Chapter 4 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 developed in Chapter 4 to the existing site/structure and design an appropriate retrofitting measure.

The design process begins with general practices that are basic to all retrofitting projects—field investigation and analysis of the existing structure—and then presents separate sections for each retrofit measure—elevation, relocation, dry floodproofing, wet floodproofing, and floodwalls and levees. These sections guide the designer through the process of developing construction details and specifications, and provide the tools to tailor each retrofitting measure to local requirements and homeowner preferences.

The design of these retrofitting measures is a straightforward but technically intensive approach that will result in the generation of construction plans that may receive building permits and mitigate potential flood and other natural hazards. This design process is illustrated in Figure 5-1.

As previously noted, the following section describes elements of the design process that are common to many or all retrofitting measures. The two main common design elements are field investigation (which includes surveys, documentation, and homeowner coordination) and the analysis of the existing structure.
Figure 5-1. Design process

<table>
<thead>
<tr>
<th>Field Investigation</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Low point of entry survey</td>
</tr>
<tr>
<td>• Site topography</td>
</tr>
<tr>
<td>• Utility locations</td>
</tr>
<tr>
<td>• Local building regulations</td>
</tr>
<tr>
<td>• Hazard and risk determinations</td>
</tr>
<tr>
<td>• Homeowner preferences</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Conceptual Design</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Calculations and analysis</td>
</tr>
<tr>
<td>• Type, size, and location</td>
</tr>
<tr>
<td>• Preliminary cost estimates</td>
</tr>
<tr>
<td>• Construction access</td>
</tr>
<tr>
<td>• Maintenance considerations</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Final Design</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Calculations and design</td>
</tr>
<tr>
<td>• Details and specifications</td>
</tr>
<tr>
<td>• Cost estimates</td>
</tr>
<tr>
<td>• Permits/access</td>
</tr>
<tr>
<td>• Maintenance considerations</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Construction</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Contractor selection</td>
</tr>
<tr>
<td>• Construction inspection</td>
</tr>
<tr>
<td>• As-built documentation</td>
</tr>
</tbody>
</table>

**KEY**

Revision  Agreement
5.1 Field Investigation

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 building requirements
- Surveys
- Final hazard determinations
- Documentation of existing structural, mechanical, electrical, and plumbing systems
- Homeowner preferences

5.1.1 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 construction of the retrofitting measure may conflict with local building regulations.

5.1.2 Surveys

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.

5.1.3 Structure Survey

The structure 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 BFE;
- 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; and

the establishment of a stable vertical datum or elevation benchmark near the house.

### 5.1.4 Topographic Survey

A detailed retrofitting design should not be developed without a site plan or map of the area. A State-registered Professional Land Surveyor can prepare a site plan of the area, incorporating the low point of entry determination information, as well as general topographic and physical features. The entire site and/or building lot should be mapped for design purposes. 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, easements, and/or lines of division;
- perimeter of house and ancillary structures (sheds, storage tanks);
- 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);
- downspout locations;
- trees of significant diameter (size varies per jurisdiction);
- large shrubs and other site landscaping features;
- building overhangs and chimney;
- window, door, and entrance dimensions;
- mechanical units such as A/C and heat pumps; and
- other appropriate flood data.

**NOTE**

Field surveys for design purposes should be performed by a State-registered Professional Land Surveyor.

**WARNING**

The location and elevation of all drainage features is critical.
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 access for materials and equipment as well as sediment and erosion control measures may also have an effect on the adjacent work area. Local building code mapping issues should also be addressed.

### 5.1.5 Site Utilities Survey

As part of the field investigation, above- and below-ground site utilities should be identified. Above-ground utilities, such as power lines, manhole covers, electric meters, etc., can be located both horizontally and vertically on the topographic map. Underground utilities, such as sanitary and storm drain lines, wells and septic tanks, and electric or gas service, will require an investigation through the appropriate utility agency. Local utility companies and county, municipal, and building code officials will be able to assist in the identification of the 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, who will prepare a sketch of their underground service. A checklist of underground services includes:

- water main and sanitary sewer pipes;
- cable television (CATV) and fiber optics;
- gas lines;
- storm drain fixtures and pipes;
- water wells;
- electric service;
- telephone cables; and
- any other local utility services.

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.

