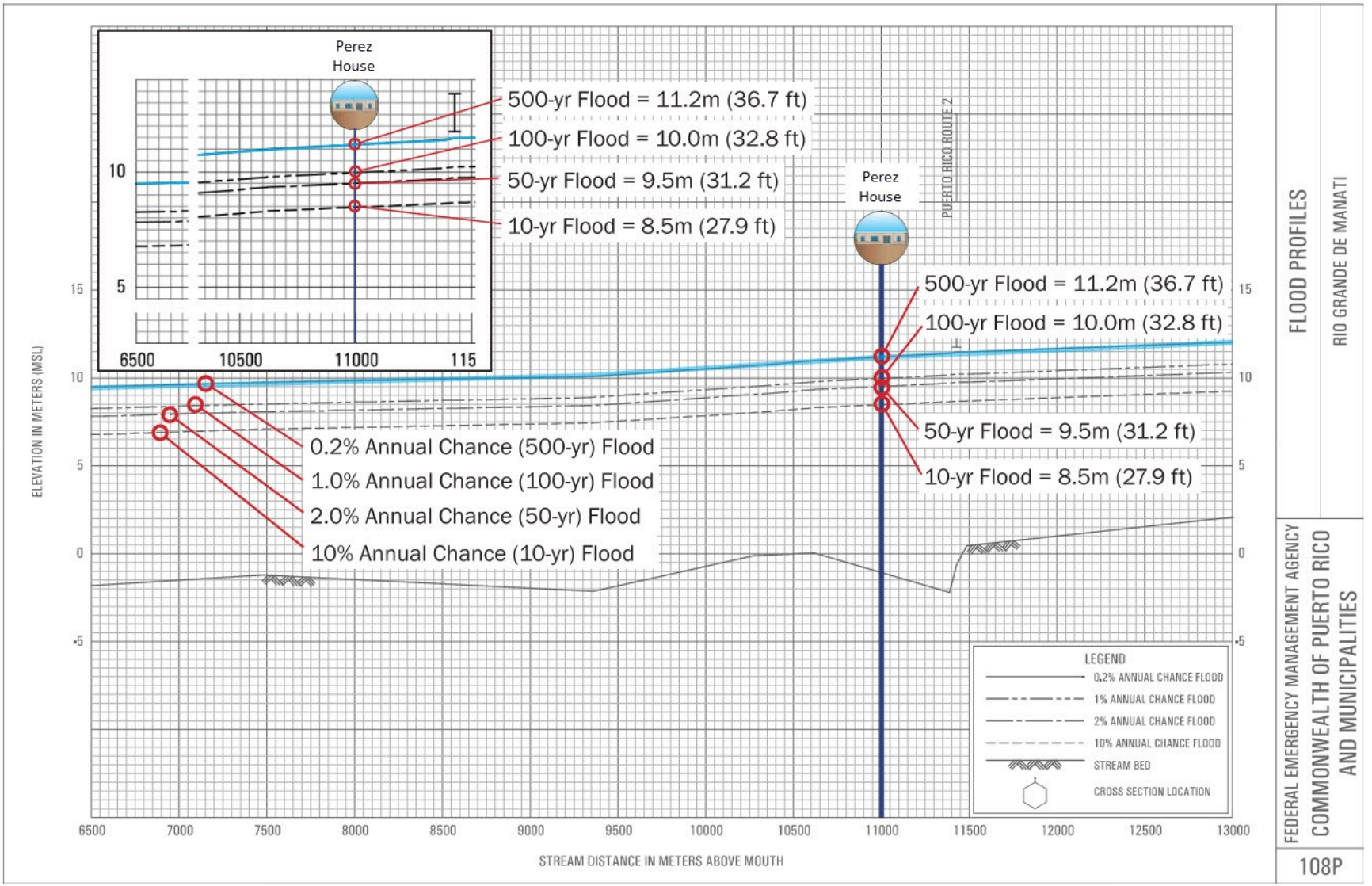


Figure C-3. Flood elevations at the Perez house on the flood profile for the Rio Grande De Manati

C.3 Building Information

The Perez home has a flat concrete roof, where both exterior walls and interior partitions are constructed out of 6-inch Concrete Masonry Unit. The exterior walls are grouted and reinforced; the interior partition walls are neither grouted nor reinforced. The home's floor is a concrete slab-on-grade, which is thickened and reinforced under both the exterior walls and interior partitions. The widths, depths, and reinforcement of the thickened portions are the same for the exterior walls and the interior partitions. The carport and utility room slabs are structurally separate and 8 inches (20.3 centimeters) below the home's floor slab. The finished floor elevation is 31.5 feet (9.6 meters); the elevation of the carport and utility room is 30.8 feet (9.4 meters).

The home is supplied by a 120/240-volt underground electrical service. Service originates at a pole-mounted transformer supplied from an overhead single-phase 7,200-volt primary. The center of the utility meter is 5 feet 6 inches (1.7 meters) above finished grade.

Window air conditioning units provide cooling to the home. A 50-gallon (189-liter) electric water heater provides domestic hot water. The water heater is in the utility room, and it is not elevated. The lowest heater element is 12 inches (30 centimeters) above the floor slab.

The home is served by municipal water and sewer, and the sewer lines are drained by gravity. In the most extreme flood events, the water depths reached 24 inches (61 centimeters), and sewer lines became surcharged. As a result, the sewage level in the municipal system exceeded the elevation of the flood rims of the two toilets in the home, and sewage backflowed into the house.

C.4 Retrofit Options Selection

Although the Perez home has not been substantially damaged due to individual or aggregated past flood events, the floods have been disruptive and have displaced household members for extended periods of time. To reduce damage and disruptions, particularly for less extreme events, the homeowners want to reduce flood risk. The homeowners are retired and living on a fixed income, so flood mitigation will need to be completed in phases as their budget allows.

The Perez family reviewed their initial preferences for retrofitting using the Preliminary Homeowner Retrofitting Preferences Matrix (Figure C-4). The family considers most of the elevation options to be far too expensive and disruptive for their current lifestyle, so most of these were eliminated. They also eliminated floodwalls and berms. They appreciate the friendly connections they maintain with neighbors, and they do not want to disrupt that with a floodwall or berm. The family documented their concerns for the remaining options: abandon/repurpose the lowest floor, dry or wet floodproof. In particular, they were unsure of the aesthetics, cost, and accessibility if they constructed a second-floor addition above the existing home. It would be important to them to get architectural input because as they age, stairs may become a bigger issue. They recognize this option would come with a lot of costs. The Perez family understands both floodproofing options will not improve their flood

insurance rates. They would prefer to wet floodproof their home as cost is a major factor. In the process, they would like to reduce the risk to mechanical, electrical, and plumbing equipment.

Input from friends with construction and engineering expertise has helped them to complete worksheets for the flood, site, and building characteristics. These worksheets have confirmed the viability of each of the three retrofitting measures, as shown in Figures C-5 through Figure C-7. After working through the screening matrices, the most suitable options were confirmed to be abandoning/repurposing the lowest floor, dry floodproofing, and wet floodproofing.

Preliminary Homeowner Retrofitting Preference Matrix											
Owner Name:	Juan and Sofia Perez							Preparer:		DKL/MH/JS	
Address:	456 Palmetto Lane, Barceloneta, Puerto Rico							Date:		7/6/2026	
Property Details:	Case Study C										
Considerations	Retrofitting Measures										
	Structural Elevation			Elevation Alternatives			Relocation	Floodproofing		Flood Barriers	
	Stem Wall (Fill)	Perimeter Wall/ Piers	Piles	Basement Infill	Abandon/ Repurpose Lowest Floor	Elevate Lowest Interior Floor		Dry	Wet	Floodwall	Berm
PART A: Local Regulations											
Measure Not Feasible (NF) or Not Allowed	X	X	X	X		X	X			X	X
PART B: Homeowner Concerns											
Aesthetics					X						
High Cost					X			X			
Risk - Flood Insurance Rates								X	X		
Accessibility					X						
Increase Flooding on Neighboring Sites											
Other:											
Total X's *(Lowest is Preferred)*	NF	NF	NF	NF	3	NF	NF	2	1	NF	NF
Purpose:	The purpose of the Preliminary Homeowner Retrofitting Preference Matrix is to determine whether or not the retrofitting measure is allowed under local regulations or homeowner requirements.										
Instructions:	Step 1: Complete Part A of the matrix by placing an "X" in the box for each measure which is not feasible or is not allowed based on the configuration of the existing structure and/or property. For these measures, skip Steps 2 through 5 and put an "NF" for Not Feasible under the Total X's at the end of Part B. Step 2: Complete Part B of the matrix for only those measures that are allowable (no "X" in Part A). Step 3: For those measures allowed under Part A, evaluate the considerations in Part B to determine if the homeowner has concerns that would affect its implementation. A concern is defined as a homeowner issue that, if unresolved, could make the retrofitting measure infeasible. Step 4: If the homeowner has a concern, place an "X" in the box under the appropriate measure/consideration. Step 5: Add up the total number of X's for each allowable measure, and input the result under the Total X's at the end of Part										
Evaluation of Results:	The retrofitting measure(s) with the least number of X's (and no NF's) is the most preferred.										

Figure C-4. Preliminary Retrofitting Preference Matrix for the Perez house

Retrofitting Screening Matrix - Part A: Flood Characteristics											
Owner Name:	Juan and Sofia Perez							Preparer		DKL/MH/JS	
Address:	456 Palmetto Lane, Barceloneta, Puerto Rico							Date:		7/6/2026	
Property Details:	Case Study C										
Flood Characteristic	Retrofitting Measures										
	Structural Elevation			Elevation Alternatives			Relocation	Floodproofing		Flood Barriers	
	Stem Wall (Fill)	Perimeter Wall/ Piers	Piles	Basement Infill	Abandon/ Repurpose Lowest Floor	Elevate Lowest Interior Floor		Dry	Wet	Floodwall	Berm
Pre-Screening from Preliminary Homeowner Preference Matrix											
Measure Not Feasible (NF)	NF	NF	NF	NF		NF	NF			NF	NF
Flood Depth											
Shallow (≤ 3 ft)					Y			Y	Y		
~~Moderate (>3 to 6 ft)~~								~~NR~~			
~~Deep (> 6 ft)~~								~~NR~~	~~NR~~	~~NR~~	~~NR~~
Flood Velocity											
Slow/Moderate (≤ 5 ft/sec)					Y			Y	Y		
~~Fast (> 5 ft/sec)~~	~~ER~~	~~ER~~						~~NR~~		~~ER~~	~~ER~~
Flash Flood Risk											
~~High~~	~~ER~~	~~ER~~						~~NR~~	~~NR~~	~~NR~~	~~NR~~
Low to Moderate					Y			Y	Y		
Debris/Ice Jam Flood Risk											
~~High~~	~~DI~~	~~DI~~						~~NR~~		~~DI~~	~~DI~~
Low to Moderate					Y			Y	Y		
Scoring											
Subtotal Y's					4			4	4		
Subtotal NR's					0			0	0		
Subtotal ER's, DI's					0			0	0		
PART A Score = [Ys - (NRs) - 0.5 (ERs + DIs)]	NF	NF	NF	NF	4	NF	NF	4	4	NF	NF
Purpose:	The purpose of the Retrofitting Screening Matrix Part A is to provide an initial technical assessment of existing flood characteristics for retrofit project to determine what retrofit measures are the most feasible.										
Matrix Notes:	NF Not Feasible: indicates the retrofit measure was pre-screened to be not allowed or not feasible based on the configuration of the existing structure and/or property. Refer to the Preliminary Homeowner Preference Matrix for details. NR Not Recommended: indicates the retrofit measure is not recommended for this flood condition. ER Erosion Risk: indicates that fast flow velocity/flash flooding is conducive to erosion and the retrofit measure may need to be modified to address this hazard. DI Debris Impact: indicates that debris flow or ice jam flooding is conducive to flood-borne debris impact and the retrofit measure may need to be modified to address this hazard.										
	Page 1 of 2. See next page for Instructions and Evaluation of Results										

Figure C-5. Retrofitting Screening Matrix: Flood Characteristics for the Perez house, with applicable characteristics boxed in red for each row

Retrofitting Screening Matrix - Part B: Site Characteristics											
Owner Name:	Juan and Sofia Perez							Preparer		DKL/MH/JS	
Address:	456 Palmetto Lane, Barceloneta, Puerto Rico							Date:		7/6/2026	
Property Details:	Case Study C										
Site Characteristic	Retrofitting Measures										
	Structural Elevation			Elevation Alternatives			Relocation	Floodproofing		Flood Barriers	
	Stem Wall (Fill)	Perimeter Wall/ Piers	Piles	Basement Infill	Abandon/ Repurpose Lowest Floor	Elevate Lowest Interior Floor		Dry	Wet	Floodwall	Berm
Pre-Screening from Preliminary Homeowner Preference Matrix											
Measure Not Feasible (NF)	NF	NF	NF	NF		NF	NF			NF	NF
Site Flood Risk											
~~Low (Zone X)~~											
Moderate (Zone A)			NR		Y			Y	Y		
~~High (Floodway)~~	~~NR~~	~~ER~~						~~NR~~	~~DR~~	~~NR~~	~~NR~~
~~High (Coastal A/Zone V)~~	~~NR~~	~~NR~~						~~NR~~	~~DR~~	~~NR~~	~~NR~~
Property Location											
~~Rural (large lots, widely spaced)~~											
Suburban (medium lots, moderately spaced)					Y			Y	Y		NR
~~Urban (small lots, densely spaced)~~	~~NR~~	~~NR~~	~~NR~~				~~NR~~	~~NR~~		~~NR~~	~~NR~~
Soil Type											
~~Permeable (granular)~~								~~NR~~		~~NR~~	~~NR~~
Impermeable (cohesive)					Y			Y	Y		
Scoring											
Subtotal Y's					3			3	3		
Subtotal NR's					0			0	0		
Subtotal ER's, DR's					0			0	0		
PART B Score = [Ys - (NRs) - 0.5 (ERs + DRs)]	NF	NF	NF	NF	3	NF	NF	3	3	NF	NF
Purpose:	The purpose of the Retrofitting Screening Matrix Part B is to provide an initial technical assessment of existing site characteristics for retrofit project to determine what retrofit measures are the most feasible.										
Matrix Notes:	NF Not Feasible: indicates the retrofit measure was pre-screened to be not allowed or not feasible based on the configuration of the existing structure and/or property. Refer to the Preliminary Homeowner Preference Matrix for details. NR Not Recommended: indicates the retrofit measure is not recommended for this site condition. ER Erosion Risk: indicates that Floodways are generally conducive to erosion and the retrofit measure may need to be modified to address this hazard. DR Damage Risk: indicates that wet floodproofing measures can be damaged by high-velocity flooding from Floodways, Coastal A or V Zones. Page 1 of 2. See next page for Instructions and Evaluation of Results										

Figure C-6. Retrofitting Screening Matrix: Site Characteristics for the Perez house, with applicable characteristics boxed in red for each row

Retrofitting Screening Matrix - Part C: Building Characteristics											
Owner Name:	Juan and Sofia Perez							Preparer		DKL/MH/JS	
Address:	456 Palmetto Lane, Barceloneta, Puerto Rico							Date:		7/6/2026	
Property Details:	Case Study C										
Building Characteristic	Retrofitting Measures										
	Structural Elevation			Elevation Alternatives			Relocation	Floodproofing		Flood Barriers	
	Stem Wall (Fill)	Perimeter Wall/ Piers	Piles	Basement Infill	Abandon/ Repurpose Lowest Floor	Elevate Lowest Interior Floor		Dry	Wet	Floodwall	Berm
Pre-Screening from Preliminary Homeowner Preference Matrix											
Measure Not Feasible (NF)	NF	NF	NF	NF		NF	NF			NF	NF
Building Foundation											
Slab-on-Grade			NR		Y		NR	Y	Y		
~~Basement~~	~~NR~~		~~NR~~					~~NR~~		~~NR~~	~~NR~~
~~Crawlspace/Piers~~	~~NR~~							~~NR~~			
~~Piles~~	~~NR~~	~~NR~~						~~NR~~			
Building Construction (Framing)											
Concrete/Masonry					Y			Y	Y		
~~Wood Framing~~								~~NR~~			
Building Condition											
Excellent to Fair					Y			Y	Y		
~~Poor~~	~~NR~~	~~NR~~	~~NR~~				~~NR~~	~~NR~~			
Scoring											
Subtotal Y's					3			3	3		
Subtotal NR's					0			0	0		
PART C Score = [Ys - (NRs)]	NF	NF	NF	NF	3	NF	NF	3	3	NF	NF
PART A Score (see Part A)	NF	NF	NF	NF	2	NF	NF	2	2	NF	NF
PART B Score (see Part B)	NF	NF	NF	NF	2	NF	NF	2	2	NF	NF
FINAL SCORE = PART A Score + PART B Score +	NF	NF	NF	NF	7	NF	NF	7	7	NF	NF

Purpose: The purpose of the Retrofitting Screening Matrix Part C is to provide an initial technical assessment of existing building characteristics for retrofit project to determine what retrofit measures are the most feasible, and provide an initial combined assessment of flood, site, and building characteristics.

Matrix Notes:

NF Not Feasible: indicates the retrofit measure was pre-screened to be not allowed or not feasible based on the configuration of the existing structure and/or property. Refer to the Preliminary Homeowner Preference Matrix for details.

NR Not Recommended: indicates the retrofit measure is not recommended for this building condition.

ER Erosion Risk: indicates that fast flow velocity is conducive to erosion and the retrofit measure may need to be modified to address this hazard.

DI Debris Impact: indicates that debris flow or ice jam flooding is conducive to flood-borne debris impact and the retrofit measure may need to be modified to address this hazard.

Page 1 of 2. See next page for Instructions and Evaluation of Results

Figure C-7. Retrofitting Screening Matrix: Building Characteristics for the Perez house, with applicable characteristics boxed in red for each row

C.5 Flood Load Calculations

After discussions with the local floodplain manager and a floodproofing contractor, the Perez family intends on wet floodproofing the home to an elevation of 10.3 meters (33.8 feet), which is Base Flood Elevation + 1 foot. The finished floor of the home has an elevation of 9.6 meters (31.5 feet). This will result in wet floodproofing to 0.9 meters (36 inches) above the utility room floor and 0.7 meters (2 feet 4 inches) above the finish floor level of the home. Based on the flood elevations in the effective FIS, the wet floodproofing elevation correlates to a flood event with a 150-year return interval.

Flood Openings: Flood openings will be installed in the utility room. The 6.7 square meters (72 square feet) of floor area will require 465 square centimeters (72 square inches) of net free flood openings area.

The Perez family is presently not planning on installing flood openings in the home. They realize that not doing so may expose the home to hydrostatic flood loads, particularly from rapidly rising or rapidly falling floodwaters whose flood levels will not be adequately equalized by anticipated seepage in the building's exterior. They will consult with a local design professional to determine if the structure is adequate to resist expected hydrostatic forces. If not, flood openings will be installed. The following worksheets in Figures C-8, C-9, and C-10 demonstrate the flood loads that would be applied to the home if flood openings are not installed.



Note

As stated in Section 6.1, wet floodproofing, in part, involves installing flood openings that allow floodwater to enter and exit a building. When National Flood Insurance Program compliance is required, the flood openings must be associated with areas used for storage, parking, or access and the flood openings must automatically open without human intervention in order for them to work as intended. Allowing floodwater to enter and exit a building equalizes flood levels and minimizes hydrostatic loads that can cause structural damage. For National Flood Insurance Program compliance, one square inch of net free opening area is required for each one square foot (70 square centimeters per square meter) of enclosed area below the Base Flood Elevation. Also, the bottom of all flood openings must be no more than 12 inches (0.3 meters) above the adjacent grade. The minimum opening size is to allow sufficient floodwater flow to equalize flood levels. The maximum height above exterior grade is to limit the difference in flood levels to 1 foot (0.3 meters) or less.

