3 Parameters of Retrofitting

In this chapter, the factors that influence retrofitting decisions are examined and compared with various methods to determine the viability of specific retrofitting techniques. These factors include:

- homeowner preferences;
- community regulations and permitting requirements; and
- technical parameters.

Factors such as homeowner preference and technical parameters are key elements in identifying appropriate retrofitting measures, while consideration of the multiple flood-related and non-flood-related hazards is critical in designing the retrofitting measure and/or avoiding the selection of a poor retrofitting method.

This selection of alternatives can be streamlined through the use of two generic retrofitting matrices, which are designed to help the designer narrow the range of floodproofing options:

- **Preliminary Floodproofing/Retrofitting Preference Matrix** (Figure 3-1), which focuses on factors that influence homeowner preference and those measures allowable under local regulations.
- **Retrofitting Screening Matrix** (Figure 3-3), which focuses on the objective physical factors that influence the selection of appropriate retrofitting techniques.

3.1 Determination of Homeowner Preferences

The proper evaluation of retrofitting parameters will require a series of homeowner coordination and design input meetings. Ultimately, the homeowner will have to deal with the flood protection environment on a daily basis. Therefore, the functional and cosmetic aspects of the retrofitting measure, such as access, egress, landscaping, appearance, etc., need to be developed by including the homeowner's thoughts and ideas. Most retrofitting measures are permanent and should be considered similar to a major home addition or renovation project. The design should incorporate the concepts of those who will be using the retrofitted structure.

Issues that should be addressed include:

- retrofitting aesthetics;
- economic considerations;
- risk considerations;
- accessibility;
- local code requirements;
- building mechanical/electrical/plumbing system upgrades; and
- off-site flooding impacts.

NOTE

In order to avoid any future misunderstandings, designers should use their skills and knowledge of retrofitting projects to address technical implications while working with homeowners. Many owners have little or no technical knowledge of retrofitting and naturally look to the designer or local official for guidance and expert advice.

The Preliminary Floodproofing/Retrofitting Preference Matrix (Figure 3-1) assists the designer in documenting the initial consultation with the homeowner. The first consideration, Measure Allowed [by community] or Owner Requirement, enables the designer to screen alternatives that are not permissible and must be eliminated from further consideration. Discussion of the considerations for the remaining measures should lead to a "no" or "yes" for each of the boxes (see the instructions under Figure 3-1 for instructions to fill out the matrix). Examination of the responses will help the homeowner and designer select retrofitting measures for further examination that are both viable and preferable to the owner. If a "no" or "yes" cannot be determined, then more research may be required. In some cases, conservative assumptions should be made and later revisited to keep the process moving forward.

3.1.1 The Initial Homeowner Meeting

The first step in the homeowner coordination effort is the educational process for both the designer and the property owner. This step is a very important one.

The homeowner learns:

- how it was determined that the home is in the floodplain;
- possible impacts of an actual flood;
- benefits of flood insurance;

NOTE

The evaluation of information obtained during the initial meeting with the homeowner will help the designer and owner address the flood threat to the entire structure and the vulnerability of specific openings to floodwater intrusion.

Preliminary Floodproofing/Retrofitting Preference Matrix

Owner Name:_____ Prepared By:_____

Address: _____ Date: _____

Property Location: _____

	Floodproofing Measures								
Considerations	Elevation on Foundation Walls	Elevation on Fill	Elevation on Piers	Elevation on Posts and Columns	Elevation on Piles	Relocation	Dry Flood-proofing	Wet Flood-proofing	Floodwalls and Levees
Note the measures NOT allowed									
Homeowner Concerns									
Aesthetic Concerns									
High Cost Concerns									
Risk Concerns									
Accessibility Concerns									
Code Required Upgrade Concerns									
Off-Site Flooding Concerns									
Total “x’s”									

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

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

Figure 3-1. Preliminary Floodproofing/Retrofitting Preference Matrix

- physical, economic, and risk considerations; and
- what to expect during each step in the retrofitting process.

The deigner learns:

- flood history of the structure;
- homeowner preferences;
- financial considerations;
- special issues, such as accessibility requirements for the disabled; and
- information about the subject property such as:
  - topographic surveys;
  - site utility information; and
  - critical home dimensions.

During this initial meeting, the homeowner and designer should jointly conduct a preliminary assessment of the property to determine which portions of the structure require flood protection and the general condition of the structure. This initial evaluation will identify the elevation of the lowest floor and the elevation of potential openings throughout the structure through which floodwater may enter the residence.

3.1.2 Initial Site Visit

A low point of entry determination, illustrated in Figure 3-2, identifies the elevation of the lowest floor and each of the structure's openings. and may include:

- lowest floor or basement slab;
- windows, doors, and vents;
- mechanical/electrical equipment and vents;
- drains and other floor penetrations; and
- water spigots, sump pump discharges, and other wall penetrations.

NOTE

Sometimes it is necessary for a field survey to be conducted by a professional land surveyor before design documents are developed. However, frequently the homeowner and designer may be able to develop a rough elevation relationship between the expected flood elevation, the elevation of the lowest floor, and the low points of entry to the structure sufficient for an initial evaluation.

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

- finished floor elevation of the structure (unless already identified as lowest floor);
- other site provisions that may require flood protection, such as storage sheds, wellheads, and storage tanks; and
- an elevation reference mark on or near the house.