By identifying the utility services and units, provisions can be developed during the detailed design that will protect these utilities and keep them operational during a flood. Design provisions for utility relocation, encasement, elevation, anchoring, and, in some instances, new service, can be prepared.
5.1.6 Hazard Determinations

The designer (with the homeowners) should review the risk determinations previously conducted in Chapter 3 and confirm the flood protection design level and required height of the retrofitting measure selected. Not merely a function of expected flood elevation, freeboard, and low point of entry, this analysis should consider the protection of all components below the design elevation (i.e., below-grade basement walls and associated appurtenances).

The analysis of flood- and non-flood-related hazards was presented in detail in Chapter 4. The designer should utilize the calculation templates presented there to finalize expected design forces.

5.1.7 Documentation of Existing Building Systems

Documentation of the condition of the existing structure is an important aspect of the design of elevation, relocation, and dry and wet floodproofing measures. This topic was introduced in Chapter 3 as reconnaissance designed to provide preliminary information on the condition of an existing structure and its suitability for the various retrofitting methods.

As the design of a specific elevation, relocation, or dry and wet floodproofing measure is begun, the designer should conduct a detailed evaluation of the type, size, location, and condition of the existing mechanical, electrical, and plumbing systems. The enclosed Mechanical, Electrical, Plumbing, and Related Building Systems Data Sheet (Figure 5-2) can be used to document the results of this examination.
## Mechanical, Electrical, Plumbing, and Related Building Systems Data Sheet

(Note: Collect only the data necessary for your project)

<table>
<thead>
<tr>
<th>Owner Name: _______________________________________</th>
<th>Prepared By: _______________________________________</th>
</tr>
</thead>
<tbody>
<tr>
<td>Address: ___________________________________________</td>
<td>Date: ______________________________________________</td>
</tr>
<tr>
<td>Property Location: __________________________________</td>
<td></td>
</tr>
</tbody>
</table>

### 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

<table>
<thead>
<tr>
<th>[ ] Overhead</th>
<th>[ ] Underground</th>
<th>[ ] Voltage</th>
<th>[ ] 120/240 volt 10</th>
<th>[ ] 120/208 volt 10</th>
</tr>
</thead>
</table>

- [ ] 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

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Figure 5-2. 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

Figure 5-2. Mechanical, Electrical, Plumbing, and Related Building Systems Data Sheet (continued)
### Mechanical, Electrical, Plumbing, and Related Building Systems Data Sheet (concluded)

<table>
<thead>
<tr>
<th>Type:</th>
<th>☐ Upflow</th>
<th>☐ Downflow</th>
<th>☐ Horizontal</th>
<th>☐ Low Boy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fuel:</td>
<td>☐ Natural Gas</td>
<td>☐ LPG</td>
<td>☐ Electric</td>
<td>☐ Coal</td>
</tr>
<tr>
<td>Burner:</td>
<td>☐ Atmospheric</td>
<td>☐ Fan assisted</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Condensing:</td>
<td>☐ Yes</td>
<td>☐ No</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Venting:</td>
<td>☐ Natural draft</td>
<td>☐ Forced draft</td>
<td>☐ Direct vent</td>
<td></td>
</tr>
<tr>
<td>Air Distribution:</td>
<td>☐ Gravity</td>
<td>☐ Ducted</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Air Outlets:</td>
<td>☐ Floor</td>
<td>☐ Low sidewall</td>
<td>☐ High sidewall</td>
<td>☐ Ceiling</td>
</tr>
<tr>
<td>Hot Water/Steam:</td>
<td>☐</td>
<td>☐</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Boiler:</td>
<td>☐ Hot Water</td>
<td>☐ Steam</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Location:</td>
<td>☐ Basement</td>
<td>☐ 1st Floor</td>
<td>☐ ___floor</td>
<td>☐ Attic</td>
</tr>
<tr>
<td>Fuel:</td>
<td>☐ Natural Gas</td>
<td>☐ LPG</td>
<td>☐ Electric</td>
<td>☐ Coal</td>
</tr>
<tr>
<td>Terminal Units:</td>
<td>☐ Baseboard</td>
<td>☐ Radiators</td>
<td>☐ Other</td>
<td></td>
</tr>
<tr>
<td>In-Space Heating Equipment:</td>
<td>☐</td>
<td>☐</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gas:</td>
<td>☐ Room heater</td>
<td>☐ Vented</td>
<td>☐ Unvented</td>
<td></td>
</tr>
<tr>
<td></td>
<td>☐ Wall furnace</td>
<td>☐ Conventional</td>
<td>☐ Direct vent</td>
<td></td>
</tr>
<tr>
<td></td>
<td>☐ Floor furnace</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Oil/Kerosene:</td>
<td>☐ Vaporizing oil pot heater</td>
<td>☐ Powered atomizing heater</td>
<td>☐ Portable kerosene heater</td>
<td></td>
</tr>
<tr>
<td>Electric Heaters:</td>
<td>☐ Wall</td>
<td>☐ Floor</td>
<td>☐ Toe space</td>
<td>☐ Baseboard</td>
</tr>
<tr>
<td>Radiant Heat:</td>
<td>☐ Panels</td>
<td>☐ Embedded fireplace</td>
<td>☐ Portable cord and plug</td>
<td></td>
</tr>
<tr>
<td>Stoves:</td>
<td>☐ Conventional</td>
<td>☐ Advanced design</td>
<td>☐ Fireplace insert</td>
<td>☐ Pellet stove</td>
</tr>
</tbody>
</table>