Hydrostatic Force Computation Worksheet			
Owner Name:	**Juan and Sofia Perez**	**Preparer**	**DKL/MH/JS**
Address:	**456 Palmetto Lane, Barceloneta, Puerto Rico**	**Date:**	**7/6/2026**
Property Details:	**Case Study C**		

Constants

γ_w = unit weight of water = **62.4** lbs/ft^3

(62.4 lbs/ft^3 for fresh water and 64.0 lbs/ft^3 for saltwater)

Variables

H = flood design depth (ft) = **3.00** ft

z = flood design depth extended below grade (ft) = **0.0** ft

D = depth of saturated soil (ft) = **0.0** ft

Soil Type = USDA Unified Soil Classification = **ML-CL**

S = equivalent fluid weight of saturated soil (lbs/ft^3) = **106.0** lbs/ft^3

(see Table 3-1 for S as a function of Soil Type)

Vol = volume of floodwater displaced by a submerged object (ft^3) = **3,120** ft^3

Summary of Loads

f_{sta} = **280.8** lbs/LF

f_{stae} = **0.0** lbs/LF

f_{dif} = **0.0** lbs/LF

f_{comb} = **281** lbs/LF

F_{buoy} = **194,688** lbs

Hydrostatic Force Above Grade (see Equation 3-3)

$f_{sta} = 1/2\ P_h H = 1/2\ \gamma_w\ H^2 =$ **280.8** lbs/LF

Hydrostatic Force Extended Below Grade (see Equation 3-4)

$f_{stae} = 1/2\ \gamma_w\ z^2 =$ **0.0** lbs/LF

Submerged Soil and Water Force (see Equation 3-5)

$f_{dif} = 1/2\ (S - \gamma_w)\ D^2 =$ **0.0** lbs/LF

Buoyancy Force (see Equation 3-6)

$F_{buoy} = \gamma_w\ (Vol) =$ **194,688** lbs

Note: Equations 3-3, 3-4 and 3-5 do not account for equivalent hydrostatic loads due to the low velocity of floodwaters (less than 10 ft/sec). If velocity floodwater exists, use hydrodynamic force Equations 3-7, 3-8, 3-9 and 3-10.

Figure C-8. Hydrostatic Force Computation Worksheet for the Perez house without flood openings

Hydrodynamic Force Computation Worksheet			
Owner Name:	**Juan and Sofia Perez**	**Preparer**	**DKL/MH/JS**
Address:	**456 Palmetto Lane, Barceloneta, Puerto Rico**	**Date:**	**7/6/2026**
Property Details:	**Case Study C**		

Constants

γ_w = unit weight of water = **62.4** lbs/ft^3

(62.4 lbs/ft^3 for fresh water and 64.0 lbs/ft^3 for saltwater)

g = acceleration of gravity = 32.2 ft/sec^2

ρ = mass density of water = **1.94** slugs/ft^3

(1.94 slugs/ft^3 for fresh water and 1.99 slugs/ft^3 for saltwater)

Variables

H = flood design depth (ft) = **3.00** ft

V = velocity of floodwater (ft/sec) = **2.0** ft/sec

(use Equations 3-7 and 3-8 if V ≤ 10 ft/sec; use Equations 3-9 ad 3-10 if V > 10 ft/sec)

b = width of structure perpendicular to flow (ft) = **40.0** ft

b/H = ratio of width to height = **13.3**

C_d = drag coefficient = **1.30**

(taken from Table 3-3 as a function of b/H)

A = submerged area on upstream face of structure (ft^2) = (b)(H **120.0** ft^2

Summary of Loads

f_{dh} = **15.0** lbs/LF

f_{sta} = **280.8** lbs/LF

f_{stae} = **0.0** lbs/LF

f_{dif} = **0.0** lbs/LF

f_{comb} = **281** lbs/LF

P_d = **N/A** lbs/ft^2

F_d = **N/A** lbs

Conversion of Low Velocity Flood Flow to Equivalent Head (see Equation 3-7)

$dh = C_d V^2/2g =$ **0.08** ft

Conversion of Equivalent Head to Equivalent Hydrostatic Force (see Equation 3-8)

$f_{dh} = \gamma_w (dh)H = P_{dh} H =$ **15.0** lbs/LF

High Velocity Dynamic Pressure (see Equation 3-9)

$P_d = C_d \rho V^2/2 =$ **N/A** (flow velocity is less than 10 ft/sec)

Total Hydrodynamic Force (see Equation 3-10)

$F_d = P_d A =$ **N/A** (flow velocity is less than 10 ft/sec)

Figure C-9. Hydrodynamic Force Computation Worksheet for the Perez house without flood openings

Impact Force Computation Worksheet			
Owner Name:	**Juan and Sofia Perez**	**Preparer**	**DKL/MH/JS**
Address:	**456 Palmetto Lane, Barceloneta, Puerto Rico**	**Date:**	**7/6/2026**
Property Details:	**Case Study C**		

Variables

W = weight of the object (lbs) = **1,000** lbs
(see Note 1 for recommended values and guidance)

V = velocity of floodwater (ft/sec) = **2.0** ft/sec

C_D = depth coefficient = **0.50**
(taken from Table 3-4 as a function of hazard zone and water depth)

C_B = blockage coefficient = **1.0**
(taken from Table 3-5 as a function of flow path and upstream screening)

C_{Str} = building structure coefficient = **0.8**
= 0.2 for timber pile and masonry column-supported structures 3 stories or less in height above grade
= 0.4 for concrete pile or concrete or steel moment-resisting frames 3 stories or less in height above grade
= 0.8 for reinforced concrete (including insulated concrete forms) and reinforced masonry foundation walls

Normal Impact Loads (see Equation 3-11)

$F_i = W\,V\,C_D\,C_B\,C_{Str}$ = **800** lbs

Notes:

1. Regarding W: ASCE 7-22 Commentary recommends W = 1,000 lbs as a reasonable average weight of the object for normal impact force. Additional guidance from the ASCE 7-22 Commentary is provided below:
   a. Use W = 1,000 to 2,000 lbs for riverine and coastal floodplains with large woody debris.
   b. Use W < 1,000 lbs for arid and semi-arid regions.
   c. Use W = 1,000 to 4,000 lbs for riverine floodplains subject to floating ice.
   d. Use W = 4,000 lbs for the Pacific Northwest to represent larger trees and logs.
   e. Use W < 500 lbs for coastal areas without large pilings.

   Relocation is recommended where more extreme impact forces are a threat.

2. Regarding C_D from Table 3-4: Per ASCE 24-14, a "floodway" is a "channel and that portion of the floodplain reserved to convey the base flood without cumulatively increasing the water surface elevation more than a designated height."

Figure C-10. Impact Force Computation Worksheet for the Perez house

Flood Force Summary

Based on a review of Figures C-8, C-9, and C-10, the hydrostatic, hydrodynamic, and impact loads are summarized below.

Lateral Hydrostatic Load = 280.8 lbs/linear ft.

Buoyancy (Vertical Hydrostatic Load) = 194,688 lbs

Hydrodynamic Load = Equivalent Hydrostatic Force = 15.0 lbs/linear ft.

Impact Load = 800 lbs

C.6 Non-Flood Hazard Assessment

The Perez family is aware that flood risk is not the only natural hazard threat. Puerto Rico has a history of severe hurricanes and earthquakes. The Perez house could be exposed to high winds of 152 mph with wind-borne debris. The family currently installs plywood panels as protection for door and window openings when hurricane landfall is forecasted. The seismic risk for the home is high as well. The site has a seismic design category of D. If the family decides to abandon the first floor and construct a new, code compliant second floor for living space, they will hire an engineer to assess the existing structure's ability to handle the latest wind and seismic loads. The Wildfire Risk to Communities website does not cover Puerto Rico, so the wildfire hazard risk is listed as unknown. However, given the climate of Puerto Rico, the risk of wildfire appears to be relatively low in comparison to the risk of high wind or earthquake.

Non-Flood Hazard Worksheet - Hazard Risk Assessment

Owner Name:	**Juan and Sofia Perez**	**Preparer**	**DKL/MH/JS**
Address:	**456 Palmetto Lane, Barceloneta, Puerto Rico**	**Date:**	**7/6/2026**
Property Details:	**Case Study C**		

Non-Flood Hazard Risk Assessment Variables

Wind Hazard Risk:

Estimate V_{wind} using the ASCE Hazard Tool website (https://ascehazardtool.org) by inputting the property location, selecting the applicable version of ASCE 7 for the location, checking Risk Category II (Residential), and checking the Design Wind Speed; which assumes a Mean Recurrence Interval (MRI) = 700 years.

V_{wind} = Design Wind Speed (mph)	**152** mph	
Site Located in Wind-Borne Debris Region? (Yes/No)	**Yes**	(Check by clicking Wind Details on ASCE Hazard Tool)
Tornado Design Wind Speed (mph)	**N/A** mph	

Seismic (Earthquake) Hazard Risk:

Estimate S_{DS} using the ASCE Hazard Tool website (https://ascehazardtool.org) by inputting the property location, selecting the applicable version of ASCE 7 for the location, checking Risk Category II (Residential) and assuming Default Site Class (Site Class D unless better geotechnical data is available), then click Details. Note this is tied to a design earthquake event with a 2% chance of occurrence in the next 50 years; which equates to a Mean Recurrence Interval (MRI) of 2,475 years.

S_{DS} = Seismic Design Value at 0.2s Spectral Acceleration (%g)	**1.2** g
Seismic Design Category:	**D**

Wildfire Hazard Risk:

Estimate Wildfire Hazard Risk using the USDA-USFS Wildfire Risk to Communities website (https://wildfirerisk.org/explore) by searching community location.

Overall Wildfire Risk	**Unknown**	Indicates the overall risk of wildfire in comparison to other communities throughout the US.
Risk to Homes:	**Unknown**	Indicates the risk of wildfire damage to homes in comparison to other US communities.
Wildfire Likelihood	**Unknown**	Indicates the likelihood of a wildfire in comparison to other US communities.

Assessment of Non-Flood Hazard Risks

Conduct a qualitative assessment of non-flood hazard risks relative to one another based on the Non-Flood Hazard Risk Assessment Variables collected for Wind, Seismic and Wildfire

Wind Hazard Risk	**High**	(Low/Medium/High based on Design Wind Speed and potential for Wind-Borne Debris/Tornado)
Seismic Hazard Risk	**High**	(Low/Medium/High based on Seismic Design Value at 0.2s Spectral Acceleration)
Wildfire Hazard Risk	**Unknown**	(Low/Medium/High based on Overall Wildfire Risk)

Purpose:	The purpose of the Non-Flood Hazard Matrix - Part A: Hazard Risk Assessment is to determine the relative risk of flood hazards in comparison to non-flood hazards (wind, earthquake and wildfire) to help prioritize building retrofits.

Figure C-11. Non-Flood Hazard Worksheet for the Perez house

C.7 Geotechnical Considerations

The site has silty clay loam (ML-CL) with moderate permeability and bearing capacity. The site has a low potential for scour since the flood velocity is expected to be 2 feet per second. Even though the silty clay loam has a severe shrink/swell potential, this will not create an issue for wet floodproofing the structure. The worksheet in Figure C-12 demonstrates that the geotechnical considerations are suitable for wet floodproofing.

Geotechnical Considerations Decision Matrix											
Owner Name:	Juan and Sofia Perez							Preparer		DKL/MH/JS	
Address:	456 Palmetto Lane, Barceloneta, Puerto Rico							Date:		7/6/2026	
Soil Description (USDA Soil Type):	ML-CL										
	Retrofitting Measures										
	Structural Elevation			Elevation Alternatives			Relocation	Floodproofing		Flood Barriers	
Geotechnical Consideration	Stem Wall (Fill)	Perimeter Wall/ Piers	Piles	Basement Infill	Abandon/ Repurpose Lowest Floor	Elevate Lowest Interior Floor		Dry	Wet	Floodwall	Berm
Pre-Screening from Preliminary Homeowner Preference Matrix											
Measure Not Feasible (NF)	NF	NF	NF	NF		NF	NF			NF	NF
Allowable Bearing Capacity, Q_{BC} (see Table 3-8)											
~~High (Q_{BC} > 2,500 psf)~~											
Moderate (Q_{BC} = 1,000 to 2,500 psf)					S			S	S		
~~Low (Q_{BC} < 1,000 psf)~~	~~NS~~	~~NS~~								~~NS~~	~~NS~~
Potential for Scour											
~~High (Soil Types GW, GP, SW, SP and V> 5 ft/sec)~~	~~NS~~	~~NS~~		~~NS~~		~~NS~~				~~NS~~	~~NS~~
Moderate to Low (All Other Soil Types or V ≤ 5 ft/sec)					S			S	S		
Shrink/Swell Potential											
Severe (Soil Types CH, CL, ML-CL, MH, SC)	NS				S			S	S		NS
~~Moderate to Low (All Other Soil Types)~~											
Permeability, K (see Table 3-10)											
~~High (K > 1 ft/day)~~								~~NS~~		~~NS~~	~~NS~~
Moderate (K = 0.0015 to 1 ft/day)					S			NS	S	NS	NS
~~Low (K < 0.0015 ft/day)~~											
Scoring											
Subtotal S's	0	0	0	0	4	0	0	3	4	0	0
Subtotal NS's	0	0	0	0	0	0	0	1	0	1	2
Suitability Determination (Yes if NS's = 0, No if NS's ≥ 1)	NF	NF	NF	NF	Yes	NF	NF	No	Yes	NF	NF
Purpose:	The purpose of the Geotechnical Considerations Decision Matrix is to help the designer identify situations where soil conditions are unsuitable when applied to certain retrofitting measures, therefore eliminating infeasible measures. It is not intended to select the most suitable alternative. See next page for Matrix Notes, Instructions, and Evaluation of Results.										
Matrix Notes:	NF Not Feasible: indicates the retrofit measure was pre-screened to be not allowed or not feasible based on the configuration of the existing structure and/or property. Refer to the Preliminary Homeowner Preference Matrix for details. NS Not Suitable: indicates the retrofit measure is not suitable for this soil property. Lateral Soil Pressure and Frost Action were not considered in this matrix since both can be generally addressed using a properly reinforced foundation design placed at the appropriate frost depth. Refer to FEMA P-259 Table 3-2 for Soil Types and descriptions based on the USDA Unified Soil Classification System. Page 1 of 2. See next page for Instructions and Evaluation of Results.										

Figure C-12. Geotechnical Considerations Decision Matrix for the Perez house

C.8 Load Combinations and Building Assessment

When the Perez family hires an engineer to assess their building for flood loads, the engineer will likely recommend the inclusion of flood openings to avoid wall, footing, and slab retrofits. If the designer's calculations/recommendations confirm flood openings should be provided and they are constructed, the existing structure will not experience any significant difference in loads as compared to the original construction. Therefore, a load combination worksheet will not be prepared.

C.9 Residential Retrofit Using Floodproofing

The Perez family documented their preference for wet floodproofing in the Floodproofing and Flood Barriers Assessment Worksheet as shown in Figure C-13. In the process of completing this worksheet, they realized that a number of building components should be protected from floodwaters. They will replace building materials that can be damaged by floodwaters with flood-damage resistant materials as described below.

Floor Finishes: Floors in the Perez's home are mortar-set ceramic tiles and terrazzo. Table 2 *Common Finish Materials, Uses, and Flood Damage Resistance Ratings* from the National Flood Insurance Program Technical Bulletin 2 (revised in 2025) lists both finishes as having an acceptable flood damage rating. No mitigation is planned for the floors.

Interior and Exterior Walls: National Flood Insurance Program Technical Bulletin 2 Table 1 *Common Structural Materials, Uses, and Flood Damage Resistance Ratings* lists concrete block masonry as having an acceptable flood damage-resistant rating. However, Table 1 cautions that the unfilled cells in concrete block create reservoirs that can retain and make Concrete Masonry Units difficult or impossible (by way of excessive costs) to remove contamination caused by floodwaters. The homeowners are planning to improve flood damage resistance by repainting them with polyester-epoxy or oil-based waterproof paint, which will reduce the porosity of the masonry and impede floodwater penetration into the ungrouted cells. The paint will also facilitate cleaning after a flood.

For additional protection, the homeowners are considering filling the cores in the lower 4 feet of the interior partitions and exterior with expansive spray foam or grout to limit the amount of floodwater that can collect within the walls. This material will also help to reduce the amount of time required to dry the home after a flood. Since the footings under the partitions are the same size as the footings under the load-bearing exterior walls, the added weight of the wall, even if fully grouted, is not considered significant.

Cabinetry: Wall and base cabinets in the kitchen and bathrooms are constructed with medium-density fiberboard with solid hardwood cabinet doors, drawers, and face frames. The medium-density fiberboard is not rated as having an acceptable flood resistance rating. The homeowners are choosing not to renovate the kitchens and bathrooms at this time, but when needed, they will mitigate flood risks when restoration is required after the next flood event. Kitchen cabinets will be replaced with cabinets constructed with marine-grade plywood and doors, drawers, and face frames with solid wood of a species listed as having an acceptable flood resistance rating in Technical

Bulletin-2. Where possible, bathroom lavatories with base cabinets will be replaced with pedestal style lavatories.

Floodproofing and Flood Barriers Assessment Worksheet			
Owner Name:	Juan and Sofia Perez	Preparer	DKL/MH/JS
Address:	456 Palmetto Lane, Barceloneta, Puerto Rico	Date:	7/6/2026
Property Details:	Case Study C		

Floodproofing and Flood Barrier Measures			
Floodproofing		Flood Barriers	
Dry Floodproofing	Wet Floodproofing	Floodwall	Berm

Discussion Questions	Responses to Discussion Questions
1. After reviewing the project information and retrofitting matrices, which floodproofing or flood barrier option is best suited for the homeowner?	Wet Floodproofing
2. What is the nature of the flood source (i.e., riverine or coastal) and the associated impacts on the building (i.e., flood depth, duration, velocity, debris)?	Riverine. FFE is below BFE by (32.8 - 31.5) = 1.3 feet
3. If the building is protected to 1 ft above BFE, what is the anticipated floodproofing/flood barrier design height?	(BFE + 1 ft) = (1.3 ft + 1 ft) = 2.3 ft
4. Is the building constructed with reinforced concrete or reinforced masonry walls? Are the interior finishes constructed of flood damage-resistant materials?	Yes. Partly.
5. Does the building have space below the first floor that could be retrofitted with hydrostatic openings?	No.
6. Can the building structure be protected from flooding using sealants, shields, and an interior drainage system? What is the existing foundation type?	No. Slab on grade with turndown footings.
7. Would the proposed solution require more than 12 hours of warning time to allow for human intervention to deploy the retrofit measures? How would the building occupants be warned of imminent flood danger?	No. Local news.
8. What building utility systems and equipment must be elevated or protected in place?	Electrical receptacles and sewer line.
9. Are the site soils low permeability? Is the lot size, availability of borrow material, and topography suitable for constructing a berm?	No. No.
10. Are there any other issues that need to be considered prior to selecting floodproofing or flood barriers as a final option?	Consultation with an engineer may determine flood openings are required.

FINAL OPTION DETERMINATION	Floodproofing	Flood Barriers
	Wet Floodproofing	

Purpose: The purpose of the Floodproofing and Flood Barriers Assessment Worksheet is to develop a final technical assessment of floodproofing and flood barrier measures to determine what option(s) are the most feasible and recommended for final analysis.

Figure C-13. Floodproofing and Flood Barriers Assessment Worksheet for the Perez house

In addition to flood damage-resistant materials, wet floodproofing may involve elevating mechanical, electrical, and plumbing equipment as described below so it is less prone to being inundated and damaged by floodwaters.

Mechanical, Electrical, and Plumbing Equipment: When the existing water heater fails or reaches the end of its service life, the homeowners plan to replace it with a solar water heater mounted on the roof. Since the water heater is considered a primary component of the mechanical, electrical and plumbing system, relocating it to an elevation above the expected flood level is consistent with the recommendations described in FEMA P-348 *Protecting Building Utility Systems from Flood Damage*.

A water heater and solar collector will be installed to enable thermal circulation that does not rely on electric circulating pumps. The selection of a solar unit will reduce operating costs and produce hot water even during power outages, despite the current unreliability of electric service. Since the existing electric system can support an electric water heater, the new solar water heater will also utilize an option to provide hot water without reliance upon the solar collector. It will be equipped with electric heating elements to provide hot water even during periods when the amount of hot water the solar unit can provide is limited.