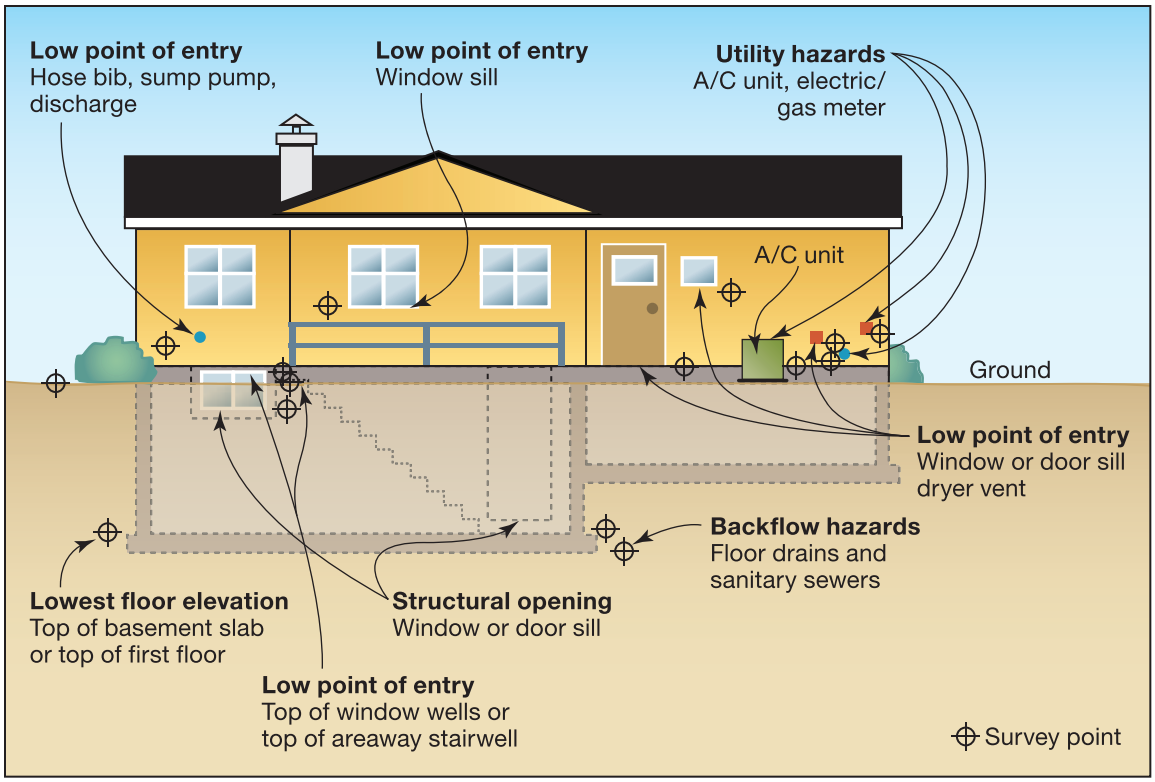

Figure 3-2. Survey to identify the low point of floodwater entry into a typical residential structure

Once the low point of entry determination has been completed, the homeowner and designer can determine the DFE and/or identify openings that need to be protected (as in the case of dry floodproofing in non-residential buildings).

The approximate height of the retrofitting measure can be used by the homeowner and designer as they evaluate each of the parameters of retrofitting discussed in this chapter. In addition to determining the low point of entry, this initial site visit should be used to assess the general overall condition of the structure.

3.1.3 Aesthetic Concerns

Although physical and economic considerations may help determine feasible retrofitting measures for individual buildings, the homeowner may consider other factors equally or more important. Aesthetics, for example, is a subjective issue.

The homeowner may reject a measure that scores high for all considerations except aesthetics. On the other hand, what may be aesthetically pleasing to the homeowner may not be technically appropriate for a project. Here, a designer must use skill and experience to achieve a common ground. In doing so, the homeowner's preference should be considered, while not jeopardizing the structural, functional, and overall success of the proposed project.

An aesthetically pleasing solution that also performs well as a retrofitting alternative can be achieved through an understanding of the relationship between the existing and proposed modifications, creative treatment and modification of surrounding landforms, proper landscaping techniques, and preservation of essential and scenic views.

3.1.4 Economic Considerations

At this point, the designer should not attempt to conduct a detailed cost analysis. Rather, general estimates of the cost of various retrofitting measures should be presented to the homeowner.

NOTE

In relocating a structure, the cost of preparing the new site and cleaning up the old site must be considered.

As discussed in Chapter 1, the cost of retrofitting will depend on a variety of factors, including the building's condition, the retrofitting measure to be employed, the DFE, the choice of materials and their local availability, the availability and limitations of local labor, and other site-specific issues (i.e., soil conditions and flooding levels) and other hazards.

The costs in Tables 3-1 through 3-4 are provided to assist in economic analysis and preliminary planning purposes. Table 3-5 provides a comparison of relative costs and risks across 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 percent of the costs of selected retrofitting measures);
- contractors' profit (10 percent of the estimated costs); and
- contingency to account for unknown or unusual conditions.