### D. Cooling System

<table>
<thead>
<tr>
<th>Type:</th>
<th>☐ Central</th>
<th>☐ In-space air conditioners (ACs)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Central Systems:</td>
<td>☐ Split system A/C</td>
<td>☐ Unitary A/C</td>
</tr>
<tr>
<td></td>
<td>☐ Split system heat pump</td>
<td></td>
</tr>
</tbody>
</table>

#### Split Systems:

<table>
<thead>
<tr>
<th>Indoor unit location:</th>
<th>☐ Basement</th>
<th>☐ 1st Floor</th>
<th>☐ ___Floor</th>
<th>☐ Attic</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type:</td>
<td>☐ Upflow</td>
<td>☐ Downflow</td>
<td>☐ Horizontal</td>
<td></td>
</tr>
<tr>
<td>Air distribution:</td>
<td>☐ Sheet metal ductwork</td>
<td>☐ Fiberglass ductboard</td>
<td>☐ Flexible non-metallic runouts</td>
<td></td>
</tr>
<tr>
<td>Air outlets:</td>
<td>☐ Floor</td>
<td>☐ Low sidewall</td>
<td>☐ High sidewall</td>
<td>☐ Ceiling</td>
</tr>
<tr>
<td>Outdoor unit location:</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td></td>
</tr>
<tr>
<td>In-space air conditioners:</td>
<td>☐ Window air conditioners</td>
<td>☐ Ductless split systems</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Page 3 of 3

Figure 5-2. Mechanical, Electrical, Plumbing, and Related Building Systems Data Sheet (concluded)
5.1.8 Homeowner Preferences

A detailed discussion of homeowner preferences was presented in Chapter 3. The designer should confirm the homeowner’s preferences regarding:

- retrofitting measure type, size, and location(s);
- project design desires/preferences;
- limitations on construction area;
- estimated construction budget; and
- 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.

5.1.9 Homeowner Coordination

Homeowner coordination is similar for each of the retrofitting methods and 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.

5.1.10 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 NFIP Technical Bulletin 3-93, *Non-Residential Floodproofing – Requirements and Certification for Buildings Located in Special Flood Hazard Areas in Accordance with the NFIP* (FEMA, 1993) 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 field investigation, design calculations and construction details, and construction issues. Since many of the key elements in the field investigation phase were discussed above, only those issues that are critical to the design and successful construction of the particular retrofitting measure are included here.
5.2 Analysis of Existing Structure

The ability of an existing structure to withstand the additional loads created as a result of 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 a retrofitting measure such as elevation, relocation, dry and wet floodproofing, and floodwalls or levees. The steps involved in this analysis include:

- structural reconnaissance;
- determination of the capacity of the existing footing and foundation system;
- analysis of the loads imposed by the retrofitting measure; and
- comparison of the capacity of the existing structure to resist the additional loads imposed by the retrofitting measure.

5.2.1 Structural Reconnaissance

In order to determine whether a structure is suited to the various retrofitting measures being considered, the type and condition of the existing structure must be surveyed. Some structural systems are more adaptable to modifications than others. 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. Floodwalls and levees are designed to prevent water from reaching the home’s and thus should not have an impact on the structure. Wet floodproofing techniques have a lesser impact on the structure due to equalization of pressures, and also require analysis of the existing structure.