The existing window unit air conditioners are above the highest flood level that the Perez family has experienced and have not been damaged by past flood events. They are thinking of replacing the units with a central air conditioning system to reduce energy consumption, reduce noise, and improve temperature control and uniformity. If installed, the exterior compressor/condenser unit will be roof mounted, while the interior air handling unit, also considered a primary mechanical, electrical and plumbing component, will be mounted on a platform. The bottom of the air handling unit will be 4 feet (1.2 meters) above the utility room floor, which is 12 inches (0.3 meters) above the wet floodproofing elevation. In addition, all supply and return ducts, grills, and registers will be routed along the ceiling, well above any anticipated flood level.



Note

Consider reducing flood risks when replacing or upgrading mechanical, electrical and plumbing systems and components, as this is consistent with FEMA P-348 recommendations (see Figure 6-8).

Since the electrical panel and the utility meter are already both 12 inches (30 centimeters) or more above the flood levels experienced during the most significant flood of record, no further mitigation is being considered. For branch circuits, the homeowners are considering relocating receptacles as high as allowed by code to reduce the risk of flooding from less extreme events. For receptacles that will remain at risk, they plan to collaborate with their electrician and have wiring and devices installed that can be more easily replaced after a flood. The homeowners are considering non-metallic sheath (Type NM) cable with insulated conductors running in non-metallic conduit and boxes.

Utilities: The homeowners are planning to have a backflow prevention valve installed in the sewer line that connects the home's main drain, waste, and house vent to the municipal sewer. The valve will be installed in a small manhole or underground utility box to provide access for maintenance and repairs (see Figure 6-30).

C.10 Cost-Effectiveness

The Perez family worked with a consultant to assess the cost-effectiveness of multiple mitigation options, including abandoning the lowest floor, dry floodproofing, and wet floodproofing their home. The results of the overall mitigation assessment and their associated cost estimates are summarized below:

Abandoning/repurposing the lowest floor = $198,000

Dry floodproofing = $80,047

Wet floodproofing = $60,771

Next, the Perez family used the Benefit Cost Analysis Determination Worksheet and associated Benefit Cost Analysis and project guidance to assess the cost-effectiveness of the three flood retrofit options: abandoning the lowest floor, dry floodproofing, and wet floodproofing, as shown in Figures C-14, C-15, and C-16. The results indicated that none of the retrofit alternatives achieved a Benefit-Cost Ratio greater than 1.0; therefore, none of the options were cost-effective. However, relatively speaking, dry floodproofing was the most cost-effective with the highest Benefit-Cost Ratio of 0.10, closely followed by abandoning/repurposing the lowest floor and wet floodproofing, both with a Benefit-Cost Ratio of 0.08.

Benefit-Cost Analysis (BCA) Determination Worksheet

Owner Name:	**Juan and Sofia Perez**	**Preparer**	**DKL/MH/JS**
Address:	**456 Palmetto Lane, Barceloneta, Puerto Rico**	**Date:**	**7/6/2026**
Property Details:	**Case Study C**		

Determine the Retrofit Project Costs

Retrofit Measure: **Abandon/Repurpose Lowest Floor**

H = Flood Design Height = **3.0** ft (determined based on previous design calculations)

T = Project Useful Life = **30** years (taken from FEMA P-259 Table 7-2)

r = Discount Rate = **7.0** *% (Discount Rate set by OMB Circular A-94)*

PVC = Present Value Coefficient = $[1 - (1 + r)^{-T}]/r$ = **12.41** (taken from FEMA P-259 Equation 7-3)

Base Cost = **$198,000** (develop based on FEMA P-259 Section 7.1.2 Steps 1-4 and Step 6)

O&M Cost = (Base Cost) x (Annual O&M %) x PVC = **$0** (develop based on FEMA P-259 Section 7.1.2 Step 5)

Project Costs = *Base Cost + O&M Cost* = **$198,000**

Estimate Expected Annnal Damages Before Mitigation (*EAD Before*)

Residential Building Details:

Number of Stories = **1.0** (choose between 1 and 3) **Building Area:** **1,100** square feet

Foundation Type = **Grade slab** (choose between basement, crawlspace, piers, piles, or grade slab)

Flood Zone = **AE (Riverine)** *Assume riverine or non-Coastal A Zone unless noted otherwise*

USACE Generic Residential Depth-Damage Functon (DDF) = **1-story no basement** (see FEMA P-259 Table 7-1)

Building Replacement Value (BRV) = **$145** (unit cost in dollars per square foot)

Total Building Value = **$159,500** (based on Building Area x BRV)

Total Contents Value = 100% Total Building Value (assumed for all USACE General Residential DDFs)

Number of Occupants = **4** *(based on tax records or U.S. Census average household size rounded to whole number)*

Meals Rate = **$68** *(unit cost in dollars per day based on FY2025 GSA Per Diem Rates for CONUS)*

Lodging Rate = **$110** *(unit cost in dollars per day night on FY2025 GSA Per Diem Rates for CONUS)*

Displacement Cost = **$382** *(unit cost in dollars per day based on ([Number of Occupants x Meals Rate) + Lodging Rate])*

Complete the following matrix of flood damages for up to four flood event recurrence intervals

Flood Event RI (years)	**Depth Above Lowest Floor** (ft)	**Event Damages and Losses** ($)				**EAD = Damage/RI** ($/year)
		Structure	**Contents**	**Displcmt**	**Total**	
10	**-3.6**	**$0**	**$0**	**$0**	**$0**	**$0**
50	**-0.3**	**$3,988**	**$3,828**	**$0**	**$7,816**	**$156**
100	**1.3**	**$37,164**	**$21,214**	**$17,190**	**$75,567**	**$756**
500	**5.2**	**$84,854**	**$45,936**	**$85,950**	**$216,740**	**$433**

Expected Annual Damages Before Mitigation, EAD_{Before} = **$1,345** *per year*

Approximate Expected Annnal Damages After Mitigation (*EAD After*)

Retrofit Measure: **Abandon/Repurpose Lowest Floor**

Use adjacent table, Post-Retrofit Appoxmations by Retrofit Measure, to estimate Flood Damages After Mitigation

Flood Event RI (years)	**Post-Event Damage** ($)	**EAD = Damage/RI** ($/year)
10	**$0**	**$0**
50	**$0**	**$0**
100	**$0**	**$0**
500	**$0**	**$0**

Post-Retrofit Approximations by Retrofit Measure

Retrofit Measure	**Project Effective-ness**	**Reduced Minimum RI Flood**	**Reduced Design RI Flood**
Elevation	High	100%	90%
Relocation	Highest	100%	100%
Wet Floodprooofing	Moderate	50%	25%
Dry Floodproofing	Moderate	100%	0%
Flood Barriers	Moderate	100%	0%

Expected Annual Damages After Mitigation, EAD_{After} = **$0** *per year*

Determine the Project Benefits

Expected Annual Benefit, *EAB* = $EAD_{Before} - EAD_{After}$ = **$1,345** *per year* (from FEMA P-259 Equation 7-2)

Project Benefits = *EAB x PVC* = **$16,696**

Determine the Benefit-Cost Ratio, BCR

***BCR* = (Project Benefits)/(Project Costs) =** **0.08 < 1.0 NG** (from FEMA P-259 Equation 7-1)

Figure C-14. Benefit Cost Analysis Determination Worksheet for abandoning/repurposing the lowest floor at the Perez house

Benefit-Cost Analysis (BCA) Determination Worksheet

Owner Name:	**Juan and Sofia Perez**	**Preparer**	**DKL/MH/JS**
Address:	**456 Palmetto Lane, Barceloneta, Puerto Rico**	**Date:**	**7/6/2026**
Property Details:	**Case Study C**		

Determine the Retrofit Project Costs

Retrofit Measure: **Dry Floodproofing**

H = Flood Design Height = **3.0** ft (determined based on previous design calculations)

T = Project Useful Life = **15** years (taken from FEMA P-259 Table 7-2)

r = Discount Rate = **7.0** *% (Discount Rate set by OMB Circular A-94)*

PVC = Present Value Coefficient = $[1 - (1 + r)^{-T}]/r$ = **9.11** (taken from FEMA P-259 Equation 7-3)

Base Cost = **$55,000** (develop based on FEMA P-259 Section 7.1.2 Steps 1-4 and Step 6)

O&M Cost = (Base Cost) x (Annual O&M %) x PVC = **$25,047** (develop based on FEMA P-259 Section 7.1.2 Step 5)

Project Costs = *Base Cost + O&M Cost* = **$80,047**

Estimate Expected Annnal Damages Before Mitigation (*EAD Before*)

Residential Building Details:

Number of Stories = **1.0** (choose between 1 and 3) **Building Area:** **1,100** square feet

Foundation Type = **Grade slab** (choose between basement, crawlspace, piers, piles, or grade slab)

Flood Zone = **AE (Riverine)** *Assume riverine or non-Coastal A Zone unless noted otherwise*

USACE Generic Residential Depth-Damage Functon (DDF) = **1-story no basement** (see FEMA P-259 Table 7-1)

Building Replacement Value (BRV) = **$145** (unit cost in dollars per square foot)

Total Building Value = **$159,500** (based on Building Area x BRV)

Total Contents Value = 100% Total Building Value (assumed for all USACE General Residential DDFs)

Number of Occupants = **4** *(based on tax records or U.S. Census average household size rounded to whole number)*

Meals Rate = **$68** *(unit cost in dollars per day based on FY2025 GSA Per Diem Rates for CONUS)*

Lodging Rate = **$110** *(unit cost in dollars per day night on FY2025 GSA Per Diem Rates for CONUS)*

Displacement Cost = **$382** *(unit cost in dollars per day based on ([Number of Occupants x Meals Rate) + Lodging Rate])*

Complete the following matrix of flood damages for up to four flood event recurrence intervals

Flood Event RI (years)	**Depth Above Lowest Floor** (ft)	**Event Damages and Losses** ($)				**EAD = Damage/RI** ($/year)
		Structure	**Contents**	**Displcmt**	**Total**	
10	**-3.6**	**$0**	**$0**	**$0**	**$0**	**$0**
50	**-0.3**	**$3,988**	**$3,828**	**$0**	**$7,816**	**$156**
100	**1.3**	**$37,164**	**$21,214**	**$17,190**	**$75,567**	**$756**
500	**5.2**	**$84,854**	**$45,936**	**$85,950**	**$216,740**	**$433**

Expected Annual Damages Before Mitigation, EAD_{Before} = **$1,345** *per year*

Approximate Expected Annnal Damages After Mitigation (*EAD After*)

Retrofit Measure: **Dry Floodproofing**

Use adjacent table, Post-Retrofit Appoxmations by Retrofit Measure, to estimate Flood Damages After Mitigation

Flood Event RI (years)	**Post-Event Damage** ($)	**EAD = Damage/RI** ($/year)
10	**$0**	**$0**
50	**$0**	**$0**
100	**$0**	**$0**
500	**$216,740**	**$433**

Post-Retrofit Approximations by Retrofit Measure

Retrofit Measure	**Project Effective-ness**	**Reduced Minimum RI Flood**	**Reduced Design RI Flood**
Elevation	High	100%	90%
Relocation	Highest	100%	100%
Wet Floodprooofing	Moderate	50%	25%
Dry Floodproofing	Moderate	100%	0%
Flood Barriers	Moderate	100%	0%

Expected Annual Damages After Mitigation, EAD_{After} = **$433** *per year*

Determine the Project Benefits

Expected Annual Benefit, *EAB* = $EAD_{Before} - EAD_{After}$ = **$912** *per year* (from FEMA P-259 Equation 7-2)

Project Benefits = *EAB x PVC* = **$8,306**

Determine the Benefit-Cost Ratio, BCR

***BCR* = (Project Benefits)/(Project Costs) =** **0.10 < 1.0 NG** (from FEMA P-259 Equation 7-1)

Figure C-15. Benefit Cost Analysis Determination Worksheet for dry floodproofing at the Perez house

Benefit-Cost Analysis (BCA) Determination Worksheet

Owner Name:	**Juan and Sofia Perez**	**Preparer**	**DKL/MH/JS**
Address:	**456 Palmetto Lane, Barceloneta, Puerto Rico**	**Date:**	**7/6/2026**
Property Details:	**Case Study C**		

Determine the Retrofit Project Costs

Retrofit Measure: **Wet Floodproofing**

H = Flood Design Height = **3.0** ft (determined based on previous design calculations)

T = Project Useful Life = **15** years (taken from FEMA P-259 Table 7-2)

r = Discount Rate = **7.0** *% (Discount Rate set by OMB Circular A-94)*

PVC = Present Value Coefficient = $[1 - (1 + r)^{-T}]/r$ = **9.11** (taken from FEMA P-259 Equation 7-3)

Base Cost = **$49,500** (develop based on FEMA P-259 Section 7.1.2 Steps 1-4 and Step 6)

O&M Cost = (Base Cost) x (Annual O&M %) x PVC = **$11,271** (develop based on FEMA P-259 Section 7.1.2 Step 5)

Project Costs = *Base Cost + O&M Cost* = **$60,771**

Estimate Expected Annnal Damages Before Mitigation (EAD_{Before})

Residential Building Details:

Number of Stories = **1.0** (choose between 1 and 3) **Building Area:** **1,100** square feet

Foundation Type = **Grade slab** (choose between basement, crawlspace, piers, piles, or grade slab)

Flood Zone = **AE (Riverine)** *Assume riverine or non-Coastal A Zone unless noted otherwise*

USACE Generic Residential Depth-Damage Functon (DDF) = **1-story no basement** (see FEMA P-259 Table 7-1)

Building Replacement Value (BRV) = **$145** (unit cost in dollars per square foot)

Total Building Value = **$159,500** (based on Building Area x BRV)

Total Contents Value = 100% Total Building Value (assumed for all USACE General Residential DDFs)

Number of Occupants = **4** *(based on tax records or U.S. Census average household size rounded to whole number)*

Meals Rate = **$68** *(unit cost in dollars per day based on FY2025 GSA Per Diem Rates for CONUS)*

Lodging Rate = **$110** *(unit cost in dollars per day night on FY2025 GSA Per Diem Rates for CONUS)*

Displacement Cost = **$382** *(unit cost in dollars per day based on ([Number of Occupants x Meals Rate) + Lodging Rate])*

Complete the following matrix of flood damages for up to four flood event recurrence intervals

Flood Event RI (years)	**Depth Above Lowest Floor** (ft)	**Event Damages and Losses** ($)				**EAD = Damage/RI** ($/year)
		Structure	**Contents**	**Displcmt**	**Total**	
10	**-3.6**	**$0**	**$0**	**$0**	**$0**	**$0**
50	**-0.3**	**$3,988**	**$3,828**	**$0**	**$7,816**	**$156**
100	**1.3**	**$37,164**	**$21,214**	**$17,190**	**$75,567**	**$756**
500	**5.2**	**$84,854**	**$45,936**	**$85,950**	**$216,740**	**$433**

Expected Annual Damages Before Mitigation, EAD_{Before} = **$1,345** *per year*

Approximate Expected Annnal Damages After Mitigation (EAD_{After})

Retrofit Measure: **Wet Floodproofing**

Use adjacent table, Post-Retrofit Appoxmations by Retrofit Measure, to estimate Flood Damages After Mitigation

Flood Event RI (years)	**Post-Event Damage** ($)	**EAD = Damage/RI** ($/year)
10	**$0**	**$0**
50	**$3,908**	**$78**
100	**$37,784**	**$378**
500	**$162,555**	**$325**

Post-Retrofit Approximations by Retrofit Measure

Retrofit Measure	**Project Effective-ness**	**Reduced Minimum RI Flood**	**Reduced Design RI Flood**
Elevation	High	100%	90%
Relocation	Highest	100%	100%
Wet Floodprooofing	Moderate	50%	25%
Dry Floodproofing	Moderate	100%	0%
Flood Barriers	Moderate	100%	0%

Expected Annual Damages After Mitigation, EAD_{After} = **$781** *per year*

Determine the Project Benefits

Expected Annual Benefit, *EAB* = EAD_{Before} - EAD_{After} = **$564** *per year* (from FEMA P-259 Equation 7-2)

Project Benefits = *EAB x PVC* = **$5,140**

Determine the Benefit-Cost Ratio, BCR

***BCR* = (Project Benefits)/(Project Costs) =** **0.08 < 1.0 NG** (from FEMA P-259 Equation 7-1)

Figure C-16. Benefit Cost Analysis Determination Worksheet for wet floodproofing at the Perez house

C.11 Final Retrofit Measure Selection

The Perez family has strong convictions on using wet floodproofing as an interim measure to limit flood damage. The lower cost of this measure makes it easier for them to fund the retrofit on their limited budget. They appreciate the way it will not require their intervention at the threat of flooding, unlike dry floodproofing. Wet floodproofing will be significantly more feasible given the costs, limited disruption, and minimal construction required as compared to abandonment of the first floor with a second-floor addition. Their rankings and scores are shown in Figure C-17.

Preference Ranking Alternative Worksheet							
Owner Name:	**Juan and Sofia Perez**					**Preparer:**	**DKL/MH/JS**
Address:	**456 Palmetto Lane, Barceloneta, Puerto Rico**					**Date:**	**7/6/2026**
Property Details:	**Case Study C**						
	Alternative Selection Factors						**Total Preference Ranking Score**
	Regulatory Compliance	**Homeowner Preferences**	**Flood, Site and Building Characteristics**	**Technical Feasibility**	**Project Cost**	**Cost-Effectiveness**	
	Importance Factor	**Importance Factor**	**Importance Factor**	**Importance Factor**	**Importance Factor**	**Importance Factor**	
Preferred Retrofit Alternatives	**0.5**	**1.0**	**1.0**	**1.0**	**1.0**	**1.0**	
Wet Floodproofing	**3**	**5**	**5**	**5**	**5**	**2**	**23.5**
Abandon/Repurpose Lowest Floor	**3**	**3**	**4**	**2**	**1**	**2**	**13.5**
Dry Floodproofing	**3**	**2**	**2**	**1**	**2**	**3**	**11.5**

Purpose: The purpose of the Preference Ranking Alternative Worksheet is to aid in the final selection of the retrofit measure from the top two or three alternatives.

Instructions:

Step 1: Review the Alternative Selection Factors and assign Importance Factors between 0.5 and 1.0 based on their relative importance to the homeowner, with highest Importance Factors set to 1.0, moderate Importance Factors set to 1.0, and lowest Importance Factors set to 0.5. If the homeowner does not want to consider a particular factor, then it can be assigned an Importance Factor of 0. If the homeowner has no preferences, then set all Alternative Selection Importance Factors equal to 1.0.

Step 2: For each Preferred Retrofit Alternative, rank the Alternative Selection Factors using a preference scale of 1 to 5 as follows:

5 = High (most preferable)
4 = Medium-High (more preferable)
3 = Medium (moderately preferable)
2 = Medium-High (less preferable)
1 = Low (least preferable)

Step 3: Once all Importance Factors are input (Step 1) and Alternative Selection Factors are ranked (Step 2), compute the Total Preference Ranking Score by multiplying each Alternative Selection Factor ranking by its Importance Factor, and summing the results for all other Selection Factors.

Evaluation of Results: The Preferred Retrofit Alternative with the highest Total Preference Ranking Score is the one recommended for final selection.

Figure C-17. Preference Ranking Alternative Worksheet for the Perez house

C.12 Other Mitigation Approaches

While wet floodproofing offers the most benefits for the least cost, it will not eliminate flood risk. Elevation, if feasible, will be more effective at reducing flood risk.

The slab-on-grade construction limits mitigation options. The existing floor slab, which presently is continuously supported by soils, likely lacks the thickness and the reinforcement needed to function as a structural slab. The fragility of the concrete masonry walls, particularly the ungrouted and unreinforced interior partitions, will further complicate any efforts to elevate the home.