Table 3-1. Relative Costs of Elevating a Home

Construction Type	Existing Foundation	Retrofit	Relative Cost
Frame	Basement, crawlspace, or open foundation	Elevate on continuous foundation walls or open foundation	Lowest
Frame with masonry veneer		Elevate on continuous foundation walls or open foundation	↓
Loadbearing masonry		Extend existing walls and create new elevated living area	
Frame	Slab-on-grade	Elevate on continuous foundation walls or open foundation	
Frame with masonry veneer		Elevate on continuous foundation walls or open foundation	
Loadbearing masonry		Elevate on continuous foundation walls or open foundation	Highest

Table 3-2. Relative Costs of Relocation

Construction Type	Existing Foundation	Retrofit	Relative Cost
Frame	Crawlspace or open foundation	Relocate existing home and install the home on a new foundation at the new site, hook up utilities, and restore the old site	Lowest
Frame with masonry veneer			
Loadbearing masonry			
Frame	Basement		
Frame with masonry veneer			
Loadbearing masonry			
Frame	Slab-on-grade		Highest
Frame with masonry veneer			
Loadbearing masonry			

WARNING

The relative relocation costs shown here are based on a small home. Because relocation costs do not increase proportionally with the size of a home, the cost per square foot of moving a larger home may be less than that shown here.

Table 3-3. Relative Costs of Floodwalls and Levees

Construction Type	Existing Foundation	Retrofit	Relative Cost
Frame, frame with masonry veneer, or loadbearing masonry	Crawlspace	Wet floodproof crawlspace to a height of 2 ft to 4 ft above LAG	Lowest
	Basement	Wet floodproof unfinished basement to a height of 2 ft to 4 ft above the basement floor	
	Basement	Wet floodproof unfinished basement to a height of 8 ft above the basement floor	Highest

LAG = Lowest Adjacent Grade

Table 3-4. Relative Costs of Wet Floodproofing

Construction Type	Existing Foundation	Retrofit	Relative Cost
Frame, frame with masonry veneer, or loadbearing masonry	Crawlspace	Wet floodproof crawlspace to a height of 2 ft to 4 ft above LAG	Lowest
	Basement	Wet floodproof unfinished basement to a height of 2 ft to 4 ft above the basement floor	
	Basement	Wet floodproof unfinished basement to a height of 8 ft above the basement floor	Highest

LAG = Lowest Adjacent Grade

Table 3-5. Relative Costs and Risks of Floodproofing Methods

Floodproofing Retrofit Method	Elevation	Relocation	Dry Floodproofing	Wet Floodproofing	Floodwalls and Levees
Cost	$$$$	$$$$$	$	$$	$$$
Risk Level	!!	!	!!!!!	!!!!	!!!

$ = cost ! = risk

Figure 3-3 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 3-3. Preliminary Cost Estimating Worksheet

3.1.5 Risk Considerations

Another element that is included in the evaluation of retrofitting measures is the risk associated with a do-nothing approach. Risk can also be established among the various measures by knowing the exceedance probability of floods and the design flood levels for competing measures. Relocation is an example of how retrofitting can eliminate the risk of flood damage. On the other hand, a levee designed to protect against a 10-percent-chance-annual exceedance probability (10-year) flood would have an 88-percent chance of being overtopped during a 20-year period. Such information will assist the homeowner in evaluating the pros and cons of each measure. Table 3-6 provides the probabilities associated with one or more occurrences of a given flood magnitude occurring within a specific number of years.

Table 3-6. Flood Risk

		Recurrence Interval (Years)				
		10	25	50	100	500
Length of Period (Years)	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 one or more occurrences of a flood of given magnitude or larger within a specified number of years. Probability (P) may be calculated for any given Length of Period (n) and Recurrence Interval (RI) using the following equation: $P = \left[1 - \left(1 - \frac{1}{RI}\right)^n\right] \times 100\%$, where RI and n are in years.

Flood probabilities are also useful in evaluating the inconvenience aspects of retrofitting. Reducing cleanup and repairs, lost time from work, and average non-use of a building from once in 2 years to once in 10 years could be a powerful incentive for retrofitting even though other aspects may be less convincing.

3.1.6 Accessibility for Individuals with Special Needs

Accessibility for individuals with special needs is an issue that must be addressed primarily on the specific needs of the owner. Many retrofitting measures can create access problems for a house that was previously fully accessible. The Americans with Disabilities Act (ADA) of 1990 and the Fair Housing Amendment Act (FHA) of 1988 and other accessibility codes and regulations do not specifically address private single-family residences, which are the focus of this manual. However, the above-mentioned regulations contain concepts that may be of assistance to a designer representing a property owner with special needs.

NOTE

A designer should become familiar with the prevailing conditions, codes, and legal restrictions particular to a building's location.

It is important for the designer to remember that the term "special needs" does not refer only to someone who uses a wheelchair. Other special needs may include:

- limited mobility requiring the use of a walker or cane, which can inhibit safe evacuation;
- a person's limited strength to open doors, climb stairs, install flood shields, or operate other devices; and
- partial or total loss of hearing or sight.

Special considerations such as small elevators may be needed.

Discussion of the above factors with the homeowner and utilization of the Preliminary Floodproofing/Retrofitting Preference Matrix in Figure 3-1 will allow the designer to rank the retrofitting methods by homeowner preference.

3.2 Community Regulations and Permitting

3.2.1 Local Codes

Most local governments regulate building activities by means of building codes as well as floodplain and zoning ordinances and regulations. With the intent of protecting health and safety, most local codes are fashioned around the model building codes discussed in Chapter 2. 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 seismic and hurricane activity, extreme cold, or humidity.

CROSS REFERENCE

Chapter 4 of FEMA P-762, *Local Officials Guide to Coastal Construction* (FEMA, 2009b) provides in-depth coverage of permits and inspections.

Determination of which retrofitting measures are allowed under local regulations is an important step in compiling the Preliminary Floodproofing/Retrofitting Preference Matrix (Figure 3-1). Retrofitting measures not allowed under local regulations will be screened and eliminated from further consideration.