Several sources of information concerning the details of construction that were used in a structure include:

- construction drawings from the architect, engineer, or builder. These are usually the best and most reliable resource for determining the structural systems and the size of the members. The retrofit designer of record should verify by inspection wherever possible that materials were installed as specified on the referenced drawings;
- information available from the building permits office;
- plans of any renovations or room additions and a recent record of existing conditions;
- contractors who have performed recent work on the home, such as plumbing, mechanical, electrical, etc.; and
- a home inspection report, if the home has been recently purchased. While these reports are not highly detailed, they may give a good review of the condition of the home and point out major deficiencies.

If the aforementioned 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 as Figure 5-3 can be used to document this information.
**General Design Practices**

**Structural Reconnaissance Worksheet**

**Sketch and Description of Existing Structure**

<table>
<thead>
<tr>
<th>Item</th>
<th>Material</th>
<th>Size</th>
<th>Condition (Excellent, Good, Fair, Unacceptable)</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flooring</td>
<td>Concrete</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Foundation Wall</td>
<td>Concrete</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Concrete Masonry</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Brick Masonry</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Walls</td>
<td>Wood Frame</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Masonry</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Metal Frame</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Floor System</td>
<td>Wood Joist</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Post and Beam</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Wood Truss</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Roof System</td>
<td>Truss</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Rafter</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Exterior Finishes</td>
<td>Wood Siding</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Brick Veneer</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Stucco</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Interior Finishes</td>
<td>Drywall</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Plaster</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Wood</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Figure 5-3. Structural Reconnaissance Worksheet**

### 5.2.2 Footings and 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 it serves as an anchor against uplift and against forces caused by wind, seismic, flooding, and other loads. Foundation walls (below grade) 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 house. 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 guidance for design and construction.

**5.2.3 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. The size of the footing can be determined by Equation 5-1.

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.

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 design of the retrofit.

![Figure 5-4. Foundation system loading](image-url)

**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 figure below, an analysis of shear and bending forces is required. Refer to ACI 318-08, Building Code Requirements for Structural Concrete and Commentary (2008), for investigations of such concrete footings.
EQUATION 5-1: DETERMINING FOOTING SIZE

\[ A_f = \frac{P}{S_{bc}} \]  
(Eq. 5-1)

where:
- \( A_f \) = bearing area of the footing (ft²)
- \( P \) = load (lb)
- \( S_{bc} \) = allowable soil bearing capacity (lb/ft²); see Table 5-2

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 5-2: MAXIMUM LOADING OF EXISTING FOOTING

\[ P_{max} = A_f S_{bc} \]  
(Eq. 5-2)

where:
- \( A_f \) = bearing area of the footing (ft²)
- \( P_{max} \) = max load (lb)
- \( S_{bc} \) = allowable soil bearing capacity (lb/ft²); see Table 5-2

CROSS REFERENCE
American Concrete Institute 530, 2008, (ACI 530-08) provides maximum height or length to thickness ratios. Height or length is based on the location of the lateral support elements that brace the masonry and permit the transfer of loads to the resisting elements. Nominal wall thickness may be used for \( t_{wall} \). Table 5-2. “Wall Lateral Support Requirements” (ACI 530-08) provides maximum slenderness ratio values for bearing and non-bearing walls.

EQUATION 5-3: BEARING CAPACITY OF EXISTING STRIP FOOTING

\[ W_f = b_f S_{bc} \]  
(Eq. 5-3)

where:
- \( W_f \) = total weight footing wall support (lb/ft)
- \( b_f \) = width of footing (ft)
- \( S_{bc} \) = allowable soil bearing capacity (lb/ft²); see Table 5-2

NOTE
\( W_f \) acts downward.

CROSS REFERENCE
Use of Equation 5-4 is limited and should be verified using ACI 530-08 and local building codes for design applications.
5.2.4 Bearing Capacity of Foundation Walls

The bearing capacity of an existing concrete masonry foundation wall can be estimated if the designer knows the size and grade of the block, using the following equation.

\[
W_w = S_c A
\]

(Eq. 5-4)

where:
- \( W_w \): total weight per linear foot (lf) wall will support (lb/ft)
- \( S_c \): bearing capacity of the masonry from Table 5-1 (lb/in.²)
- \( A \): cross-sectional area per lf of wall = \( t_w \) (12 in.)

where: \( t_w \): thickness of wall in inches

By changing the value of the bearing capacity according to the conditions identified on the site, the designer can determine the approximate weight that the foundation wall will support. If the type of block and mortar is unknown, the most conservative values should be used. Intrusive methods of investigation must be employed to determine footing depth, thickness, reinforcement, condition, or drainage. Technology exists for investigation of walls using x-ray, ultrasound, and other methods; however, these methods may be too costly for residential retrofitting projects.