First floor abandonment involves constructing a new, code compliant, second floor for living space and using the existing first floor only for access, storage, and possibly parking. For this approach to be feasible, perform the following:

- Determine whether the existing footings under the exterior walls and interior partitions can support the additional loads (live loads, dead loads, additional wind loads, and additional seismic loads) that a new second floor will create.
- Determine whether the existing exterior walls are adequate to support the additional live loads and dead loads imposed by the second floor. A new flat roof can create large uplift forces during high wind events. The walls will need to resist the tensile forces needed to transfer those loads to the foundation.
- Determine whether the existing interior partitions can adequately support the added loads of the second floor. Grouting and reinforcing will likely be needed.
- Determine whether the existing concrete roof, which was likely only designed to resist minimum roof live loads, can support the additional live loads of living spaces. Construction of a new reinforced shotcrete floor below the existing roof or pouring a new reinforced concrete slab on top of the existing roof will likely be needed.
- Analyze the entire structure and its foundation to determine whether it can resist uplift, sliding and overturning forces and moments and will not collapse during a design flood, wind and/or seismic event.

Many homes with exterior Concrete Masonry Unit walls and concrete roofs constructed prior to modern model building codes lacked the proper connections within elements like Concrete Masonry Unit walls, or between elements like the Concrete Masonry Unit walls and concrete roofs to resist current design loads. Therefore, the construction of a second floor will likely require significant renovations to the roof, load bearing walls, and footings. These actions, while theoretically possible, will likely not be feasible or cost-effective, and the homeowner will likely choose a different option.

Appendix D. Design Flood Best Practices

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D.1 Introduction: Current Updates to Flood-Related Standards and Anticipated Impacts on Buildings Codes

While developing the Fourth Edition of FEMA P-259, there were two significant updates to flood-related standards published by the American Society of Civil Engineers as described below:

- **ASCE/SEI 7-22. *Minimum Design Loads and Associated Criteria for Buildings and Other Structures, Supplement 2* (ASCE 7-22 S2)**: Published in May 2023, Flood Load Chapter 5 of ASCE 7-22 S2 introduced a risk-based approach for flood load determination. Additionally, the effective floodplain was extended to the 0.2% flood frequency (500-year) floodplain for Risk Category II – IV structures, where delineated. Additional changes included revised hydrostatic, hydrodynamic, debris impact, and wave loads, as well as a new method to calculate flood loads and load combinations.

- **ASCE/SEI 24-24. Flood Resistant Design and Construction:** Published in early 2025, this 2024 edition of ASCE/SEI 24 aligns with ASCE 7-22 Supplement 2 for design loads. Further, four primary updates were made:

  1) Expanded flood hazard area is redefined to include the 500-year (0.2% annual exceedance) floodplain for Flood Design Class 2-4 structures, where delineated.
  2) Elevation requirements are tied to the structure's Flood Design Class, with residential building (Flood Design Class 2) elevations based on the 500-year flood elevation. Additionally, specific evaluation requirements were added prior to elevating a concrete grade slab foundation.
  3) Coastal flood elevation calculations must now include sea level change.
  4) Dry floodproofing requirements were updated to include flood shield product type requirements based on the Flood Design Class and to require the use of ANSI/FM 2510-certified products.

  In addition to these updates, an additional exterior door is now required above the Design Flood Elevation for buildings with wet floodproofed building access, such as enclosures.

For decades, FEMA Building Science publications have focused not only on providing guidance for complying with minimum National Flood Insurance Program requirements but also building codes and best practices to minimize future flood damage. The updates to design flood elevations and flood loads in ASCE 7-22 S2 and ASCE 24-24 reflect best practices, and FEMA has developed guidance to apply these standards (see Cross Reference at the top of the next page). However, neither ASCE 7-22 S2 nor ASCE 24-24 are included in the current (2024) International Code Council Codes (I-Codes), and it is unclear if they will be adopted into the 2027 I-Codes. The purpose of this section is to provide a brief discussion of how to apply ASCE 7-22 S2 and ASCE 24-24 as best practices to determine the Design Flood Elevation and updated flood loads to design retrofitting measures for increased flood resilience.

Cross Reference

This appendix relies on the following design guidance to apply ASCE 7-22 S2 and ASCE 24-24:

- FEMA P-2345, *Building Designer's Guide to Calculating Flood Loads Using ASCE 7-22 Supplement 2*, April 2024. https://www.fema.gov/sites/default/files/documents/fema_p-2345-building-designers-guide-to-calculating-flood-loads.pdf

D.2 Applying Best Practices for the Design Flood Elevation

The first step in applying elements from ASCE 7-22 and ASCE 24-24 as best practices to establish the Design Flood Elevation. Previous versions of ASCE 24 determined the Design Flood Elevation using the Base Flood Elevation (100-year flood elevation or 1% annual chance flood) from the National Flood Insurance Program Flood Insurance Rate Maps plus an additional freeboard height (1 foot minimum). In ASCE 24-24, the Design Flood Elevation for residential (Flood Design Class 2) structures is redefined as the higher of the 500-year flood elevation (0.2% annual chance flood) or the flood elevation established by the community. Additionally, ASCE 24-24 requires that the Design Flood Elevation for residential structures be compared against Base Flood Elevation + 1; whichever is higher represents the required minimum elevation for ASCE 24-24. Therefore, **unless the local authority having jurisdiction has adopted flood elevations based on Base Flood Elevation plus freeboard or local maps that exceed the 500-year flood elevation, the best practice Design Flood Elevation used in Appendix D of FEMA P-259 for residential retrofitting is based on the higher of the 0.2% annual chance flood or Base Flood Elevation + 1 foot in accordance with ASCE 24-24 and ASCE 7-22.**

Given the focus of FEMA P-259 is on non-coastal flooding, **the 500-year flood elevation can be determined from the National Flood Insurance Program Flood Insurance Study profiles for the riverine flood source associated with the project site.** Where the 500-year flood elevation is not available, ASCE 24-24 provides a method for determining the 500-year flood elevation when the 100-year and 10-year flood elevations are known. However, in the absence of this data, dwellings (defined as Risk Category II structures in ASCE 7 and Flood Design Class 2 structures in ASCE 24) can apply an average freeboard to the 100-year flood elevation to approximate the 500-year flood elevation. **For non-coastal residential flooding where only the 100-year flood elevation information is available, ASCE 24-24 Table 1-3 equates the 500-year flood elevation to the 100-year flood elevation + 2.1 feet.**



Note

The 500-year flood elevation determined by ASCE 24-24 can be used for calculating flood loads in riverine areas. (FEMA P-2345, *Building Designer's Guide to Calculating Flood Loads Using ASCE 7-22 Supplement 2*, provides guidance on a scaling approach presented in ASCE 7-22 Supplement 2 for determining the 500-year flood elevation, but this approach is far more complex and not recommended for this appendix.)

D.3 Applying Best Practices for Other Aspects of Flood Design

In addition to using the Design Flood Elevation in Section D.2, applying the methods from ASCE 7-22 and ASCE 24-24 as best practices for residential retrofit projects in non-coastal flood areas involves the following adjustments to determining and combining design flood loads.

D.3.1 Hydrostatic Flood Loads

FEMA P-2345 Chapter 4 addresses hydrostatic flood loads discussed in ASCE 7-22 S2, Section 5.4.2. As stated in FEMA P-259, Section 3.2.2, hydrostatic flood loads reflect the forces exerted on a structure by standing water and increase with flood depth. Overall, the calculation of lateral hydrostatic forces, combined soil and water forces, and vertical hydrostatic forces (buoyancy), in ASCE 7-22 S2 follows the same principles outlined in FEMA P-259 Section 3.2 for residential retrofit projects in non-coastal flood areas.

D.3.2 Hydrodynamic Flood Loads

FEMA P-2345 Chapter 5 addresses hydrodynamic flood loads discussed in ASCE 7-22 S2, Sections 5.3.6 and 5.4.3. As stated in FEMA P-259, Section 3.2.3, hydrodynamic flood loads reflect the forces exerted on a structure by water flowing around it and are a function of flood velocity and structure geometry. In addition to riverine flood velocity considerations (see Note below), ASCE 7-22 S2 hydrodynamic flood load calculations require the determination of additional variables for various building components including drag coefficients, average clear spacing, and debris damming closure ratios. As a result, the calculation of hydrodynamic forces in ASCE 7-22 S2 is more complex than the calculation of low-velocity and high-velocity hydrodynamic forces outlined in FEMA P-259, Section 3.2.3 for residential retrofit projects in non-coastal flood areas. Refer to FEMA P-2345, Sections 5.3.1 and 5.3.2, for details on how to calculate hydrodynamic forces in accordance with ASCE 7-22 S2.

Note

ASCE 7-22-S2 does not provide guidance on scaling the design flood velocity to the needed mean recurrence interval (MRI) in riverine areas. FEMA P-2345 Appendix D outlines two approaches to determine the design flood velocity (V) of water for the needed mean recurrence interval when the velocity is not known for the required mean recurrence interval. Additionally, when a structure is located in a delineated floodway, the required hydrologic and hydraulic (H&H) study for the "no rise" analysis may provide the necessary velocity values. The "no rise" analysis requires calculations for the 1% annual chance event. For this reason, it is important to stipulate during scoping of the study that the 500-year mean recurrence interval (0.2% annual chance flood event) is required so that the study can provide the required elevation and velocity information for residential retrofit design.

D.3.3 Scour Depth Determination

FEMA P-2345 Chapter 7 addresses riverine scour depth determination guidance discussed in ASCE 7-22 S2, Section C5.3.8. As stated in FEMA P-259, Section 3.7.2, scour is a localized erosion caused by the movement of soil or sediment around an obstruction to flow created by the structure. ASCE 7-22 S2, does not provide a method for evaluating riverine scour at a building site. The five-step process outlined in FEMA P-259 Section 3.7.2 for determining the potential scour depth is considered acceptable for scour evaluation at residential retrofit projects in non-coastal flood areas.

D.3.4 Debris Impact Loads

FEMA P-2345, Chapter 8, addresses flood-borne debris impact loads discussed in ASCE 7-22 S2, Sections 5.3.9 and 5.4.5. As stated in FEMA P-259 Section 3.2.4, impact loads reflect the forces exerted on a structure by objects carried by moving floodwater, and are a function of debris size, flood velocity, and other risk factors. However, the techniques used to determine debris impact forces on structures in ASCE 7-22 S2 are different than the calculations used to determine normal impact forces in FEMA P-259, Section 3.2.4, for residential retrofit projects in non-coastal flood areas. Refer to FEMA P-2345, Sections 8.1 and 8.2, for details on how to calculate debris impact forces in accordance with ASCE 7-22 S2.

D.3.5 Flood Load Combinations

FEMA P-2345, Chapter 9, addresses load combinations to be considered for riverine flooding as discussed in ASCE 7-22 S2, Sections 2.3.2 and 5.5. A comparison of the two load and resistance factor design load combinations in FEMA P-259, Section 4.5.6, for non-coastal flood hazard zones based on ASCE 7-22 are almost the same as the two listed in ASCE 7-22 S2, Section 2.3.2 with one exception: the wind load factor changes from 0.5W to 1.0W in Equation 4b when using ASCE 7-22 S2, Section 2.3.2. Note that these combinations, as well as the other load and resistance factor design load combinations in ASCE 7, still need to be checked for both the vertical and horizontal load directions, as well as part of the overall building design and stability checks.

Note

ASCE 7-22-S2 also makes adjustments to the allowable stress design load combinations from ASCE 7-22, but these are not covered here since FEMA P-259 does not cover the allowable stress design approach in detail.

Cross Reference

Refer to Chapter 11 of FEMA P-2345, *Building Designer's Guide to Calculating Flood Loads Using ASCE 7-22 Supplement 2* (April 2024), for a detailed riverine flood design example using the flood load calculations in ASCE 7-22 S2. Note that this example analyzes a Risk Category III, non-residential building, so its requirements vary from a residential building (Risk Category II).

D.4 Additional Resources

FEMA resources for flood retrofit design best practices include the following publications and guidance documents.

- FEMA P-2345, *Building Designer's Guide to Calculating Flood Loads Using ASCE 7-22 Supplement 2* (April 2024, Second Issuance). https://www.fema.gov/sites/default/files/documents/fema_p-2345-building-designers-guide-to-calculating-flood-loads.pdf

Additional resources for flood retrofit design best practices include the following building standards from the American Society of Civil Engineers. Note that a PDF copy of ASCE 7-22 Supplement 2 can be downloaded free of charge, while ASCE 24-24 is available for purchase from the American Society of Civil Engineers.

- ASCE/SEI 7-22. *Minimum Design Loads and Associated Criteria for Buildings and Other Structures, Supplement 2* (May 2023). https://ascelibrary.org/doi/epdf/10.1061/9780784415788.sup2
- ASCE/SEI 24-24. Flood Resistant Design and Construction (2025). https://sp360.asce.org/personifyebusiness/Merchandise/Product-Details/productId/318295190

Appendix E. Alluvial Fan Flooding

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E.1 Alluvial Fan Background

Alluvial fans are a natural feature created when a surge of water flows down from a steep landscape to a flatter one, carrying with it “sediment” which can consist of sand, pebbles, small rocks, boulders and other debris, such as fallen trees during large storm events (Figure E-1).



Figure E-1. Alluvial Fan in Rocky Mountain National Park, Colorado

“Alluvial” refers to the alluvium, or the debris carried by water. When the water reaches a flatter landscape, it loses speed and energy needed to continue carrying the alluvium. As a result, water begins to spread out, creating a “fan” shaped area of deposit. (Figure E-2). Alluvial fan flow (flow) from the watershed is generally associated with intense rainfall. Flows appear from steep upland channels to lower gradients, which reduce the ability for the stream to transport sediment (herein “sediment” refers to soil particles, gravel, stone, and boulders). Sediment deposits radiate outward at or slightly above the point where feeder channel confinement is lost. Radiating flow patterns are consistent with changing areas of deposition over time and space. Changes to the deposition area often occur with channel separation that shifts flow paths, building multiple deposition areas, or alluvial fan segments. An alluvial fan is a triangle-shaped deposit of sediment and debris arranged in the semi-conical shape typical of an alluvial fan (Figure E-2). The alluvial fan apex marks the end of the feeder channel where the stream exits the mountain area, forming the origin of the alluvial fan. The intersection point is where the flow emerges from the confined incised channel to lower relief topography (shallower channel(s)) and continues to flow towards the distal portions of the alluvial fan. The intersection point is often found in the mid-fan location.

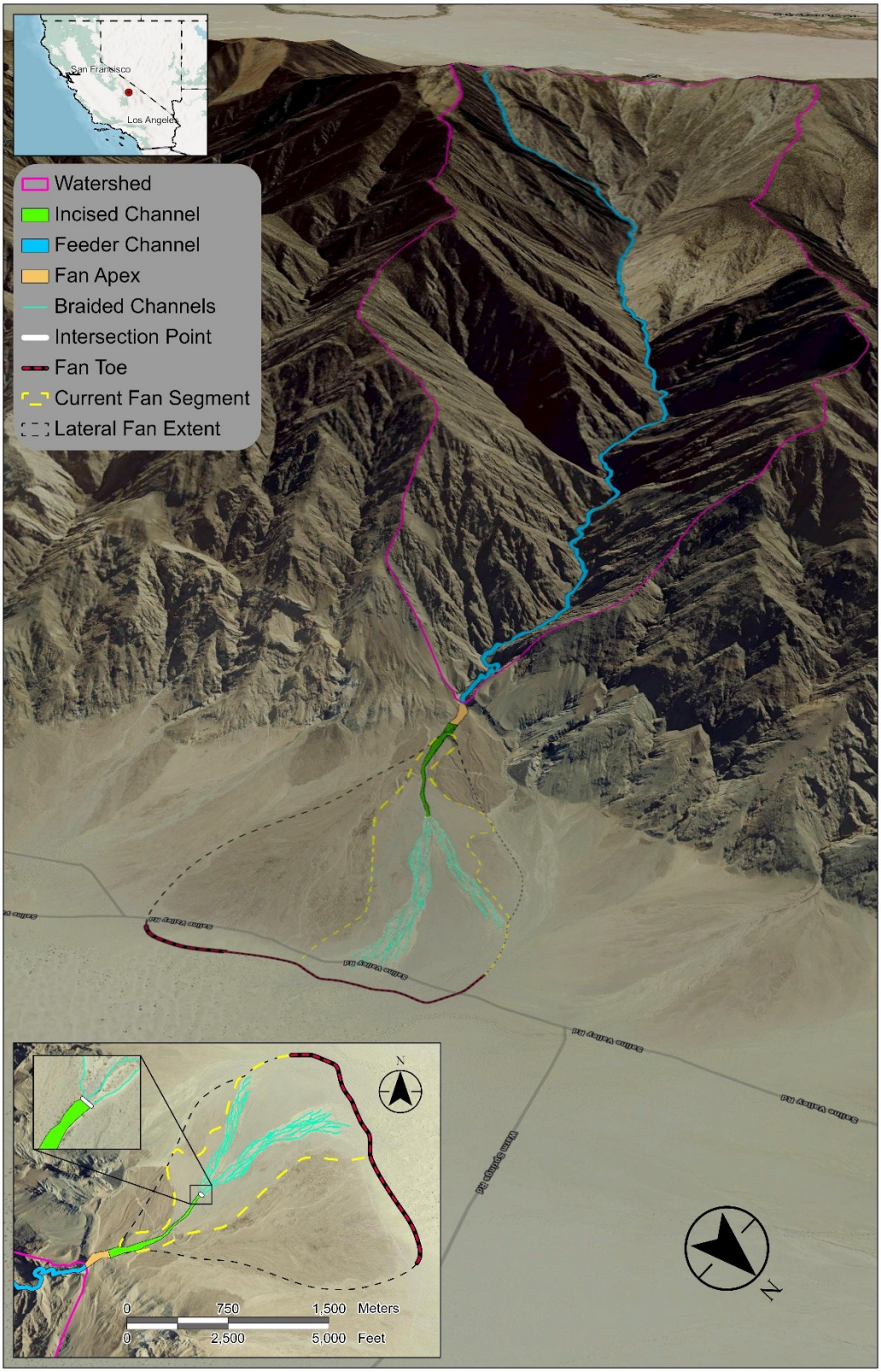


Figure E-2. Common features associated with an alluvial fan

Alluvial fans have three distinct sections (Figure E-3). Proximal, mid-fan, and distal portions of the alluvial fan are terms used to describe the broad context of event locations or features (natural and human) on an alluvial fan. Incidents where an incised channel (erosion) exists within the proximal portion of the alluvial fan eventually produce an intersection point.

- The **proximal** portion contains the apex and extends to the mid-fan section.
- The **mid-fan** area extends from the proximal to the distal portion of the alluvial fan.
- The **distal** portion terminates at the toe at the edge of the alluvial fan (Figure E-3).