3.2.2 Building Systems/Code Upgrades

Other local code requirements must be met by homeowners' building improvements. Most building codes require approval when elevation is considered, especially if structural modification and/or alteration and relocation of utilities and support services are involved.

If more stringent laws have been adopted since a building was constructed, local code restrictions can seriously affect the selection of a retrofitting method because construction may be expected to comply with new building codes.

WARNING

Some communities require that structures undergoing substantial 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.

3.2.3 Off-Site Flooding Impacts

Where a chosen retrofitting measure requires the modification of site elements, a designer shall consider how adjacent properties will be affected.

- Will construction of levees and floodwalls create diversions in the natural drainage patterns?
- Will new runoffs be created that may be detrimental to nearby properties?
- If floodproofing disturbs the existing landscape, will re-grading and re-landscaping undermine adjacent streets and structures?
- Will the measure be unsightly or increase the possibility of sliding and subsidence at a later date?
- If a building is to be relocated to another portion of the current site, or if it is to be elevated, will it encroach on established easements or rights-of-way?
- Will the relocated building infringe on wetland areas or regulated floodplains?

NOTE

Addressing off-site impacts and issues is as much a matter of responsible practice and conscience as it is a requirement of most building codes and floodplain management ordinances.

WARNING

NFIP, state, and local regulations do not allow construction within a floodway or, in some cases, within a floodplain that would back up and increase flood levels.

These and other questions must be addressed and satisfactorily answered by the homeowner and designer in selecting the most appropriate retrofitting measure. Both must be aware of the liabilities that may be incurred by altering drainage patterns and other large-scale site characteristics. The designer should ensure that any modified runoffs do not cause negative impacts on the surrounding properties. The means necessary to collect, conduct, and dispose of unwanted flood or surface water resulting from retrofitting modifications must be understood and clearly resolved.

3.3 Technical Parameters

Once the designer has resolved preliminary retrofitting preference issues with the owner, a more intensive evaluation of the technical parameters is normally conducted, including flooding, site, and building characteristics. Figure 3-4 provides a worksheet that can be used to evaluate which measures are appropriate for individual structures. Instructions for using this matrix are presented in Figure 3-5. The remainder of this chapter provides background information on each of the technical parameters, which will be useful to the designer in completing the worksheet.

Owner Name:_____ Prepared By:_____

Address: _____ Date: _____

Property Location: _____

	Parameters	Measures						
		Elevation on Foundation Walls	Elevation on Fill	Elevation on Piers, Posts, Columns, and Piles	Relocation	Dry Flood-proofing	Wet Flood-proofing	Floodwalls and Levees
Measures Permitted by Community or Preferred by Homeowner								
Flooding Characteristics	**Flood Depth**							
	Shallow (<3 ft)							
	Moderate (3 to 6 ft)					N/A		
	Deep (>6 ft)					N/A	N/A	N/A
	Flood Velocity							
	Slow/Moderate (≤5 ft/sec)							
	Fast (>5 ft/sec)	1	1	1		N/A		1
	Flash Flooding							
	Yes (<1 hour)					2	2	2
	No							
	Ice and Debris Flow							
	Yes	6		4		N/A		4
	No							
Site Characteristics	**Site Location**							
	Floodway	5	5	5	5	5	5	5
	Other Zone A							
	Soil Type							
	Permeable					3		3
	Impermeable							
Building Characteristics	**Building Foundation**							
	Slab-on-Grade							
	Crawlspace					N/A		
	Basement		6	6		6		
	Building Construction (Framing)							
	Concrete or Masonry							
	Wood and Others							
	Building Condition							
	Excellent to Good							
	Fair to Poor	6	6	6	6	6		

Figure 3-4. Retrofitting Screening Matrix

The Retrofitting Screening Matrix (Figure 3-4) is designed to screen and eliminate retrofitting techniques that should not be considered for a specific situation.

Steps to Complete Matrix	
Step 1:	Screen alternatives that are neither permitted nor preferable to the homeowner and are eliminated from further consideration, by inserting N/P (not permitted) in the appropriate box(es) on the Measures Permitted by Community or Preferred by Homeowner row. If an N/P is placed in a column representing a retrofitting measure, that alternative is eliminated from consideration.
Step 2:	Select the appropriate row for each of the characteristics that best reflect the flooding, site, and building characteristics.
Step 3:	Circle the N/A (not advisable) boxes that apply in the rows of characteristics selected. Do not circle any N/A boxes where there is a plan to engineer a solution to address the specific characteristic.
Step 4:	Examine each column representing the different retrofitting measures. If one or more N/A boxes are circled in a column representing a retrofitting measure, that alternative is eliminated from consideration.
Step 5:	The numbers enclosed in the boxes represent special considerations (detailed below) that must be accounted for to make the measure applicable. If the consideration cannot be addressed, the number should be circled and the measure eliminated from consideration.
Step 6:	Retrofitting measures that remain should be further evaluated for technical, benefit-cost, and other considerations. A preferred measure should evolve from the evaluation.