5.2.5 Lateral Loads

The ability of exterior foundation walls and interior structural walls to withstand flood-related and non-flood-related forces is dependent upon the wall size, type, and material. Interior and exterior walls are checked for failure from overturning, bending, and shear (horizontal, vertical, and diagonal). If the stress caused by the expected loading is less than the code-allowable stress for the expected failure mode, the wall design is acceptable. Conversely, if the stresses caused by the expected loadings are greater than the code-allowable stresses for the expected failure mode, the design is unacceptable and reinforcing is required.

\[
NOTE
\]

The approximate bearing capacity of concrete and reinforced concrete materials may be quite variable 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 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 318-08.
### General Design Practices

Values shown in Table 5-1 are guidelines. Additional information on the capacity and strength of masonry construction can be obtained from ACI 530-08.

For masonry walls, use ACI 530-08 to determine allowable stress information. For plywood shear walls, the Engineered Wood Association offers allowable load information. For reinforced concrete walls, consult ACI 318-08. For non-reinforced concrete walls, consult Chapter 22 of ACI 318-08.

Values shown in Table 5-2 are guidelines.

#### Table 5-1. Approximate Bearing Capacity for Masonry Wall Types

<table>
<thead>
<tr>
<th>Masonry Units</th>
<th>Approximate Compressive Bearing Capacity for Masonry Walls, $S_{cr}$ Based on Gross Cross-Section (lb/in²)*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Solid masonry of brick and other solid units of clay or shale; sand-lime or concrete brick **</td>
<td>100 to 115</td>
</tr>
<tr>
<td>Grouted masonry of clay or shale; sand-lime or concrete**</td>
<td>100 to 115</td>
</tr>
<tr>
<td>Hollow units of concrete masonry</td>
<td>55 to 75</td>
</tr>
</tbody>
</table>

** Compressive strength of masonry unit, gross area, equal to 1,500 psi

Note: See ACI 530-08 if dimensions stated above are not met.

#### Table 5-2. Presumptive Vertical Load-Bearing Capacities for Different Materials

<table>
<thead>
<tr>
<th>Material Class</th>
<th>$S_{bc}$, lb/ft²*</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Rock</td>
<td>4,000+</td>
</tr>
<tr>
<td>2. Sandy gravel, gravel</td>
<td>3,000</td>
</tr>
<tr>
<td>3. Sand, silty sand, clayey sand, silty gravel, clayey gravel</td>
<td>2,000</td>
</tr>
<tr>
<td>4. Clay, sandy clay, silty clay, clayey silt</td>
<td>1,500</td>
</tr>
</tbody>
</table>

** Compressive strength of masonry unit, gross area, equal to 1,500 psi

Note: See ACI 530-08 if dimensions stated above are not met.
Due to the large number of wall types and situations that can be encountered that 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.

### 5.2.6 Vertical Loads

In addition to the loads imposed by floodwater, other types of loads must be considered in the design of a structural system, such as building dead loads, live loads, snow loads, wind loads, and seismic loads (if applicable). Flood, wind, and seismic loads were discussed earlier in Chapters 3 and 4. This section deals with the computation of dead loads, live loads, and roof snow loads.

### 5.2.7 Dead Loads

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 some construction components and assemblies is provided in Table 5-3. 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 at Figure 5-5 can be used to make a preliminary estimate of the weight of a structure. To use Figure 5-5, 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.
### Table 5-3. Weights of Construction Types