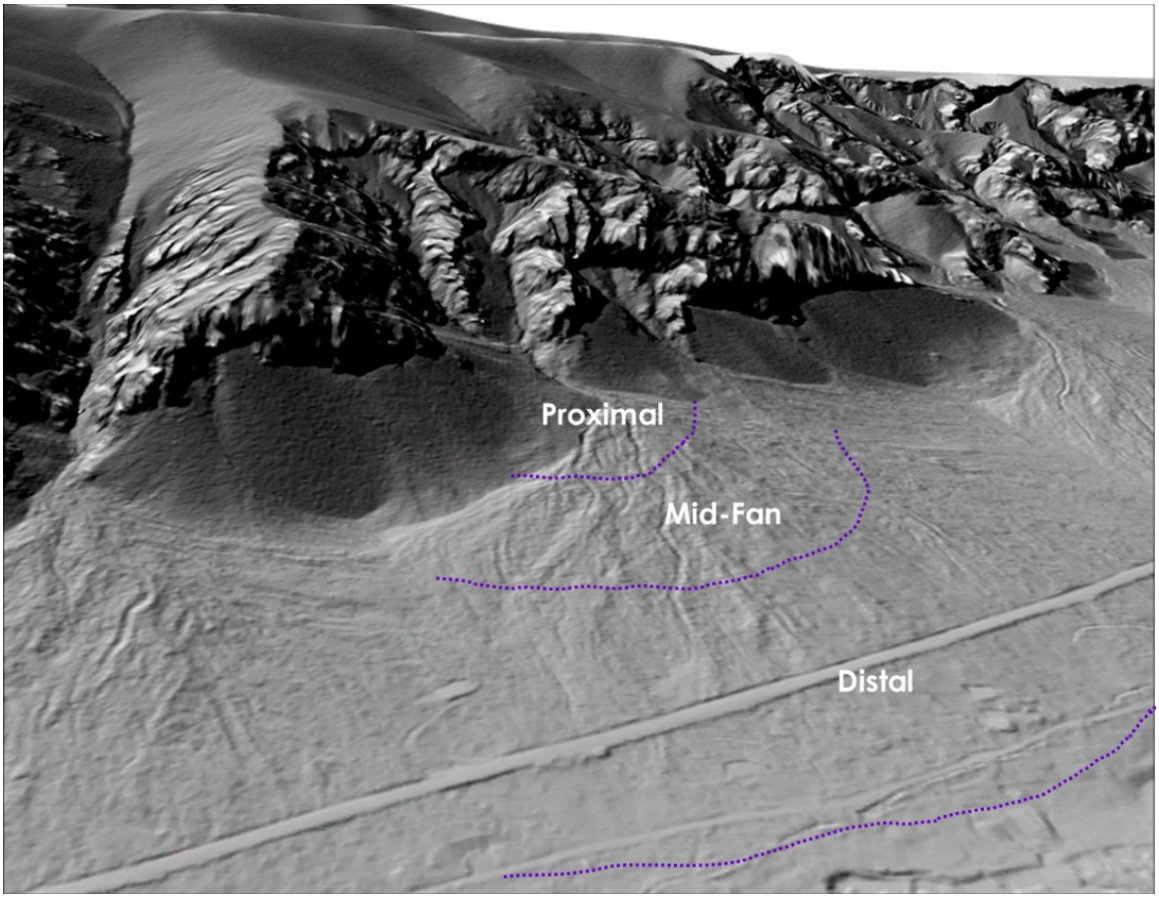


Figure E-3. General locations of the proximal, mid-fan, and distal portions of an alluvial fan

The size and shape of an alluvial fan is limited by the amount of accommodation space where the alluvial fan forms. Accommodation space refers to the amount of space available near the feeder channel mouth for the alluvial fan to grow. Accommodation space can be significant, such as where mountains drain into lakes or large open valleys (Figure E-4). Within smaller river valleys, there is less accommodation space, and the main trunk stream often erodes the distal or toe portion of the alluvial fan, inhibiting alluvial fan growth. Bajadas are joined alluvial fans. Isolated alluvial fans display classic semi-conical form, while fans within bajadas can take on more of a pie-piece or elongated form due to a lack of accommodation space. Accommodation space impacts the overall

shape and topography of an alluvial fan, ultimately impacting flood patterns. In addition, within bajadas, channels often form at the lateral extent of the fans receiving water from both fans.

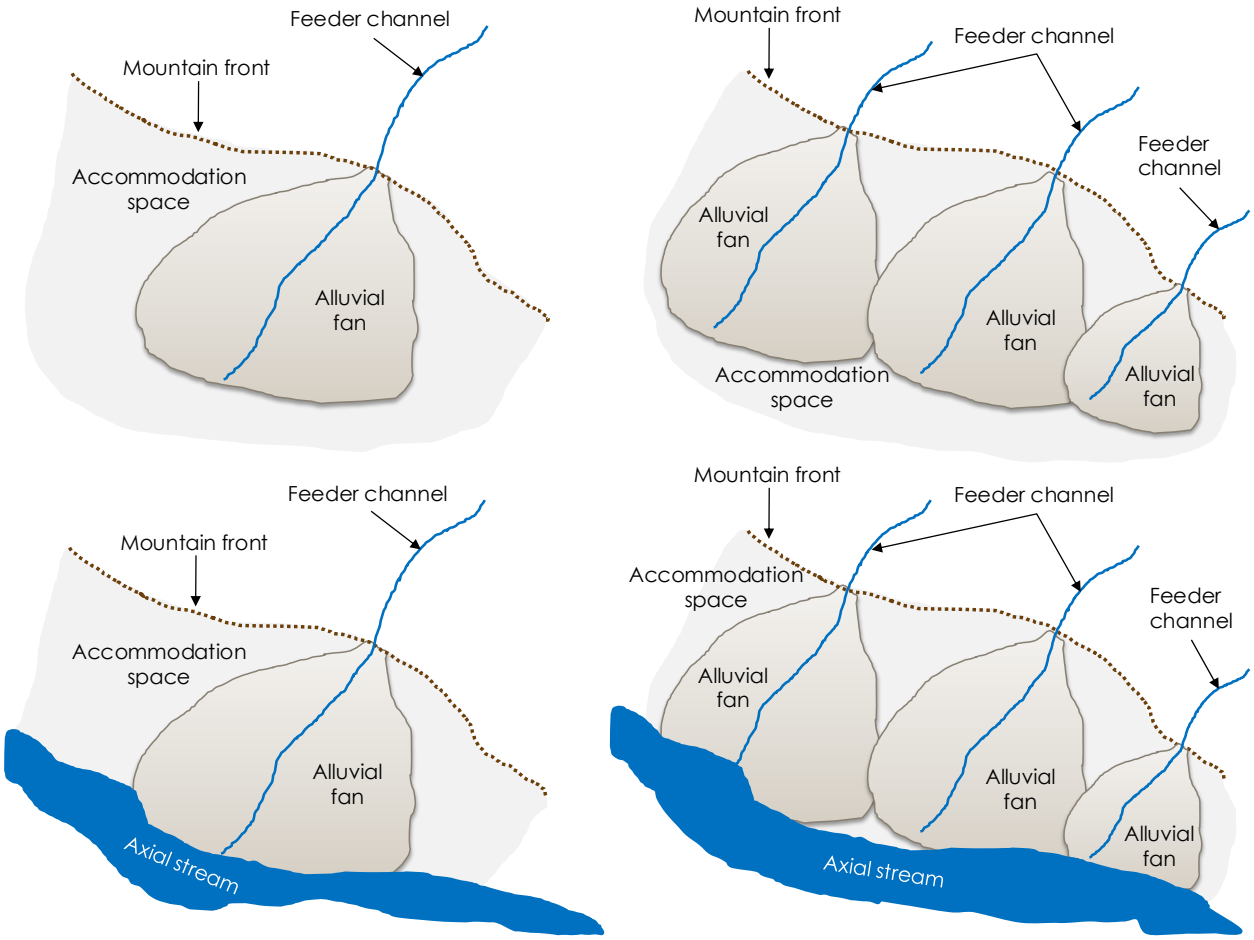


Figure E-4. Examples of potential accommodation space. Light gray demarcates accommodation space where the fan can grow laterally or prograde, where there is no axial stream.

E.2 Alluvial Fan Dominant Processes

A key aspect of alluvial fan development is sediment transport to alluvial fans. Intense rainfall leads to runoff to the feeder channel, where material is transported. Sediment delivery to the alluvial fan is determined by the ratio of water to sediment, which defines the dominant processes that form an alluvial fan. Four processes are often identified on alluvial fans: floods, debris floods, debris flows, and debris avalanches (Figure E-5).

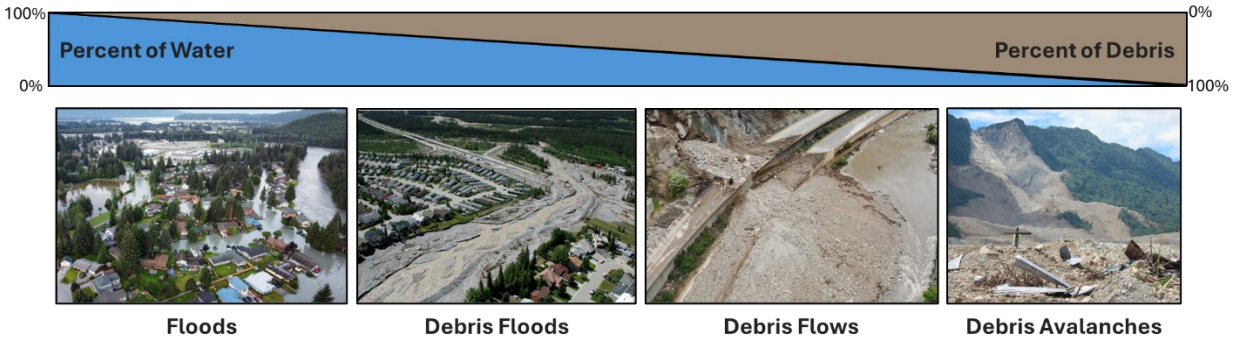


Figure E-5. Dominant processes operating on alluvial fans. Percent values for water and sediment are for demonstrative purposes as opposed to defining sediment bulking.

- Floods contain the least amount of sediment and tend to carry finer sediment loads. Alluvial fans in larger watersheds mostly experience floods featuring a range of fan areas and fan slopes averaging 2° to 7°.

- Debris floods are stream flows in a steep channel where peak discharge transports a significant portion of the streambed. Sediments range from fine clay particles to boulders, depending on sediment characteristics along the feeder channel. Water concentrations remain higher than sediment concentrations, despite the large amount of mobilized sediment.

- Debris flows are high velocity flows with high concentrations of sediment to water. A range of sediment sizes in debris flows with frequent transport of large boulders is common. Debris flow fan slopes range between 5° to 15°.

- Debris avalanches contain largely colluvial material lubricated by minimal amounts of water and significant air. They have a high sediment load and tend to consist of coarser grains. Alluvial fans formed via debris avalanches occur in exceedingly small, steep watersheds with 27° to 50° fan slopes. While debris avalanches can occur at the end of geomorphological processes, they are usually driven by gravity processes, not typical of alluvial fan flooding.

Understanding the dominant process(es) operating on an alluvial fan is a first step in categorizing potential alluvial fan flood hazards.

E.3 Identifying Dominant Processes

Morphometry is a common approach used to define the dominant process(es) occurring on alluvial fans. Morphometric analyses are a quantitative analysis of landform and landscape shape, dimensions, and geometric properties, often using mathematical and statistical analysis. Watersheds and alluvial fans are the landforms considered when understanding relationships between these two landforms. The Melton index, watershed length, and fan slope are common measures used to assess alluvial fan processes. The Melton index represents the gravitational energy of a watershed, measured via a ratio of watershed relief by the square root of the watershed area. Watershed length is measured as the distance from the fan apex to the farthest proximal

distance on the drainage divide. Fan slope is commonly measured from the fan apex to the lowest point of the fan perimeter.

Mapping and modeling focus on flood features using HEC-RAS, Flo2D, or other comparable models that focus on bulk flows. Some watersheds are modeled with software specifically designed to model debris flow runout like ProDF, RAMMS-DF, DebrisFlow Predictor, and MassWasting Router. Watersheds that fall between the debris flow and debris flood dominant are likely a mixture of floods and debris flows that reach the alluvial fan. The model selection in this instance will likely be a debris flow or flood model that can approximate the conditions occurring on the alluvial fan. Field mapping along incised channels can provide insights into the characteristics of flows building an alluvial fan. In each case, the alluvial fan slope can also be used to develop further clarity on the processes that develop the alluvial fan.

E.4 Basics of Alluvial Fan Flooding and Avulsions

Establishment of the alluvial fan formation process provides insight into flood hazards associated with the alluvial fan. Flooding, as explained here, does not include a recurrence interval or flood magnitude. Additional resources at the end of this Appendix provide details on recurrence interval specific flooding." Floods" refers to intense rainfall that:

- Increases flow conditions that mobilize the stream bed during a debris flood.
- Increases pore sediment water pressure on steep slopes, which leads to shallow landslides converting rapidly to a debris flow.
- Leads to sediment runoff bulking along the feeder channel to produce a debris flood or debris flow.

A range of flow magnitudes is experienced, and this flow variability is critical to long-term alluvial fan development.

Alluvial fan channels usually respond quickly to changing flows and associated sediment transport. Flow variation is critical to channel evolution and geometry. Channel geometry is vastly different in watersheds with variable flood magnitudes when compared to watersheds with a single discharge identified within a regime model analysis. Channel geometry alters in response to the mass flux (water and sediment) transported to and along an alluvial fan. If the channel conveyance is incapable of maintaining flow, or becomes impaired through channel plugging by boulders, sediment, or large woody debris, then the flow direction likely will change, forming a new channel.

Once leaving the feeder channel, sediment transporting flows typically occupy a portion of the alluvial fan surface. The entire alluvial fan is not inundated during flooding at a single point in time. While only a portion of the alluvial fan is occupied during floods, that portion can change rapidly as avulsions commonly occur. A portion of an alluvial fan segment may initially be inundated during a flood, but should an avulsion take place, another portion of the fan segment or a different fan segment could become inundated. The potential changes in the runout and inundation from avulsions lead to a high degree of flow path uncertainty as well as the size and extent of the inundation area during alluvial fan flooding.

Avulsions are an inherent feature of alluvial fan evolution, as the semi-conical alluvial fan form resulted from constant shifts in sediment transport through space and time. Common avulsion locations along channels are found where bank heights are low and along channel meanders. In flood-dominated fans, small floods can deposit sediment within the channel and fill the channel, reducing bank heights and channel conveyance. Localized channel filling can be produced by secondary processes such as weathering, aeolian processes, erosion and deposition, and surface runoff occurring within the fan segment on the alluvial fan surface. Flows overtopping the stream banks due to reduced channel capacity can flow to an abandoned channel, which may erode headward into the bank to capture the flow from the currently occupied channel.

Avulsions on debris flow dominated alluvial fans can result from a variety of factors: flow composition and grain-size distribution, longitudinal position along the fan, path obstructions, degree of lateral confinement, channel depth, and magnitude and frequency distributions. Avulsions may occur along an outer channel bend where debris flows tend to elevate and overtop a channel (Figure E-6). However, debris flow avulsions can result from debris flow deposition of the boulders obstructing the channel, reducing channel conveyance. “Channel plugging” describes how these avulsions often lead to subsequent debris flows overtopping the riverbank and occupying an abandoned channel near the avulsion. Larger boulders are more likely to cause avulsions as they reduce the channel conveyance to a higher degree than smaller material. Smaller channel plugs can be removed by subsequent larger flows.

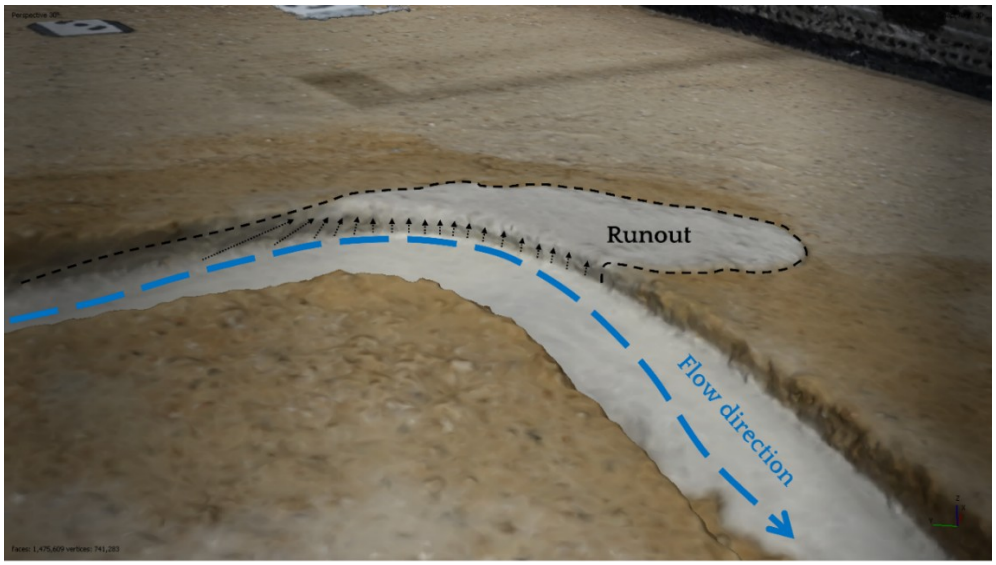
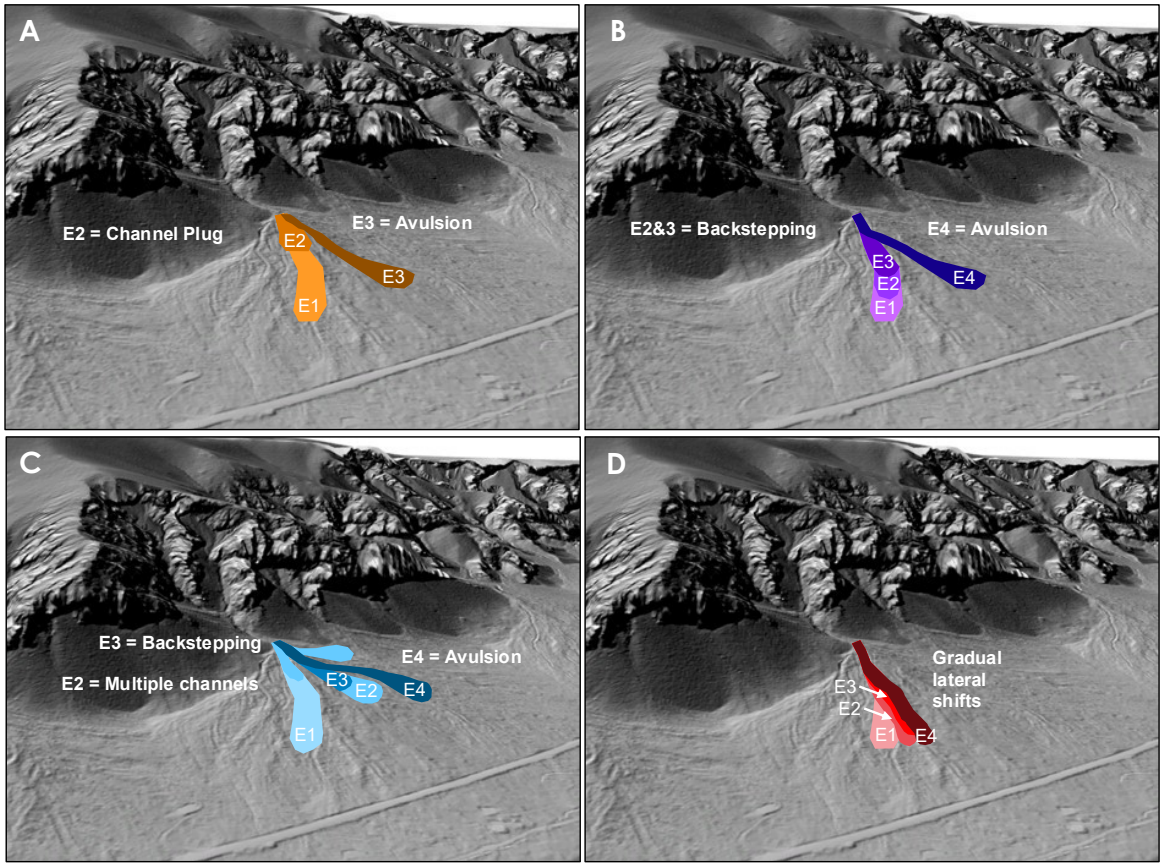


Figure E-6. Superelevation and avulsion in a channel (note flow direction) from a physical model. The superelevation begins where the bend starts (black arrows) and throughout the bend and overtops the stream bank. Superelevation occurs when the channel straightens. Where the flow overtops the channel, it runs out for a short distance in this example, but no new channel is formed. A debris flow lobe is deposited outside the channel.

Debris flow avulsions can take place over multiple flows or pulses within the same debris flow event. In general, avulsions and subsequent debris flow gradually shift the deposition toward lower locations on the alluvial fan. Four common patterns of avulsions on debris flow fans have been

identified and are often related to flow variability. The four avulsion pathways commonly identified with channel plugging are illustrated in Figure E-7.