Matrix Keys	
N/A	Not advisable in this situation.
N/P	Not permitted in this situation.
1	Fast flood velocity is conducive to erosion and special features to resist anticipated erosion may be required.
2	Flash flooding usually does not allow time for human intervention; thus, these measures must perform without human intervention. Openings in foundation walls must be large enough to equalize water forces and should not have removable covers. Closures and shields must be permanently in place, and wet floodproofing cannot include last-minute modifications.
3	Permeable soils allow seepage under floodwalls and levees; therefore, some type of subsurface cutoff feature would be needed beneath structures. Permeable soils become saturated under flood conditions, potentially increasing soil pressures against a structure; therefore, some type of foundation drain system or structure may be needed.
4	Ice and debris loads should be considered and accounted for in the design of foundations and floodwall/levee closures.
5	Any retrofitting alternative considered for the floodway must meet NFIP, state, local, and community floodplain requirements concerning encroachment/obstruction of the floodway conveyance area.
6	Not advisable in this situation, unless a specific engineering solution is developed to address the specific characteristic or constraint.

Figure 3-5. Instructions for Retrofitting Screening Matrix

3.3.1 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 surges with waves, 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 for a given area, but can also be used to anticipate the performance of different retrofitting measures based on the potential hazards associated with each. These factors are outlined below.

3.3.1.1 Flood Depth and Elevation

The depth and elevation of flooding are directly related. Flood depth is measured from the floodwater surface to the adjacent ground level, while flood elevation is measured against an established standard datum. Determining the potential depth of flooding for certain flood frequencies is a critical step because it is often the primary factor in evaluating the potential for flood damage.

A building is susceptible to floods of various depths. Floods of greater depth occur less frequently than those of lesser depths. Potential flood elevations from significant flooding sources are shown in FISs for most participating NFIP communities. For the purpose of assessing the depth of flooding a structure is likely to endure, it is convenient to use the flood levels shown in the study, historical flood levels, and flood information from other sources. The depth of flooding affecting a structure can be calculated by determining the height of the flood above the ground elevation at the site of the structure. Figure 3-6 illustrates historic flood depths documented by measuring mud lines or high water marks on a building.

For those areas outside the limits of an FIS or State, community, or privately prepared local floodplain study, determination of flood depth may require a detailed engineering evaluation of local drainage conditions to develop the necessary relationship between flow (discharge), water-surface elevation, and flood frequency. The designer should contact the local municipal engineer, building official, or floodplain administrator for guidance on computing flood depth in areas outside existing study limits.

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 normally) 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 3-7 illustrates the hydrostatic and buoyancy forces generated by water depth.

Figure 3-6. Measuring mud lines or high water marks to establish flood depth

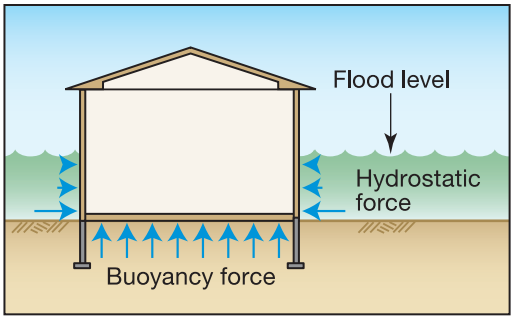

Figure 3-7. Hydrostatic and buoyancy forces

If a well-constructed building is subject to flooding depths of less than 3 feet, it is possible that unequalized hydrostatic forces may not cause significant damage. Therefore, consideration can be given to using barriers, sealants, and closures as retrofitting measures. If shallow flooding (less than 3 feet) causes a basement to fill with water, then wet floodproofing methods can be used to reduce flood damage to basements.

If a residential building is subject to flooding depths greater than 3 feet, either elevation or relocation is often the most effective method of retrofitting. Water depths greater than 3 feet can often create hydrostatic forces with enough load to cause structural damage or collapse if the house is not moved or elevated. One other potential method (provided the cost is not prohibitive) is the use of floodwalls and levees designed to withstand flooding depths greater than 3 feet.

3.3.1.2 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. In coastal areas, wind speed also frequently influences flow velocity. Beyond the potential structural damage from hydrodynamic forces and potential debris impact described below, flowing water often causes erosion and scour. Both erosion and scour can weaken structures by undermining the building foundation. Erosion and scour are discussed further in Section 3.3.2.

NOTE

The use of existing and historical data can be very useful in analyzing the flood threat. Through interviews with residents, approximate dates of flooding may be established, as well as remembered depths of flooding, types of velocity (moving or standing water), duration of flooding, etc. Once the dates have been established, the designer can check other sources such as newspapers and the National Weather Service for additional information.

As floodwater velocity increases, 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 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 quickly erode, or scour, the soil supporting and/or surrounding buildings. 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.

Unfortunately, there is usually no definitive source of information to determine potential flood velocities in the vicinity of specific buildings. Hydraulic computer models or hand computations based on existing

floodplain studies may provide flood velocities in the channel and overbank areas. Where current analysis data is not available, historical information from past flood events is probably the most reliable source.

3.3.1.3 Flood Frequency

As discussed in Section 3.1.5, flood frequency analyses define the probability that a flood of a specific size will be equaled or exceeded in any given year. Therefore, a flood elevation with a 1-percent-annual-chance of being equaled or exceeded in any given year is referred to as the "100-year flood." Table 3-6 illustrates the relationship between flood RIs and the probability of that event occurring within a given period. While the 100-year flood serves as the basis for NFIP insurance rates and regulatory floodplain management requirements, the relative frequency of any given flood (2-year vs. 10-year) can also be helpful when choosing between retrofitting options.

3.3.1.4 Rates of Rise and Fall

In areas of steep topography or those areas with a small drainage area, floodwater can rise very quickly with little or no warning. This condition is known as flash flooding. High velocities usually accompany these floods and may preclude certain types of retrofitting, especially those requiring human intervention. In a flash flooding situation, damage usually begins to occur within 1 hour after significant rainfall. If a building is susceptible to flash floods, insufficient warning time can preclude the installation of shields on windows, doors, and floodwalls, as well as the activation of pump systems and backup energy sources. Temporarily relocating movable contents to a higher level may also be impractical. However, such measures may be effective if a building is not subject to flash flooding and the area has adequate flood warning systems, such as television and radio alerts.