<table>
<thead>
<tr>
<th>Construction</th>
<th>Weight, lb/ft² surface area</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wood stud wall, 2x4, interior, ½-in. drywall 2S</td>
<td>8</td>
</tr>
<tr>
<td>Interior, wood or metal 2x4s, plaster 2S</td>
<td>19</td>
</tr>
<tr>
<td>Exterior, drywall; 4-in. batt insulation; wood siding</td>
<td>11</td>
</tr>
<tr>
<td>Exterior, drywall; 4-in. batt insulation; 4-in. brick (MW)</td>
<td>47</td>
</tr>
<tr>
<td>Exterior, drywall; 4-in. batt insulation; 8-in. concrete block</td>
<td>60-65</td>
</tr>
<tr>
<td>Metal stud wall, 2x4, interior, ½-in. drywall 2S</td>
<td>7</td>
</tr>
<tr>
<td>Exterior, drywall; 4-in. batt insulation; 1-in. stucco</td>
<td>23</td>
</tr>
<tr>
<td>Metal stud wall, exterior, drywall; 4-in. batt insulation; 2-in. drywall</td>
<td>18</td>
</tr>
<tr>
<td>Exterior, drywall; 4-in. batt insulation; 3-in. granite or 4-in. brick</td>
<td>55</td>
</tr>
<tr>
<td>Plaster, per face, wall, or ceiling, on masonry or framing</td>
<td>8</td>
</tr>
<tr>
<td>Ceramic tile veneer, per face</td>
<td>10</td>
</tr>
<tr>
<td>MW, 4-in. brick, MW, per wythe (continuous vertical section of masonry, one unit in thickness)</td>
<td>39</td>
</tr>
<tr>
<td>4-in. conc. block, heavy aggregate, per wythe</td>
<td>30</td>
</tr>
<tr>
<td>8-in. conc. block, heavy aggregate, per wythe</td>
<td>55</td>
</tr>
<tr>
<td>Glass block wall, 4-in. thick</td>
<td>18</td>
</tr>
<tr>
<td>Glass curtain wall</td>
<td>10-15</td>
</tr>
<tr>
<td>Floor or ceiling, 2x10 wood deck, outdoors</td>
<td>8-10</td>
</tr>
<tr>
<td>Wood frame, 2x10, interior, unfinished floor; drywall ceiling</td>
<td>8-10</td>
</tr>
<tr>
<td>Concrete flat slab, unfinished floor; suspended ceiling</td>
<td>80-90</td>
</tr>
<tr>
<td>Concrete pan joist (25 in. o.c., 12-in. pan depth, 3-in. slab), unfinished floor; suspended ceiling</td>
<td>90-100</td>
</tr>
<tr>
<td>Concrete on metal deck on steel frame, unfinished floor; suspended ceiling</td>
<td>65-70</td>
</tr>
<tr>
<td>Finished floors, add to above:</td>
<td></td>
</tr>
<tr>
<td>Hardwood</td>
<td>3</td>
</tr>
<tr>
<td>Floor tile 1½-in. terrazzo</td>
<td>10</td>
</tr>
<tr>
<td>Wall-to-wall carpet</td>
<td>25</td>
</tr>
<tr>
<td><strong>Roofing, add to above:</strong></td>
<td></td>
</tr>
<tr>
<td>Roof, sloping rafters or timbers, sheathing; 10-in. batt insulation; ½-in. drywall</td>
<td>12-15</td>
</tr>
<tr>
<td>Built-up 5-ply roofing, add to above</td>
<td>6</td>
</tr>
<tr>
<td>Metal roofing, add to above</td>
<td>3-4</td>
</tr>
<tr>
<td>Asphalt shingle roofing, add to above</td>
<td>4</td>
</tr>
<tr>
<td>Slate or tile roofing, ¼-in. thick, add to above</td>
<td>12</td>
</tr>
<tr>
<td>Wood shingle roofing, add to above</td>
<td>3-5</td>
</tr>
<tr>
<td><strong>Insulation, add to above:</strong></td>
<td></td>
</tr>
<tr>
<td>Insulation, batt, per 4-in. thickness</td>
<td>1</td>
</tr>
<tr>
<td>Insulation, rigid foam boards or fill, per inch thickness</td>
<td>0.17</td>
</tr>
<tr>
<td><strong>Stairways:</strong></td>
<td></td>
</tr>
<tr>
<td>Concrete</td>
<td>80-95</td>
</tr>
<tr>
<td>Steel</td>
<td>40-50</td>
</tr>
<tr>
<td>Wood</td>
<td>15-25</td>
</tr>
</tbody>
</table>

2S = 2 sides  
MW = Masonry walls  
o.c. = on centers
### Building Weight Estimating Worksheet

<table>
<thead>
<tr>
<th>Construction Type (1)</th>
<th>Surface Area (2)</th>
<th>Weight (lb/ft²) of Surface Area (3)</th>
<th>Weight Component(4)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Walls Exterior</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Interior</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>First Floor</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Second Floor</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Attic</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Roof Special Items</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fireplace*</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Chimney*</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Structure Weight</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Total Weight</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Do not include if chimney/fireplace has a separate foundation

**Figure 5-5. Building Weight Estimating Worksheet**

**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.

### 5.2.8 Live Loads

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 is a uniformly distributed load of 40 pounds per square foot.