A higher magnitude debris flow with high mobility will move out of the channel at a channel plug; this debris flow will erode a new channel or occupy an abandoned channel. Should an intermediate or smaller magnitude debris flow be obstructed by the channel plug, the debris flow might deposit behind the plug. This may set in motion a series of backstepping deposits towards the alluvial fan apex. Eventually, channel conveyance is decreased, and a subsequent debris flow can divert flows along a favorable pathway. Higher magnitude debris flows may overtop the channel and form multiple new flow pathways. The most favorable pathway in the vicinity of overtopping will eventually become the current channel. Smaller and steeper debris flow dominated alluvial fans often experience lateral deposits (e.g., levees) adjacent to the debris flow lobe, which gradually shift subsequent debris flow laterally into a favorable path.



Note: E# in each case is the debris flow event and the time it occurred (E1 – first event, E2 - second event, E3 – third event, and E4 – fourth event).

Figure E-7. Avulsion processes on debris flow fans. A (top left)- Avulsion at a channel plug. B (top right)- Avulsion because of backstepping processes. C (bottom left)- Avulsion from an initial multiple channel debris flow with backstepping. D (bottom right)- Avulsion via lateral shift in channel.

Backstepping processes are often associated with more uniform mass flow conditions. Where a greater range of flow conditions exists, channel plugging is the more likely scenario to lead to avulsions.

Investigation of avulsion frequency on alluvial fans and debris flow fans is limited. With limited data on avulsion frequency, it is critical to gather data on each alluvial fan to inform mapping, modeling, and flood zone determination.

E.5 Variations in Alluvial Fan Flood Hazards

Alluvial fans with flood-dominated flows often have terraces that become older with distance from the current channel. Terraces result from varying sediment pulses, uplift, base-level changes, or internal fluvial dynamics. Channels may take on a braided pattern or other less pronounced topography on flood-dominated fans. Flood-dominated channels generally lack levees and large boulders associated with debris flows.

Maps of surface features provide insights into topographic controls that may operate on the alluvial fan surface and inform the history of fan development. Topography is critical in controlling the current and future flow pathways on the alluvial fan surface. Alluvial fan surfaces with a high potential for flooding often include channels that have historically flooded, and areas along the flow pathway prone to avulsions. Moderate alluvial fan flooding potential is associated with low terraces adjacent to the historical channels, which are not high enough to avoid inundation during extreme floods.

FEMA's alluvial fan guidance encourages practitioners to define "active" versus "inactive" portions of an alluvial fan with the overarching goal to "narrow the area of concern." This activity has been established to reduce the amount of area to consider in flood modeling. The *"active,"* surface is meant to capture flooding within the last 100 years. All other locations on the alluvial fan surface are considered "inactive." There are varying degrees of available data and differing ways to define "active." Defining alluvial fans as "active" and "inactive" does not fit into the context of the current understanding of how alluvial fans evolve through space and time. Alluvial fans are by nature formed via periodic, rapid changes to the location of water and sediment transport across the fan surface. Considering a portion of an alluvial fan as "inactive" runs counter to the underlying processes that form the alluvial fan, which continually shifts the flow pathways occurring across the alluvial fan. "Active" refers to the current flow pathway without assumption of the pathway's history. The current flow pathway has the potential to shift to another portion of the alluvial fan.

Terms which accurately describe active and inactive alluvial fan characterization and flood modeling process include:

- **Active** –refers to the currently occupied flow path with the assumption that a current flow path has the potential to shift and occupy another portion of the alluvial fan during a flood event. This term is not used to refer to a surface or other portion of the alluvial fan.

- **Connected** – the hydrologically connected portion of the alluvial fan. This includes all sections of the fan that are connected to the feeder channel and could be a flow path for a given flood event.

- **Disconnected** – a hydrologically disconnected portion of the alluvial fan. These areas, surfaces, or flow paths, although formed as part of the alluvial fan, are no longer connected to the feeder channel and are not included within the flood map analysis area. An example of a disconnected surface would be a surface that, due to tectonic activity and/or erosion, sits above the connected alluvial fan surface.

Evaluation of the 1% flood hazard area is key to alluvial fan flood hazard delineation. These flood hazard assessments have evolved from river systems where stream gauge data is available to characterize the flood hazard potential. Most alluvial fan feeder channels remain ungauged, with limited available sediment data. Federal and academic research projects are collecting data, dependent on funding availability. Therefore, limited physics-based data is available to inform flood modeling (flood and debris flow). The design flood approach does not inform alluvial fan formation data and flow path uncertainty modeling. A design flood is further complicated by watershed wildfire history and anthropogenic modifications to the watershed and alluvial fan surface.

Alluvial fan flooding probability increases in recently burned watersheds. Intense wildfire changes soil chemistry and creates hydrophobic soil conditions that reduce soil infiltration capacity. When there are no channel blockages combined with a decrease in surface roughness due to vegetation loss, runoff is increased and can lead to debris flows and/or floods. Research consensus highlights that post-wildfire debris flows correlated with 15-minute rainfall intensities greater than 1-year to 2-year recurrence intervals. Post-wildfire debris flows are most frequent within the first year after a wildfire, but can occur three or more years following a wildfire. Debris flows and floods can occur prior to fire containment. Alluvial fan flooding associated with wildfire will typically exceed alluvial fan flooding in unburned watersheds.

Debris flows following wildfires tend to have higher velocities and increased height when compared to floods in unburned watersheds. Debris flows pose a greater risk to people, buildings, and infrastructure along flow pathways than flood flows. Debris flow runout extends over long distances, but runout lengths on alluvial fans are variable. In post-wildfire settings, multiple debris flows within the same watershed under favorable conditions are common.

Alluvial fan flooding is frequently modified by development and infrastructure within the watershed, which can impact hydrology and hydraulics as well as potential risk. Reduced infiltration from additional structures, roads, and parking lots allows more water to remain at the surface, potentially increasing the flood magnitude. This leads to greater inundation along the alluvial fan. Roads and culverts on alluvial fans can influence flow directions. Culverts often clog with sediment and debris transported in floods. Culvert plugging can lead to an avulsion around the culvert, increasing road overtopping risk that can cause significant downstream erosion with the potential to erode backwards into the road prism. This results in roadway flooding in areas that normally do not flood. Road and rail prisms can also change flow direction through damming. Multiple sources of water

input along the alluvial fan should be considered due to artificial redirection of water because of development diversions. Buildings, agricultural fields, and drainage infrastructure (canals, ditches, etc.) can redirect flow and should be considered in flood modeling. There are benefits to running terrain models without buildings/infrastructure, with the buildings/infrastructure, and future condition scenarios to provide insight into the potential outcomes from complex interactions between the alluvial fan topography and built environment.

E.6 Regulatory Framework for Alluvial Fans

The National Flood Insurance Program considers alluvial fans a flood hazard. Federal regulations define *"a*lluvial fan flooding*"* as flood flows originating at a fan apex with high velocity flows, sediment transport, and unpredictable paths. On FEMA Flood Insurance Rate Maps (FIRMs), active alluvial fan areas are typically mapped as Zone AO (shallow 1% annual flood) with specified depths and velocities, although there are other options that might be considered.

FEMA regulations recognize debris flows, often defined as "mud flows." The term mudslide is defined in the National Flood Insurance Program Regulations Appendix E (page E-6) as *a condition where there is a river, flow, or inundation of liquid mud down a hillside, usually as a result of a dual condition of loss of brush cover, and the subsequent accumulation of water on the ground preceded by a period of unusually heavy or sustained rain. A mudslide (i.e., mudflow) may occur as a distinct phenomenon while a landslide is in progress and will be recognized as such by the Administrator only if the mudflow, and not the landslide, is the proximate cause of damage that occurs.* Mudslides have been traditionally preliminarily mapped as a Zone M designation on Flood Hazard Boundary Maps, and the Zone AO designation may be refined to a Special Flood Hazard Area as a detailed study is developed for incorporation within the FIRM. There is limited guidance provided for debris flow mapping and modeling. FEMA's mapping and mitigation guidance considers debris flows an integral component of alluvial-fan flooding and encourages the definition of apex locations and assessment of debris-flow potential to ensure the design of flood controls for alluvial fan sediment transport.

Many states have specific regulations. Some community ordinances and permitting processes, along with state regulations, define detailed study requirements for proposed development in high hazard alluvial fan areas. Many communities require a licensed geologist or engineer to evaluate alluvial fan flooding hazards prior to project permitting.

E.7 Building Codes for Alluvial Fans

Federal guidance encourages the use of the International Building Code, International Residential Code, and ASCE 24 (Flood-Resistant Design), which often provide more stringent design of "higher standards" requirements for special flood hazard areas, including alluvial fans. FEMA encourages communities to exceed these minimums when regulating alluvial fans where possible. Under Title 44 Code of Federal Regulations Section 60.3 (National Flood Insurance Program floodplain management), construction in an AO zone on an alluvial fan must elevate the lowest floor above the

flood depth shown on the map and provide drainage to carry flows around structures. FEMA's *Alluvial Fan Flooding* guidance (FEMA Form 6, 2024) explicitly states that simply filling or elevating a site *will not serve as a basis for removing areas subject to alluvial fan flooding from [the] area of special flood hazards.* In practice, FEMA will only approve a map revision (LOMA/LOMR) if a comprehensive flood control project eliminates the alluvial fan hazard. National Flood Insurance Program regulations designate active alluvial fans as Special Flood Hazard Areas (Zone AO/A) subject to strict elevation grade controls and anchoring requirements.

Most states have adopted model building codes consistent with the International Building Code and International Residential Code, but a few states delegate regulation of construction projects to local governments. The model International Codes, when adopted throughout this nation as written, require flood-resistant design on alluvial fans (equal to or exceeding National Flood Insurance Program requirements), even though debris flow and fan sediment hazards are not specified. Debris flow and sediment hazards are generally managed under these building codes, which incorporate numerous required standards by reference unless amended out, through consideration of flood load, scour, erosion, debris impacts, and local geotechnical foundation design requirements.

Local ordinances may recommend development of mitigation measures such as engineered drainage, open pile foundations, scour protection, and debris flow mitigation. Local codes may prohibit basements or fill. State, local, tribal, and territorial participating National Flood Insurance Program communities must adopt and enforce floodplain management ordinances that comply with National Flood Insurance Program requirements at a minimum, but can be more restrictive. In high-risk zones, best practices include but are not limited to requiring open foundations or elevated utilities, preserving alluvial fans as open space, and prohibiting extensive fill or excavation without engineering.

It should be noted that the most effective mitigation is to avoid construction lateral or downstream of known alluvial fans or areas that are vulnerable to alluvial fan development. Consultation with the U.S. Geological Survey State Offices (www.usgs.gov), the state Geologist, university geology departments, or a registered Professional Geologist is recommended prior to any planned development in areas with historic or suspected alluvial fan activity.

Additional Resources for Alluvial Fans

Federal Sources:

- FEMA Guidance for Flood Risk Analysis and Mapping: Alluvial Fans: https://www.fema.gov/sites/default/files/2020-02/Alluvial_Fans_Guidance_Nov_2016.pdf
- Instructions for Form 6 – Alluvial Flooding - https://www.fema.gov/flood-maps/change-your-flood-zone/paper-application-forms/mt-2/instructions-form-6-alluvial-fan-flooding
- FEMA Definitions - https://www.ecfr.gov/current/title-44/chapter-I/subchapter-B/part-59/subpart-A/section-59.1
- FEMA Appendix E: National Flood Insurance Program Regulations - https://www.fema.gov/pdf/floodplain/nfip_sg_appendix_e.pdf
- FEMA MT-2 Guidance - https://www.fema.gov/sites/default/files/documents/fema_MT-2-requests-guidance_112021.pdf
- US Army Corps of Engineers Flood Risk Reduction on Alluvial Fans - https://usace.contentdm.oclc.org/utils/getfile/collection/p16021coll2/id/7634
- International Building Codes - https://codes.iccsafe.org/content/IBC2024P1

State Sources:

- California Geological Survey Alluvial Fan Flooding Report - https://www.researchgate.net/publication/341794022_ALLUVIAL_FAN_FLOODING_HAZARDS_AN_ENGINEERING_GEOLOGIC_APPROACH_TO_PRELIMINARY_ASSESSMENT_ALLUVIAL_FAN_FLOODING_HAZARDS
- California Hazard Mitigation Plan- https://www.caloes.ca.gov/wp-content/uploads/Hazard-Mitigation/Documents/2023-California-SHMP_Volume-2-Appendix-T_12.15.2023.pdf
- Utah Alluvial Fan Flood Hazards - https://floodhazards.utah.gov/home/alluvial-fans/#:~:text=%2A%20Require%20a%20comprehensive%20engineering,resistant%20materials

Local Sources:

- Thousand Oaks, California - https://codelibrary.amlegal.com/codes/thousandoaks/latest/thousandoaks_ca/0-0-0-5002
- Carlin, Nevada - https://codelibrary.amlegal.com/codes/carlinnv/latest/carlin_nv/0-0-0-6005
- Whatcom County, Washington - https://www.whatcomcounty.us/2756/Completed-Plans-Alluvial-Fans

Appendix F. Floodwall Design Details and Calculations

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F.1 Detailed Floodwall Design Process

The design of floodwalls consists of the proper selection and sizing of the floodwall and the specification of any necessary drainage systems; waterproof materials to stop seepage and leakage; and miscellaneous details to meet site and homeowner preferences for patios, steps, wall facings, and support of other overhead structures (posts and columns). This section describes the detailed design process for design professionals referenced in Section 6.3.1.3. By contrast, a simplified design approach is included later in Section 6.3.1.3 of this document.



Note

The permeability of concrete block may necessitate the use of a monolithic core or the application of sealants to eliminate seepage through the wall.

The detailed structural design of a floodwall to resist anticipated flood and flood-related forces follows the detailed, eight-step process (Figure F-1).

The stability of the floodwall should be investigated for different modes of failure.

Sliding: A wall, including its footing, may fail by sliding if the sum of the lateral forces is greater than the total forces resisting the displacement. The resisting forces should always be greater than the sliding forces by a factor of safety (Figure F-2).

Overturning: Another mode of failure is overturning at the foundation toe. This type of failure may occur if the sum of the overturning moments is greater than the sum of the resisting moments above the toe. The sum of resisting moments should be greater than the sum of the overturning moments by a factor of safety (Figure F-3).

Excessive Soil Pressure: Finally, a wall may fail if the pressure under its footing exceeds the allowable soil bearing capacity (Figure F-4).

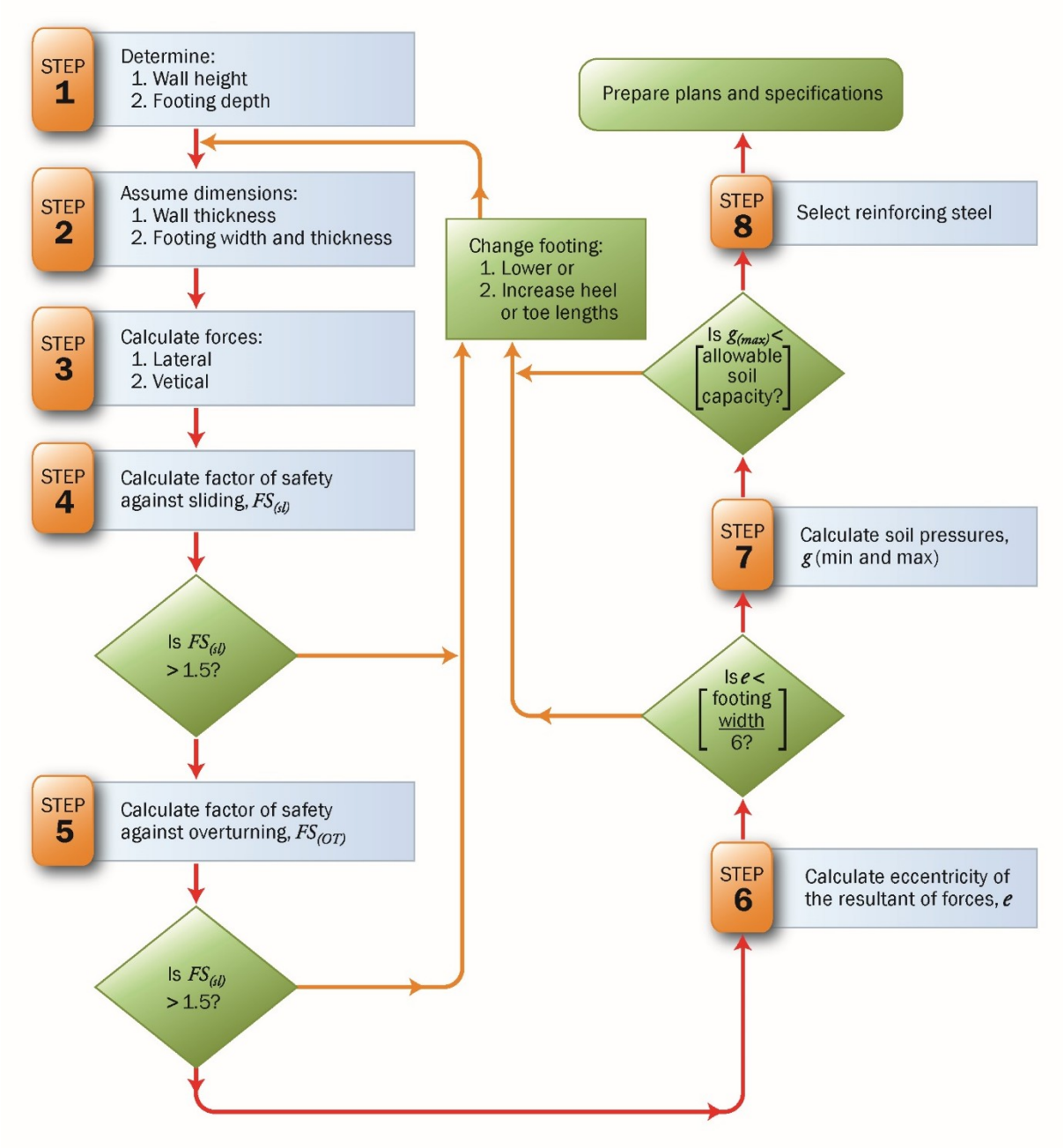


Figure F-1. Floodwall design process

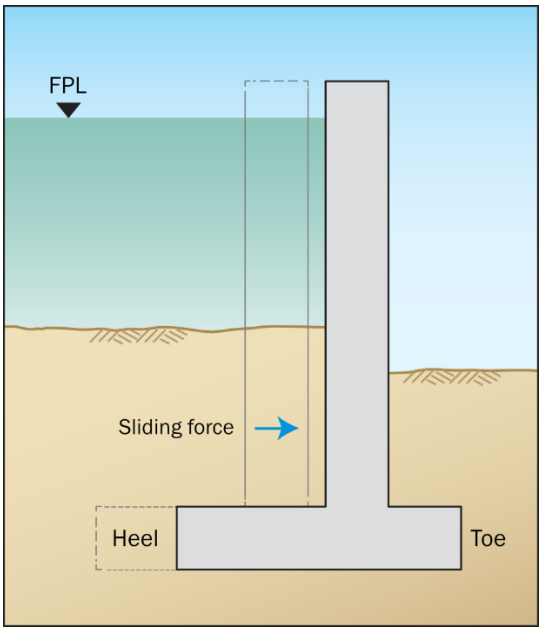


Figure F-2. Failure by sliding.