WARNING

Flash flooding will usually preclude the use of any retrofitting measure that requires human intervention.

High rates of floodwater rise and fall may also lead to increased hydrostatic pressures. This is due primarily to the fact that the water level inside the structure rises and falls more slowly than the level outside.

3.3.1.5 Flood Duration

In many floodplains, duration is related to rates of rise and fall. With long-duration flooding, certain measures such as dry floodproofing may be inappropriate due to the increased chance of seepage and failure caused by prolonged exposure to floodwater. Long periods of inundation are also more likely to cause greater damage to structural members, interior finishes, and service equipment than short periods.

NOTE

A detailed hydrograph can provide information on duration of flooding. However, such information is usually not available, and the cost of creating a new study is usually prohibitive. One potential source of information is to check similarly sized drainage basins in neighboring areas to see if historical data exists.

3.3.1.6 Debris Impact

While not intrinsic to flooding itself, debris impact is a flood hazard directly related to flood characteristics—depth,

velocity, rate of rise and fall—with respect to 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 and flash floodwater may transport the debris downstream and endanger any object that intersects its path. In colder climates and spring thaws, floodwater may carry chunks of ice that can act as a battering ram on structural and non-structural elements alike. Debris impact can destroy most retrofitting measures as well as the structure itself.

Retrofitting measures suitable for debris impact may include relocation, levees, and armored floodwalls.

NOTE

Another flood-related hazard besides debris impact is alluvial fans. Because of the potential for high flood velocities, significant debris flow, and varying channel locations, alluvial fans present many unique challenges. The hazards associated with alluvial fan flooding are discussed in detail in Appendix D of this manual.

3.3.2 Site Characteristics

Site characteristics such as site location, erosion vulnerability, and underlying soil conditions play a critical role in the determination of an applicable retrofitting method.

3.3.2.1 Site Location

The floodplain is usually defined as the area inundated by a flood having a 100-year flood frequency. 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 of the surrounding land to enable floodwater to pass without increasing flood depths greater than a predetermined amount. 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 and increase flood levels. For these reasons, the NFIP and local communities prohibit new construction or substantial improvement in identified floodways that would increase flood levels. Relocation is the recommended retrofitting option for a structure located in a floodway. Community and state regulations may prohibit elevation of structures in this area. However, elevation on an open foundation will allow for more flow conveyance than a structure on a solid foundation.

The portion of the floodplain outside 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 this area with an acceptable degree of safety.

3.3.2.2 Vulnerability to Erosion

Erosion refers to the wearing or washing away of land masses and occurs in both coastal and riverine environments. Difficult to predict, erosion is capable of threatening existing coastal structures by destroying dunes, lowering ground elevations, transporting sediments landward (overwash), breaching low-lying barrier islands, and undermining coastal bluffs. Erosion may be caused by natural or manmade actions including, but not limited to flood inducing storms, construction, and human activities such as dredging channels, damming rivers and altering surface vegetation. Section 3.3 of FEMA P-55, *Coastal Construction Manual,*

(FEMA, 2011) includes an extensive discussion on the phenomenon of coastal erosion. Similarly, riverine erosion impacts the stability of stream banks and adjacent structures through the interaction of multiple geophysical and geotechnical factors that are listed in Section 4.2 of this publication. Consideration of siting and the erodibility of in situ land masses is critical when retrofitting in the floodplain as fast-moving floodwater can undermine buildings and cause building, floodwall, and levee failure.

Shallow foundation systems generally do not provide sufficient protection against soil erosion without some type of protection or armoring measure of below-grade elements. Shallow foundation systems are prohibited altogether in Zone V new construction for reasons evidenced in Figure 3-8. Significant scour in coastal areas can potentially undermine deep foundation piles, individually and in groups, as described in Section 4.2.2 of this publication. The local office of the NRCS will generally have information concerning the erodibility of the soils native to a specific site. FEMA conducted an erosion mapping feasibility study that concluded that mapping of erosion-prone areas was feasible (FEMA, 1999b).

CROSS REFERENCE

The *Riverine Erosion Hazard Areas Mapping Feasibility Study*, (FEMA, 1999b) is located in FEMA's electronic library at http://www.fema.gov/library/viewRecord.do?id=2209.

Figure 3-8. Large, fast-moving waves combined with erosion and scour to destroy this Gulf of Mexico home during Hurricane Opal

3.3.2.3 Soil Type

Permeable soils, such as sand and gravel, are those that allow groundwater flow. In flooding situations, these soils may allow water to pass under floodwalls and levees unless extensive seepage control measures are employed as part of the retrofitting measures. Also, saturated soil pressure may build up against basement walls and floors. 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.

Saturated soils subject horizontal surfaces, such as floors, to uplift forces, called buoyancy. Like lateral hydrostatic forces, buoyancy forces increase in proportion to the depth of water/saturated soil above the horizontal surface. Figure 3-9 illustrates the combined lateral and buoyancy forces resulting from saturated soil.

NOTE

Contact the local office of the NRCS or a local geotechnical engineering firm to obtain guidance on the permeability or consolidation features of soils native to the area. Because the site may have been backfilled with non-native materials during original construction, NRCS data should be carefully used.