**CROSS REFERENCE**

Check local codes for guidance on acceptable live loads. In the absence of code information use ASCE 7.
5-20 ENGINEERING PRINCIPLES AND PRACTICES for Retrofitting Flood-Prone Residential Structures

5.2.9 Roof Snow Loads

The roof snow load varies according to the geography, roof slope, and thermal, exposure, and importance 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 this information. In areas of little snowfall, codes may require a minimum roof snow load.

5.2.10 Calculation of Vertical, Dead, Live, and Snow Loads

Dead, live, and snow loads act vertically downward and are carried by the load-bearing walls or the columns to the foundation system. The load-bearing walls support any vertical load in addition to their own weight. The amount of the dead load carried by a wall or column is calculated based on the partial area of the roof and floor system (tributary areas) that are supported by that wall or column plus its own weight (self weight). The tributary areas are illustrated in Figures 5-6 and 5-7 and determined using Equation 5-6, Equation 5-7, or Equation 5-8.

For the load-bearing walls, the tributary area is the area bounded by the length of the wall perpendicular to the floor joists or roof trusses multiplied by half the span length of the joist or truss.

### EQUATION 5-6: CALCULATION OF TRIBUTARY AREA FOR LOAD-BEARING WALLS

\[ A_w = \frac{lw}{2} \]  

(Eq. 5-6)

where:
- \( A_w \) = wall tributary area (ft\(^2\))
- \( l \) = length of the wall (ft)
- \( w \) = span length between walls or the wall and center girder (ft)
EQUATION 5-7: CALCULATION OF TRIBUTARY AREA FOR CENTER GIRDER

\[ A_g = \frac{l(a+b)}{2} \]

(Eq. 5-7)

where:
- \( A_g \) = center girder tributary area (ft\(^2\))
- \( l \) = length of the girder (ft)
- \((a+b)\) = length between adjacent parallel supports – wall or girder – per Figure 5-7 (ft)

For columns, the tributary area is the area bounded by imaginary lines drawn halfway between the column and the adjacent load-bearing wall or column in each direction.

EQUATION 5-8: CALCULATION OF TRIBUTARY AREA FOR COLUMNS

\[ A_t = \frac{w(2l)}{4} \]

(Eq. 5-8)

where:
- \( A_t \) = column tributary area (ft\(^2\))
- \( l \) = length of the wall surrounding the column (ft)
- \( w \) = span length between walls surrounding the column (ft)

To calculate the loads, follow the steps below:

**Step 1**: Inspect the roof and the floor construction to identify load-bearing walls. Mark the direction, the span length, and the supporting walls or columns for the roof trusses and floor joists.

**Step 2**: Calculate the roof and the floor tributary areas for each load-bearing wall and column.

**Step 3**: For each load-bearing wall and column, multiply the tributary areas by the dead, live, and snow loads to find the total loads.
Figure 5-6. Column tributary area

Figure 5-7. Wall/girder tributary area
EQUATION 5-9: CALCULATION OF WALL/COLUMN LOADS

\[ TL_{dis} = (DL + LL + SL)A_t \]  

(Eq. 5-9)

where:

- \( TL_{dis} \) = total dead, live, and snow loads acting on a specific wall or column (lb)
- \( DL \) = dead load (lb/ft\(^2\)); see Figure 5-5
- \( LL \) = live load (lb/ft\(^2\)); see Equation 5-5
- \( SL \) = snow load (lb/ft\(^2\)); taken from building code
- \( A_t \) = tributary area of the wall or column (ft\(^2\)) taken from Equations 5-6 and 5-8
  (when analyzing walls, use \( A_w \) instead of \( A_t \))

Step 4: Calculate the self weight of the wall or column. Add any overbearing soil and foundation weight to the total. This information can be taken from the calculation worksheet shown in Figure 5-5.