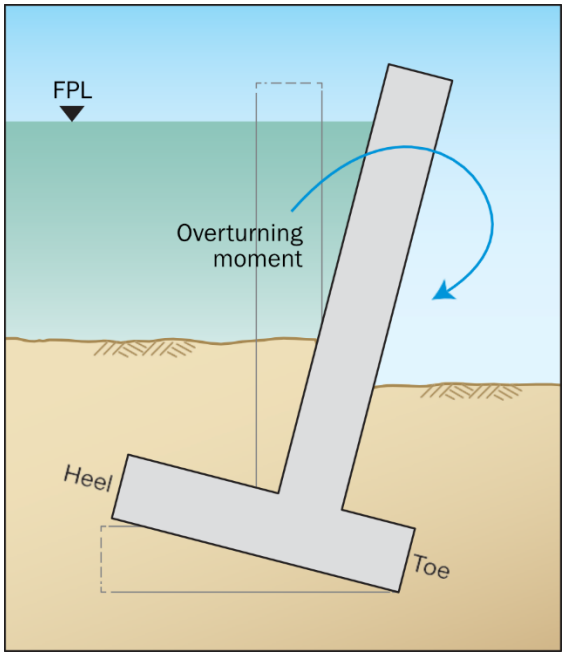


Figure F-3. Failure by overturning

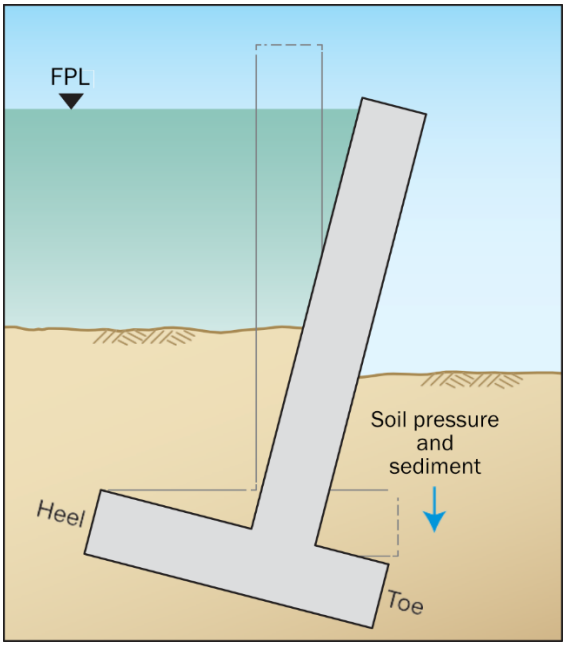


Figure F-4. Failure due to excessive soil pressure

The step-by-step process for completing the structural design of a floodwall follows with an example illustrating the use of the equations. Note that the floodwall design process is iterative: an initial design is informed by experience and T_{past} successful designs, checked against design loads and conditions, then revised as needed until all requirements are satisfied by the design. Table F-1 provides soil information that is necessary in the computations that follow.

Table F-1. Soil Factors for Floodwall Design

Unified Soil Classification System Soil Type	Allowable Bearing Pressure S_{bc} (lb/ft²)	Coefficient of Friction, C_f
Clean, dense sand and gravel, GW, GP, SW, and SP	2,000	0.55
Dirty sand and gravel of restricted permeability, GM, GM-GP, SM, and SM-SP	2,000	0.45
Firm to stiff silts, clays, silty fine sands, clayey sands and gravel, CL, ML, CH, SM, SC, and GC	1,500	0.35
Soft clay, silty clay, and silt, CL, ML, and CH	600	0.30

Step 1: Determine wall height and footing depth.

- Determine wall height based on the Flood Protection Level.
- Determine minimum footing depth based on the frost depth, local code requirements, and the soil conditions. The footing should rest on suitable natural soil or on controlled and engineered backfill material.

Step 2: Assume dimensions.

- Based on the following guidelines or reference to engineering handbooks, assume dimensions for the wall thickness, footing width, and footing thickness.
- The choice of wall thickness depends on the wall material, the strength of the material, and the height of the wall. Typical wall thicknesses are eight, 12, and 16 inches for masonry, concrete, or masonry/ concrete walls.
- The footing width depends on the magnitude of the lateral forces, allowable soil bearing capacity, dead load, and the wall height. The typical footing width is the proposed wall height. Typically, the footing is located under the wall in such a manner that 1/3 of its width forms the toe and 2/3 of the width forms the heel of the wall (Figure F-5). Typical footing thicknesses are based upon strength requirements and include 8, 12, and 16 inches.

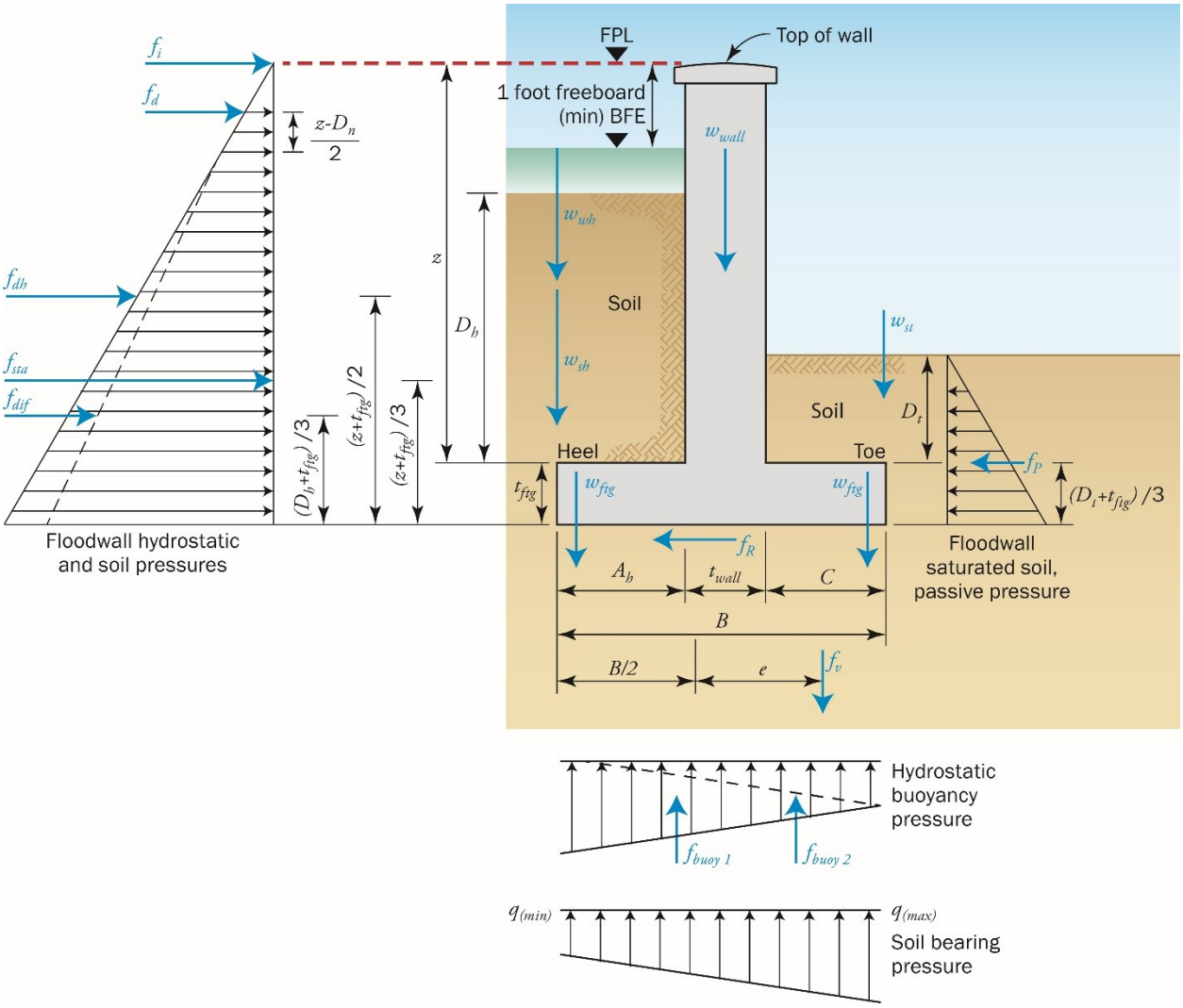


Figure F-5. Forces acting on a floodwall

Step 3: Calculate forces.

There are two types of forces acting on the wall and its footing: lateral and vertical. These forces were discussed in Chapter 3.

- **Lateral forces:** The hydrostatic and differential soil/water forces on the heel side of the wall, and the saturated soil force on the toe side of the wall. Hydrostatic and soil forces are as described in Chapter 4.
- **Vertical forces:** The vertical forces are buoyancy and the various weights of the wall, footing, soil, and water acting upward and downward on the floodwall. The buoyancy force, f_{buoy}, acting at the bottom of the floodwall footing is computed as shown in Equation F-1.



EQUATION F-1: BUOYANCY ON A FLOODWALL

$$f_{buoy} = f_{buoy1} + f_{buoy2}$$

with f_{buoy1} and f_{buoy2} computed as follows:

$$f_{buoy1} = \gamma_\omega \left[(z)\left(\frac{1}{2}t_{wall}\right) + \left(A_h + \frac{1}{2}t_{wall}\right)\left(t_{ftg}\right)\right] \textit{ (based on Equation 3-6)}$$

$$f_{buoy2} = \gamma_\omega \left[(D_t)\left(\frac{1}{2}t_{wall}\right) + \left(C + \frac{1}{2}t_{wall}\right)\left(t_{ftg}\right)\right] \textit{ (based on Equation 3-6)}$$

Where:

f_{buoy} = total force due to buoyancy (lb/lf)

f_{buoy1} = buoyancy force due to hydrostatic pressure at the floodwall heel acting at an approximate distance of B/3 from the heel (lb/lf)

f_{buoy2} = buoyancy force due to hydrostatic pressure at the floodwall toe, acting at an approximate distance of B/3 from the toe (lb/lf)

γ_w = specific weight of water (62.4 lb/ft^3 for fresh water and 64.0 lb/ft^3 for saltwater)

A_h = width of the footing above the heel (ft)

C = width of the footing above the toe (ft)

z = floodproofing design depth extended below grade (ft)

D_t = depth of soil above the floodwall toe (ft)

t_{ftg} = thickness of the floodwall footing (ft)

t_{wall} = thickness of the floodwall (ft)

(Refer to Figure F-5)

The gravity forces acting downward are:

- The unit weight of floodwall (w_{wall}), computed using Equation F-2.
- The unit weight of the footing (w_{ftg}), computed using Equation F-3.

- The unit weight of the soil over the toe (w_{st}), computed using Equation F-4. The unit weight of the soil over the heel (w_{sh}), computed using Equation F-5.
- The unit weight of the water above the heel (w_{wh}), computed using Equation F-6.

EQUATION F-2: FLOODWALL WEIGHT

$W_{wall} = (z)t_{wall}\,S_g$ (Refer to Figure F-5)

Where:

W_{wall} = weight of the wall (lb/lf)

z = floodproofing design depth extended below grade (ft)

t_{wall} = wall thickness (ft)

S_g = unit weight of wall material S (lb/ft^3)

EQUATION F-3: FOOTING WEIGHT

$W_{ftg=}B\ t_{ftg}\ S_g$ (Refer to Figure F-5)

Where:

w_{ftg} = weight of the footing (lb/lf)

B = width of the footing (ft)

t_{ftg} = footing thickness (ft)

S_g = unit weight of wall material (concrete is 150 lb/ft^3)

EQUATION F-4: WEIGHT OF SOIL OVER FLOODWALL TOE

$W_{st} = C(D_t)(\gamma_{soil})$ (Refer to Figure F-5)

Where:

W_{st}= weight of the soil over the toe (lb/lf)

C = width of the footing toe (ft)

D_t = depth of the soil above the floodwall toe (ft)

γ_{soil} = unit weight of soil (lb/ft^3)

Cross Reference

The unit weight of soil, γ_{soil}, can be obtained from Chapter 6 in Table 6-1 or from the soil survey, engineering texts, or a geotechnical engineer.

EQUATION F-5: WEIGHT OF SOIL OVER FLOODWALL HEEL

$$W_{sh} = A_h(D_h)(\gamma_{soil} - \gamma_\omega)$$ (Refer to Figure F-5)

Where:

W_{sh} = weight of the soil over the heel (lb/lf)

A_h = width of the footing heel (ft)

D_h = depth of the soil above the heel (ft)

γ_{soil} = unit weight of the soil (lb/ft^3)

γ_w = specific weight of water (62.4 lb/ft^3 for fresh water and 64.0 lb/ft^3 for saltwater)

EQUATION F-6: WEIGHT OF WATER OVER FLOODWALL HEEL

$$w_{wb} = A_b(z)(\gamma_w)$$ (Refer to Figure F-5)

Where:

w_{wb} = weight of the soil over the heel (lb/lf)

A_b = width of the footing heel (ft)

z = depth of the water above the heel (ft)

γ_w = specific weight of water (62.4 lb/ft^3 for fresh water and 64.0 lb/ft^3 for saltwater)

The total gravity forces acting downward, w_G, in pounds per linear foot can be computed using Equation F-7 as the sum of the individual gravity forces computed in Equations F-2 through F-6:

EQUATION F-7: TOTAL GRAVITY FORCES PER LINEAR FOOT OF WALL

$$W_G = w_{wall} + w_{ftg} + w_{st} + w_{sh} + w_{wh}$$ (Refer to Figure F-5)

Where:

W_G = total gravity forces acting downward (lb/ft)

w_{wall} = weight of wall (lb/ft)

w_{ftg} = weight of footing (lb/ft)

w_{st} = weight of soil over the toe (lb/ft)

w_{sh} = weight of soil over the heel (lb/ft)

w_{wh} = weight of water above the heel (lb/ft)

Therefore, the net vertical force, f_v, is then calculated using Equation F-8.

EQUATION F-8: NET VERTICAL FORCE

$$f_v = w_G - f_{buoy} > 0$$ (Refer to Figure F-5)

Where:

f_v = net vertical force (lb/ft)

w_G = total gravity forces acting downward (lb/ft)

f_{buoy} = total force due to buoyancy (lb/ft)

The net vertical forces in Equation F-8 must be greater than or equal to zero. If the value is determined to be less than zero, the designer should change the footing dimensions, then go back to Step 3 and try again (Figure F-1).

Step 4: Calculate factor of safety against sliding.

This step involves the computation of the sliding forces, the forces resisting sliding, and the factor of safety against sliding. For a stable condition, the sum of forces resisting sliding should be larger than the sum of the sliding forces.

Sliding Forces: The sum of the sliding (lateral hydrostatic, hydrodynamic, and impact) forces, f_{comb}, is computed in Equation F-9 as follows:

EQUATION F-9: SLIDING FORCES

$f_{comb} = f_{sta} + f_{dif} + (f_{db} \; or \; F_d/b)$ (Refer to Figure F-5)

Where:

f_{comb} = cumulative lateral hydrostatic force acting at a distance $\frac{H}{3}$ from the point under consideration (lb/ft)

f_{stae} = lateral hydrostatic force due to standing water extended below grade (lb/ft)

f_{dif} = differential soil/water force acting due to combined free-standing water and saturated soil conditions (lb/ft)

f_{dh} = equivalent hydrostatic pressure due to low velocity flood flows (lb/ft)

F_d/b = hydrodynamic force against the structure due to high velocity flood flows (lb/ft)

Note: The computations of f_{stae}, f_{dif}, f_{dh}, and F_d/b and are presented in Equations 3-4, 3-5, 3-8, and 3-10. However, for floodwall design, H used in equations 3-4 and 3-8 is replaced with $(z + f_{ftg})$, and D used in equation 3-5 is replaced with $(D_b + t_{ftg})$, where:

z = floodproofing design depth extended below grade (ft)

D_b = depth of soil above the floodwall heel (ft)

t_{ftg} = thickness of the floodwall footing (ft)

- **Resisting Forces:** The forces resistant to sliding are the frictional force, f_{fr}, between the bottom of the footing; the cohesion force, f_c, between the footing and the soil; and the soil and saturated soil force, f_p, over the toe of the footing. These resisting forces are computed as follows:

- **Frictional Force:** The frictional force, f_{fr}, between the bottom of the footing and the soil is a function of net vertical force, f_v, times coefficient of friction, C_f (Equation F-10). The coefficient of friction, C_f, between the base and the soil depends on the soil properties (see Table F-1).

EQUATION F-10: FRICTIONAL FORCE

$f_{fr} = C_f f_v$

Where:

f_{fr} = friction force between the footing and the soil (lb/ft)

C_f = coefficient of friction between the footing and the soil

f_v = net vertical force acting on the footing as was previously presented in Equation F-8 (lb/ft)

Cohesion Force: The cohesion force between the base and the soil, fc, is obtained by multiplying the width of the footing, B, by the allowable cohesion value of the soil (Equation F-11). This allowable cohesion value is usually obtained from a geotechnical analysis of the soil. The cohesion between the footing and the soil may be destroyed or considerably reduced due to contact from water. Due to potentially high variations in the allowable cohesion value of a soil, the cohesion is usually neglected in the calculations; unless the value of cohesion is ascertained by soil tests or other means, it should be taken as zero in the calculations.

EQUATION F-11: COHESION FORCE

$$f_c = C_s B$$ (Refer to Figure F-5)

Where:

f_c = cohesion force between the base and the soil (lb/ft)

C_s = allowable cohesion force between (lb/ft^2) (usually assumed to be zero)

B = width of the footing (ft)

- **Saturated Soil Force Over the Toe:** The saturated soil force over the toe, f_p, is calculated using Equation F-12.

EQUATION F-12: SATURATED SOIL FORCE OVER THE TOE

$$f_p = \frac{1}{2}\left[\kappa_p(\gamma_{soil} - \gamma_w) + \gamma_w\right]\left(D_t + t_{ftg}\right)^2$$ (Refer to Figure F-5)

Where:

f_p = passive saturated soil force over the toe (lb/ft)

γ_{soil} = unit weight of the soil (lb/ft^3)

D_t = depth of the soil over the floodwall toe (ft)

t_{ftg} = thickness of the floodwall footing (ft)

κ_p = passive soil pressure coefficient

γ_w = specific weight of water (62.4 lb/ft^3 for fresh water and 64.0 lb/ft^3 for saltwater)

Note

The passive soil pressure coefficient, kp, typically ranges from 2 to 5. Typical values are 2 for plastic clays, 3 for clayey silts and poorly graded gravels, and 3–4 for well-graded soils. Consult a geotechnical engineer for more precise values.

The sum of the resisting forces to sliding f_R, is calculated as the sum of the individual resisting forces to sliding, computed in Equations F-10 through F-12, as shown in Equation F-13.

EQUATION F-13: SUM OF RESISTING FORCES TO SLIDING

$$f_R = f_{fr} + f_c + f_p$$ (Refer to Figure F-5)

Where:

f_R = resisting force to sliding (lb/ft)

f_{fr} = friction force between the footing and the soil (lb/ft)

f_c = cohesion force between the base and the soil (lb/ft)

f_p = passive saturated soil force over the toe (lb/ft)

- **Factor of Safety Against Sliding:** For the stability of the wall, the sum of resisting forces to sliding f_R should be larger than the sum of the sliding forces, f_{comb}. The ratio of f_R over f_{comb} is called the Factor of Safety against sliding, $FS_{(SL)}$, and is calculated as shown in Equation F-14:

EQUATION F-14: FACTOR OF SAFETY AGAINST SLIDING

$$FS_{(SL)} = \frac{f_R}{(f_{comb}+f_i)} \geq 1.5$$

Where:

$FS_{(SL)}$= factor of safety against sliding (should be greater than 1.5)

f_R = sum of the forces resisting sliding in (lb/ft)

f_{comb} = sum of the sliding forces (cumulative lateral hydrostatic force) (lb/ft)

f_i = normal impact force (lb/ft)

Note: The fi is expressed in lb/lf based on impact the force F_i (lbs) computed in Equation 3-11 conservatively applied over a unit length of one foot.

The factor of safety against sliding in Equation F-14 should be at least 1.5. If the factor of safety is determined to be less than 1.5, the designer should lower the footing, increase the amount of fill over the footing, and/or change the footing dimensions, then go back to Step 3 and try again (Figure F-1).

Step 5: Calculate the factor of safety against overturning.

The potential for overturning should be checked at the bottom of the toe (Figure F-5). For a stable condition, the sum of resisting moments, M_R, should be larger than the sum of the overturning moments, M_O. The ratio of M_R over M_O is called the Factor of Safety against overturning, $FS_{(OT)}$.

- **Overturning Moments:** The overturning moments are due to hydrostatic and hydrodynamic forces, impact loads, saturated soil, and the buoyancy forces acting on the footing. The sum of the overturning moments, M_O, is calculated as shown in Equation F-15.