For example, a typical wood-frame home without a basement or proper anchoring to the foundation may float if floodwater reaches 3 feet above the first floor. A basement without floodwater in it could fail when the ground is saturated up to 4 feet above the 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 allow the use of dry floodproofing measures.

Other problems with soil saturated by floodwater need to be considered. If a building is located on unconsolidated soil, wetting of the soil may cause uneven (differential) settlement. The building may then be damaged by inadequate support and subject to rotational, pulling, or bending forces. Some 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 even make contact with the structure itself.

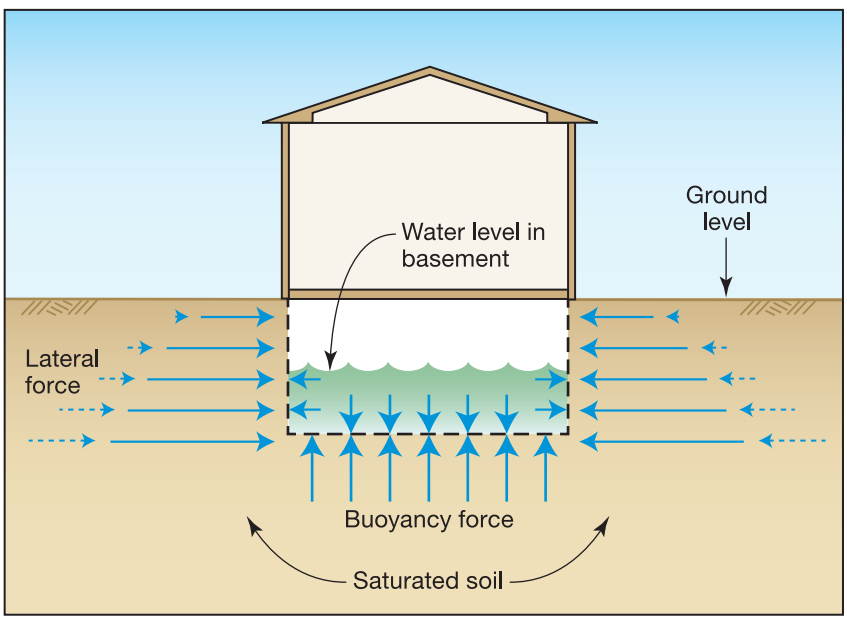

Figure 3-9. Lateral and buoyancy forces resulting from saturated soil

3.3.3 Building Characteristics

Ideally, a building consists of three different components: substructure, superstructure, and support services. The substructure consists of the foundation system. The superstructure consists of the structural elements and the building envelope (cladding, roofing, windows and doors, etc.) above the foundation system. The support services are those elements that are introduced into a building to make it habitable.

These components are integrally linked together to help a building maintain its habitability and structural integrity. Any action that considerably affects one may have a minimal or sometimes drastic effect on the others. An understanding of building characteristics and types of construction involved is therefore an important consideration in deciding upon an appropriate retrofitting measure.

3.3.3.1 Substructure

The substructure of a building supports the building envelope. It includes components found beneath the earth's surface, as well as above-grade foundation elements. This system consists of both the vertical foundation elements such as walls, posts, piers, and piles, which support the building loads and transmit them to the ground, and the footings that bear directly on the soil.

At any given time, there are a number of different kinds of loads acting on a building. The foundation system transfers these loads safely into the ground. In addition to dead and live loads, retrofitting decisions must take into account the buoyant uplift thrust on the foundation, the horizontal pressure of floodwater against the building, and any loads imposed by multiple hazards such as wind and earthquake events.

The ability of a foundation system to successfully withstand these and other loads or forces, directly or indirectly, is dependent to a large extent on its structural integrity. A 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 column/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 located outside coastal high hazard areas are supported on shallow foundations. Each type has its own advantages and limitations when retrofitting measures are being evaluated. Whichever is used in a building, a designer should carefully check for the structural soundness of the foundation system.

NOTE

A cracked foundation is one indication of a weak foundation. The use of floodwalls and levees may be the easiest and most practical approach to retrofitting a structure with a poor foundation. Another solution may be an entire relocation of the building's super-structure onto a new foundation.

Basement walls may be subject to increased hydrostatic and buoyancy forces; thus, retrofitting a building with a basement is often more involved and costly.

3.3.3.2 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). A 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 be the only reasons needed to rule out elevation as a retrofitting measure.

3.3.3.3 Support Services

These are elements that help maintain a human comfort zone and provide needed energy, communications, and disposal of water and waste. For a typical residential building, the combination of the mechanical, electrical, telephone, cable TV, water supply, sanitary, and drainage systems provides these services. An understanding of the nature and type of services used in a building is necessary for a designer to be able to correctly predict how they may be affected by retrofitting measures.

For example, the introduction of new materials or the alteration of a building's existing features may require resizing existing services to allow for the change in requirements. Retrofitting may also require some form of relocated ductwork and electrical rewiring. Water supply and waste disposal systems may have to be modified to prevent future damage. This is particularly true when septic tanks and groundwater wells are involved. If relocation is being considered, the designer must consider all these parameters and weigh the cost of repairs and renovation against the cost of total replacement.

3.3.3.4 Building Construction

Modern buildings are constructed with a limitless palette of materials integrated into various structural systems. A building may be constructed with a combination of various materials. Thus, the suitability of applying a specific retrofitting measure may be difficult to assess.

NOTE

For general consideration of retrofitting measures, all construction should be classified as wood material unless all walls and foundations are concrete and masonry.