EQUATION F-15: SUM OF OVERTURNING MOMENTS

$$M_O = f_{sta}\left(\frac{(z+t_{ftg})}{3}\right) + f_{dif}\left(\frac{(D_b+t_{ftg})}{3}\right) + f_{buoy}\left(\frac{2B}{3}\right) + \left[f_{dh}\left(\frac{(z+t_{ftg})}{2}\right) \text{ or } (F_d/b)\left((z+t_{ftg}) - \frac{(D_b+t_{ftg})}{2} + (D_b+t_{ftg})\right)\right] + f_i(z+t_{ftg}) + f_{buoy2}\left(\frac{B}{3}\right)$$

Where:

M_O = sum of the overturning moments (ft-lbs/lf)

f_{stae} = lateral hydrostatic force due to standing water extended below grade (lb/lf) (Eq. 3-4)

f_{dif} = differential soil/water force acting due to combined free-standing water and saturated soil conditions (lb/lf) (Eq. 3-5)

f_{buoy} = buoyancy force, in lb/lf, due to hydrostatic pressure at the floodwall heel acting at an approximate distance of $\frac{B}{3}$ from the heel (Eq. F-1)

f_{buoy2} = buoyancy force, in lb/lf, due to hydrostatic pressure at the floodwall toe, acting at an approximate distance of $\frac{B}{3}$ from the toe (Eq. F-1)

f_{dh} = low velocity force (lb/ft) (Eq. 3-8)

F_d/b = high velocity hydrodynamic force (lb/ft) (Eq. 3-10)

f_i = normal impact force (lb/ft) (Eq. 3-11)

B = width of the footing (ft)

z = height of the wall extended below grade (ft)

D_b = height of the soil above the heel (ft)

t_{ftg} = thickness of the floodwall footing (ft)

Note: The computations of f_{sta}, f_{dif}, f_{dh}, f_d, and f_i are presented in Equations 3-4, 3-5, 3-8, 3-10, and 3-11. However, for floodwall design, *H* used in Equations 3-4 and 3-8 should be replaced with ($z + t_{ftg}$), and *D* used in Equation 3-5 should be replaced with ($Dh + t_{ftg}$). Additionally, the f_i presented in Equation 3-11 is expressed in lb/lf based on impact force Fi (lbs) conservatively applied over a length of 1 foot.

Note

When hydrostatic input loads act on the floodwall sections parallel to the flow and the downstream facing wall, Equations F-9 and F-15 will produce conservative results. Further detailed analysis may result in smaller sections and a corresponding reduction in cost.

- **Resisting Moments:** The resisting moments are due to all vertical downward forces and the lateral force due to soil over the toe. The sum of resisting moments, M_R, is calculated in Equation F-16.

EQUATION F-16: SUM OF RESISTING MOMENTS

$$M_R = w_{wall}\left(C + \frac{t_{wall}}{2}\right) + w_{ftg}\left(\frac{B}{2}\right) + w_{st}\left(\frac{C}{2}\right) + w_{sh}\left(B - \frac{A_b}{2}\right) + w_{wh}\left(B - \frac{A_b}{2}\right) + f_p\left(\frac{(D_t + t_{ftg})}{3}\right)$$

Where:

M_R = sum of the resisting moments in (ft-lbs/lf)

w_{wall} = weight of the wall (lb/lf)

t_{wall} = wall thickness (ft)

t_{ftg} = footing thickness (ft)

w_{ftg} = weight of the footing (lb/lf) (Eq. F-3)

B = width of the footing (ft)

w_{st} = weight of the soil over the toe (lb/lf) (Eq. F-4)

C = width of the footing toe (ft)

D_t = depth of the soil above the floodwall toe (ft)

w_{sh} = weight of the soil over the heel (lb/lf) (Eq. F-5)

A_b = width of the footing heel (ft)

w_{wh} = weight of the water above the heel (lb/lf) (Eq. F-6)

f_p = passive saturated soil force over the toe (lb/lf) (Eq. F-12)

- **Factor of Safety Against Overturning:** As mentioned earlier, for a stable condition, the sum of resisting moments, M_R, should be larger than the sum of the overturning moments, M_O, resulting in a factor of safety greater than 1.0. However, the factor of safety against overturning, $FS_{(OT)}$, computed in Equation F-17, should not be less than 1.5. If $FS_{(OT)}$ is found to be less than 1.5, the designer should increase the footing dimensions, then go back to Step 3 and try again (see Figure F-1).

EQUATION F-17: FACTOR OF SAFETY AGAINST OVERTURNING

$$FS_{(OT)} = \frac{M_R}{M_O} \geq 1.5$$

Where:

$FS_{(OT)}$ = factor of safety against overturning (should be greater than 1.5)

M_R = sum of the resisting moments in ft-lbs/lf (Equation F-16)

M_O = sum of the overturning moments in ft-lbs/lf (Equation F-15)

Step 6: Calculate eccentricity.

The result of all the forces acting on the wall and its footing is a force acting at a distance, *e,* from the centerline of the footing. This distance, *e*, is known as eccentricity. The calculation of eccentricity is important to ensure that the bottom of the footing is not in tension. The eccentricity value is also needed for the calculation of soil pressures in Step 7. The eccentricity, *e*, is calculated as shown in Equation F-18.

EQUATION F-18: ECCENTRICITY

$$e = \left(\frac{B}{2}\right) - \left(\frac{(M_R - M_O)}{f_v}\right)$$ (Refer to Figure F-5)

Where:

e = eccentricity (ft)

B = width of the footing (ft)

f_v = net vertical force acting on the footing (lb/ft) (Eq. F-8)

M_O = overturning moment (ft-lbs/lf) (Eq. F-15)

M_R = resisting moment (ft-lbs/lf) (Eq. F-16)

This eccentricity, *e*, should be less than 1/6 of the footing width. If *e* is found to exceed *B*/6, change the footing dimensions, go back to Step 3, and try again (Figure F-1).

Step 7: Calculate soil pressures.

The soil pressures, q, are determined from Equation F-19.

EQUATION F-19: SOIL PRESSURE

$$q = \left(\frac{f_v}{B}\right)\left(1 \pm \left(\frac{6e}{B}\right)\right)$$ (Refer to Figure F-5)

Where:

q = soil pressure created by the forces acting on the wall (lb/ft^2)

f_v = net vertical force acting on the footing (lb/ft)

B = width of the footing (ft)

e = eccentricity (ft)

The maximum value of q should not exceed the allowable soil bearing capacity. The bearing capacity of soil varies with the type of soil, moisture content, temperature, and other soil properties. A geotechnical engineer should determine the allowable values. Some conservative allowable bearing values for a few soil types are given in Table F-1. If the computed value of q is more than the allowable soil bearing value, increase the footing size, then go back to Step 3 and try again (see Figure F-1).

Step 8: Select reinforcing steel.

Select an appropriate reinforcing steel size and spacing to resist the expected bending moment, Mb. Figure F-6 illustrates a typical floodwall reinforcing steel installation. The cross-sectional area of steel reinforcing required can be computed using Equation F-20. This equation assumes use of steel with a Fy = 60 ksi.

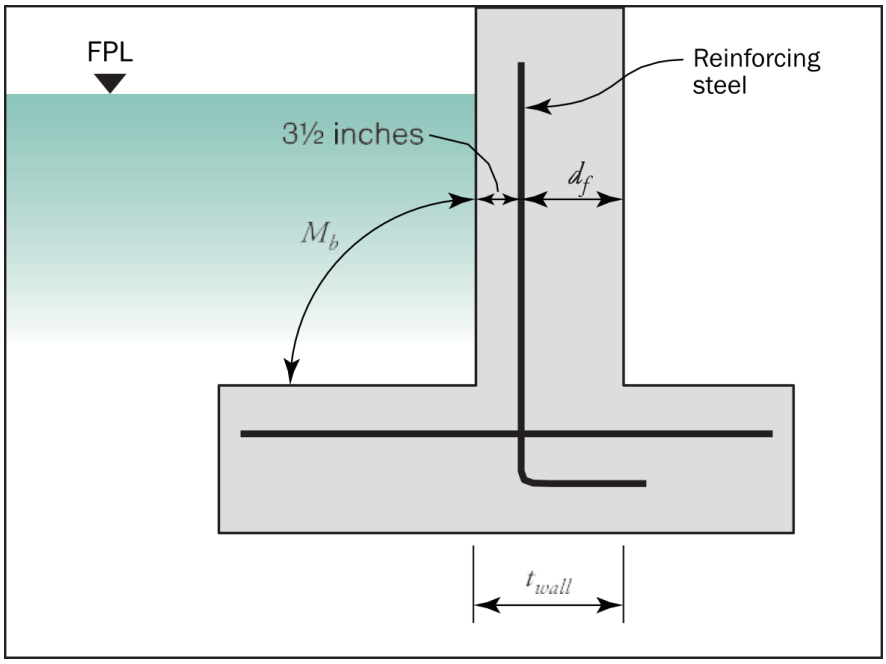


Figure F-6. Typical floodwall reinforcing steel configuration

Note

The bending moment *(M_b)* for sizing reinforcing steel in the vertical floodwall component is the product of the lateral hydrostatic force *(F_{sta})* and the distance between the point of force application and the bottom of the vertical floodwall component *($z/3 - t_{ftg}$)*.

EQUATION F-20: CROSS-SECTIONAL AREA OF REINFORCING STEEL

$$A_s = \left(\frac{\left(\frac{M_b}{1{,}000}\right)}{1.76 d_f}\right)$$

(Refer to Figure F-5)

Where:

A_s = cross-sectional area of reinforcing steel required per foot width of wall (in.^{2})

M_b = bending moment (ft-lbs/lf)

$1{,}000$ = factor used to convert ft-lbs to ft-kips

d_f = distance between the reinforcing steel and the floodwall face opposite retained material (in.)

Note

d_f is typically the floodwall thickness minus 3½ inches to allow a minimum of 3 inches between the reinforcing steel and the floodwall edge.

Note

The selection of reinforcing steel in the footing portion of a floodwall is computed using Equation F-20 while modifying M_b for top and bottom steel considerations. For top steel, the moment is the product of the weight of soil and water over the heel (w_{sh}+w_{wh}) and the heel length (A_h) divided by 2.

The selection of bottom steel is a function of the soil bearing pressure. The moment can be computed by adding the soil bearing pressure at the toe edge of the vertical floodwall section to twice the maximum soil bearing pressure ($q + 2q_{max}$) and multiplying this sum by toe length squared over 6 ($C^2/6$). The soil bearing pressure at the toe edge of the vertical floodwall section (q) can be computed by ratio from the calculations (for q_{min}, q_{max}) shown in Step 7.

Using the computed cross-sectional area of reinforcing steel, refer to ACI 318 to select the most appropriate steel reinforcing bar size and spacing.

F.2 Detailed Floodwall Closure Design

Many of the principles discussed earlier in Section F.1 apply to floodwall closure design. Watertight closures must be provided for all access openings, such as driveways, stairs, and ramps. Seals should be provided for all utility penetrations. The type of closure material used depends primarily on the size of the opening that needs to be protected (Figure F-7).

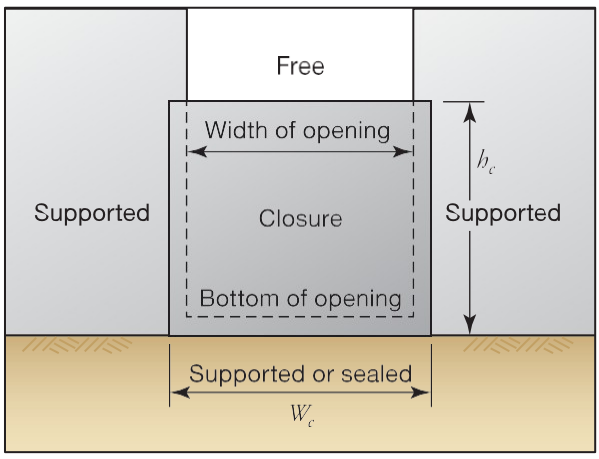


Figure F-7. Closure variables

The closure material must be of sufficient strength and thickness to resist bending and deflection failures. The ability of a specific material to withstand bending stresses may be substantially different from its ability to withstand deflection stresses. Therefore, to provide for an adequate factor of safety, the required closure thickness should be calculated twice: for bending stresses and deflection stresses. The resulting thicknesses should be compared, and the larger value specified in the final closure design.

Warning

Orientation of Openings: It is highly recommended that openings in floodwalls and levees not be placed on the upstream side. If they are, Equations F-21, F-22, F-23, and F-24 should be modified to include the expected hydrodynamic forces. Closures should not be used on upstream sides where impact loads are expected.

One method of determining the thickness of the closure for steel and aluminum is presented in *Roark's Formulas for Stress and Strain* (Roark and Young, 1989). For a flat plate supported on three sides, the plate thickness required due to bending stresses may be determined by the following equation:

EQUATION F-21: PLATE THICKNESS DUE TO BENDING STRESSES

$$t = \sqrt{\frac{P_h + (P_{dh} \text{ or } P_d) W_c^2 \beta}{Max\sigma}}$$ (Refer to Figure F-7)

Where:

t = plate thickness (in.)

P_h = hydrostatic pressure due to standing water (psi) from Equation 3-4

W_c = width of closure (in.)

$Max\ \sigma$ = allowable stress for the plate material (from material handbooks) (lb/in.^{2})

β = moment coefficient from Table F-2

$P_{dh}\ and\ P_d$ = are defined in Equations 3-8 and 3-10, respectively

Similarly, for a steel or aluminum flat plate supported on three sides, the plate thickness required due to deflection stresses may be determined by the following equation:

EQUATION F-22: PLATE THICKNESS DUE TO DEFLECTION STRESSES

$$t = \sqrt{\frac{360\alpha P + (P_{dh} \text{ or } P_d) W_c^3}{E}}$$ (Refer to Figure F-6)

Where:

α = deflection coefficient from Table F-2

E = modulus of elasticity for the plate material (from material handbooks) (lb/in.^{2})

P_{dh} *or* P_d = are defined in Equations 3-8 and 3-9, respectively

Table F-2 details the moment and deflection coefficients as a function of the ratio of plate height to width.

Table F-2 Moment (β) and Deflection (α) Coefficients

h_c/W_c*	0.05	0.67	1.00	1.50	2.00	2.50	3.00	3.50	4.00
α	0.11	0.16	0.20	0.28	0.32	0.35	0.36	0.37	0.37
β	0.03	0.03	0.04	0.05	0.06	0.06	0.07	0.07	0.07

*See Figure F-7

Allowable values for *x* and *E* may be found for steel plates in the *Steel Construction Manual* (AISC, 2005), and for aluminum plates in the *Aluminum Construction Manual (*AA, 1959).

The method of designing plywood closure plates is like that for steel and aluminum closure plates, except that the varying structural properties of plywood make using a single equation inappropriate. Because these structural properties are dependent upon the grades of plywood sheet, the type of glue used, and the direction of stress in relation to the grain, thickness, and grade required for a plywood closure is best achieved by assuming a thickness and grade of plywood and calculating its ability to withstand bending, shear, and deflection stresses. This involves calculating the actual bending, shear, and deflection stresses in the plywood closure plate for the thickness and grade specified. These actual stress values are then compared with the maximum allowable bending, shear, and deflection stresses (taken from *Plywood Design Specifications* [APA, 1997]).

Warning

Designers are referred to Plywood Design Specifications, published by the Engineered Wood Association (APA, 1997), for a detailed discussion of design guidelines.

If the actual stresses computed are less than the maximum allowable stresses for bending, shear, and deflection, the thickness and grade specified are acceptable for that application. However, if

either of the actual bending or shear stresses or deflection exceeds the maximum allowable values, the closure plate is not acceptable, and a new thickness and/or grade of plywood closure plate should be specified, and the calculations repeated until all actual stresses are less than the maximum allowed. The following guidance has been prepared to illustrate one method of designing plywood closure plates. Note that a one way horizontal span is assumed because the variability of plywood properties is dependent upon grain and stress direction.

Compute bending moment on horizontal one way span (supported on two sides only) using Equation F-23. Check bending stress using Equation F-24.

EQUATION F-23: BENDING MOMENT

$$M_b = \frac{[P_h + (P_{dh} \text{ or } P_d)]W_c^3}{8} \geq 1.5$$ (Refer to Figure F-7)

Where:

M_b = bending moment in (in.lbs/in.);

P_h = hydrostatic pressure due to standing water (psi) from Equation 3-4

W_c = width of the closure (in.)

$P_{dh} \text{ or } P_d$ = are defined in Equations 3-8 and 3-9, respectively

EQUATION F-24: BENDING STRESS

$$f_b = \frac{M_b}{KS}$$

Where:

f_b = bending stress (lb/in.^{2})

M_b = bending moment (in.lbs/in.)

KS = effective section modulus from a reference (in.^{3}/in.)

If the calculated bending stress for the specified plate (f_b) is less than the maximum bending stress allowed (F_b) by the plate manufacturer, the closure plate is adequately designed for bending applications. If not, the closure should be redesigned and the calculation repeated.

Compute shear force using Equation F-25.

EQUATION F-25: SHEAR FORCE

$$V_s = \frac{[P_h + (P_{dh} \text{ or } P_d)]W_c^2}{2}$$ (Refer to Figure F-7)

Where:

V_s = shear force (lbs)

P_h = hydrostatic pressure due to standing water from Equation 3-4 (lb/in.^{2})

W_c = width of the closure plate (in.)

P_{dh} *or* P_d = are defined in Equations 3-8 and 3-9, respectively

Check shear stress using Equation F-26.

EQUATION F-26: SHEAR STRESS

$$F_s = \frac{V_s}{C_{RS}}$$

Where:

F_s = shear stress (lbs)

V_s = shear force (lbs)

C_{RS} = rolling shear constant dimensionless

If the calculated shear stress for the specified plate (F_s) is less than the maximum shear stress allowed ($F_{s\ (allowable)}$), the closure plate is adequately designed for shear applications. If not, the closure should be redesigned and the calculations repeated.

Compute deflection for a single one way span using Equation F-27.

EQUATION F-27: PLATE DEFLECTION FOR A ONE WAY SPAN

$$\Delta_b = \frac{[P_h + (P_{dh} \text{ or } P_d)](W_c + y)^4}{921.6(E)(I)}$$ (Refer to Figure F-7)

Where:

Δ_b = computed deflection (in.)

P_h = hydrostatic pressure from Equation 3-4 (lb/in.^{2})

W_c = unsupported width (in.)

y = support width factor (in.)

E = Modulus of Elasticity (lb/in.^{2})

I = Effective Moment of Inertia (in.^{4}/ft)

P_{dh} *or* P_d = are defined in Equations 3-8 and 3-9, respectively

Check deflection.

A customary and acceptable level of deflection may be expressed as shown in Equation F-28.

EQUATION F-28: ALLOWABLE DEFLECTION

$$\Delta_{b\,(allowable)} = \frac{W_c}{240}$$ (Refer to Figure F-7)

Where:

$\Delta_{b\,(allowable)}$= allowable deflection (in.)

W_c = unsupported width (in.)

If the calculated deflection (Δ_b) is less than the allowable deflection ($\Delta_{b\,(allowable)}$), the closure plate is adequately designed for deflection situations. If not, the closure should be redesigned and the calculations repeated.

Closure plates of plywood are limited to short spans and low water heights. It should also be noted that most plywood will deteriorate when exposed to high moisture. Therefore, plywood closure plates should be periodically examined and replaced.

Appendix G. Resources and References

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G.1 FEMA Resources

Building Science Resource Library: https://www.fema.gov/emergency-managers/risk-management/building-science/publications

Floodplain Management Library and Resource Center: https://www.fema.gov/floodplain-management/manage-risk/resource-library

National Flood Insurance Program

- FEMA National Flood Insurance Program Technical Bulletins available at https://www.fema.gov/emergency-managers/risk-management/building-science/national-flood-insurance-technical-bulletins:
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- *Reasonably Safe from Flooding Requirement for Building on Filled Land Removed From the Special Flood Hazard Area in Accordance with the National Flood Insurance Program.* National Flood Insurance Program Technical Bulletin 10, March 2023. https://www.fema.gov/sites/default/files/documents/fema_nfip-technical-bulletin-10.pdf

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