Concrete and masonry construction may be considered for all types of retrofitting measures, whereas other materials may not be structurally sound or flood damage-resistant and therefore not suitable for some measures. When classifying building construction as concrete and masonry, it is important that all walls and foundations be constructed of this material. Otherwise, there may be a weak link in the retrofitting measure, raising the potential for failure when floods exert hydrostatic or hydrodynamic forces on the structure.

Masonry-veneer-over-wood-frame construction must be identified since wood-frame construction is less resistant to lateral loading than a brick-and-block wall section.

3.3.3.5 Building Condition

A building's condition may be difficult to evaluate, as many structural defects are not readily apparent. However, careful inspection of the property should provide for a classification of "excellent to good" or "fair to poor." This classification is only for the reconnaissance phase of selecting appropriate retrofitting measures. More in-depth planning and design may alter the initial judgment regarding building condition, thereby eliminating some retrofitting measures from consideration at a later time.

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.

Analysis of a building's substructure, superstructure, and support services may be done in two stages: an initial analysis usually based on visual inspection, and a detailed analysis (discussed in Section 5.2) that is often more informative, involves greater scrutiny, and usually requires detailed engineering calculations.

In the course of an analysis, a designer should visually inspect the walls, floors, roof, ceiling, doors, windows, and other superstructure and substructure components. Walls should be examined for type 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 vast range of treatments. It involves the use of virtually every material that can be walked upon, from painted concrete slabs to elegant, custom-designed wood parquet floors. A designer should investigate the nature of both the floor finishes and the underlying subfloor. Vinyl or rubberized plastic finishes may appear untouched due to their resistance to indentations and water; 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 at a later date to fully evaluate the extent of possible damage and need to retrofit. The roofs over most residential buildings consist of simple to fairly 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 pop up a ceiling tile; remove some shingles, slate, or roof tiles, or even bore into a roof to achieve a thorough inspection.

The inspection also determines if the building materials and component parts are sound enough for the building to easily undergo the process of elevation, relocation, or dry or wet floodproofing. If not, floodwalls or levees around the structure may be the best alternative if allowable.

Figure 3-10 presents a two-page worksheet that a designer can use to document findings during the initial building condition survey.

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 3-10. 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	☐ Masonry; CMU only			
☐ Stem wall slab	☐ Masonry; CMU and brick			
☐ Basement	☐ ICF*			
☐ Crawlspace	☐ Poured concrete			
☐ Timber piles	☐ Pre-cast			
☐ Other _____	☐ 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				

* ICF = insulated concrete forms

Figure 3-10. Preliminary Building Condition Worksheet (page 2 of 2)

3.4 Balancing Historic Preservation With Flood Protection

Many historic building features were developed, either deliberately or intuitively, as responses to natural and environmental hazards, and to local climate or topography. Recognizing how and why these features were intended to work can help in designing a program of preventive measures that is historically appropriate and that 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 its particular features. Preventive measures can be carried out without harming or detracting from historic character, as long as design and installation are carefully supervised by a professional knowledgeable in historic preservation. State and local historic preservation offices may require plan review and approval for flood retrofit projects on historic buildings.

There may well be instances, however, when a measure that best protects the site also may result in some loss of historic character. In such a case, the owner and the designer will have to weigh the costs of compromising character or historic authenticity against the benefits of safeguarding the site or a particular site feature against damage or total destruction. One example of such a choice is the decision whether to elevate a historic structure located in a flood hazard area, relocate it out of the area, retrofit it with dry or wet floodproofing techniques, or leave it in its existing state to face the risks of damage or loss. It is difficult to prescribe an equation for such a decision, since each situation will be unique, considering location, structural or site conditions, the variety of preventive alternatives available, cost, and degree of potential loss of historic character. Here are some questions the designer may wish to pose in deliberating such a decision:

- What is the risk that the historic feature or the entire site could be totally destroyed or substantially damaged if the preventive measure is not taken? If the measure is taken, to what degree will this reduce the risk of damage or total destruction?
- 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?
- Is there a design treatment that could be applied to the preventive measure to lessen detraction of historic character?

3.5 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. These multiple hazards can be accommodated through careful design of the retrofitting measures or may necessitate selection of a different retrofitting method. Detailed information concerning the analysis and design for these multiple hazards is contained in Chapters 4 and 5.

Significant flood-related hazards to consider include ice and debris flow, impact forces, erosion forces. These hazards were discussed in Sections 3.3.1 and 3.3.2. Mudslide or alluvial fan impacts are addressed in Appendix D. The major non-flood-related hazards to consider include earthquake and wind forces. Less significant hazards addressed in Chapter 4 include land subsidence, fire hazards, snow loads, movable bed

streams, and closed basin lakes. Multiple hazards may affect a structure independently, as with flood 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 (its own weight or dead load) plus loads that considered building contents and people (live loads) on the floors. The roofs of the structures were constructed to resist rain and snow. However, the designer of the structures may not have considered lateral and uplift loads from earthquakes and winds.

3.5.1 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 7-10. 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, in some cases, retrofitted to withstand earthquake forces as part of the complete retrofit project.

NOTE

FEMA 530, *Earthquake Safety Guide for Homeowners* (FEMA, 2005b) 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* (FEMA, 2006a).

3.5.2 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. FEMA P-762, *Local Officials Guide for Coastal Construction* (FEMA, 2009b) provides a detailed discussion of this topic. 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.

NOTE

FEMA P-804, *Wind Retrofit Guide for Residential Buildings* (FEMA, 2010b) 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.