EQUATION 5-10: CALCULATION OF WALL/COLUMN LOADS

\[ W_{self} = (SA \times W_u) + OSW + FW \]  

(Eq. 5-10)

where:

- \( W_{self} \) = self weight of the component (lb)
- \( SA \) = section area of the component (ft\(^2\))
- \( W_u \) = unit weight of the component (lb/ft\(^2\) of surface)
- \( OSW \) = overbearing soil weight (lb)
- \( FW \) = foundation weight (lb)
EQUATION 5-11: CALCULATION OF TOTAL LOAD CARRIED BY THE WALL OR COLUMN TO THE FOOTING OR FOUNDATION

\[ TL = W_{self} + TL_{dis} \]  

(Eq. 5-11)

where:

- \( TL \): total load carried by the wall or column to the footing or foundation (lb)
- \( W_{self} \): self weight of the component (lb)
- \( TL_{dis} \): total dead, live, and snow loads acting on a specific wall or column (lb)

Step 5: Add all the above calculated loads to find the load carried by the wall or column to the foundation or footing.

5.2.11 Capacity versus Loading

The next step is to examine the capacity of the existing foundation component or system versus the expected loading from a combination of dead, live, flood, wind, snow, and seismic loads. This analysis will provide an initial estimate of the magnitude of foundation modifications necessary to accomplish an elevation or relocation project.

The IBC and IRC 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 foundation or structural member concerned.

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.

5.2.12 Load Combination Scenarios

ASCE 7-10 prescribes how to analyze flood loads in concert with other loading conditions. This guidance involves the use of two methods: allowable stress design and strength design. In the case of 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).

In strength design, design specifications provide load factors, and, in some instances, resistant factors.

The analysis of loading conditions may be checked using either method provided that method is used exclusively for proportioning elements of that construction material.
The designer should consult ASCE 7-10 for guidance in analyzing the multi-hazard loading conditions.

The following symbols are used in defining the various load combinations.

- \( D \) = Dead Load
- \( E \) = Earthquake Load
- \( F \) = Load due to fluids with well-defined pressures and maximum heights
- \( F_a \) = Flood Load
- \( H \) = Load due to lateral earth pressure, ground water 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

These symbols are based upon information from ASCE 7-10 but do not match exactly as several symbols had to be revised to accommodate symbols already used in this manual. Refer to ASCE 7-10 for clarification and additional information.

### 5.2.13 Strength Design Method

When combining loads using the strength design methodology, structures, components, and foundations should be designed so that their strength equals or exceeds the effects of the factored loads in the following combinations:

1. \( 1.4D \)
2. \( 1.2D + 1.6L + 0.5(L_r \text{ or } S \text{ or } R) \)
3. \( 1.2D + 1.6(L_r \text{ or } S \text{ or } R) + (L \text{ or } 0.5W) \)
4. \( 1.2D + 1.0W + L + 0.5(L_r \text{ or } S \text{ or } R) \)
5. \( 1.2D + 1.0E + L + 0.2S \)
6. \( 0.9D + 1.0W \)
7. \( 0.9D + 1.0E \)
Exceptions:

1. The load factor on $L$ in combinations (3), (4), and (5) is permitted to equal 0.5 for all occupancies in which $L_o$ in Table 4-1 of ASCE 7-10 is less than or equal to 100 lb/ft$^2$, with the exception of garages or areas occupied as places of public assembly.

2. In combinations (2), (4), and (5), the companion load $S$ shall be taken as either the flat roof snow load ($p_f$) or the sloped roof snow load ($p_s$).

   Where fluid loads $F$ are present, they shall be included with the same load factor as dead load $D$ in combinations (1 through 5 and 7).

   Where loads $H$ are present, they shall be included as follows:

   1. Where the effect of $H$ adds to the primary variable load effect, include $H$ with a load factor of 1.6.

   2. Where the effect of $H$ resists the primary variable load effect, include $H$ with a load factor of 0.9 where the load is permanent or a load factor of 0 for all other conditions.

Effects of one or more loads not acting should be investigated. The most unfavorable effects from both wind and earthquake loads should be investigated, where appropriate, but they need not be considered to act simultaneously. Refer to Section 12.4 of ASCE 7-10 for specific definition of the earthquake load effect $E$. Each relevant strength limit state shall be investigated.

When a structure is located in a flood zone, the following load combinations should be considered in addition to the basic combinations in Section 2.3.1 of ASCE 7-10:

- in Zone V or Coastal A Zones, $1.0W$ in combinations (4) and (6) shall be replaced by $1.0W + 1.0F_a$.
- in Zone A in noncoastal areas, $1.0W$ in combinations (4) and (6) shall be replaced by $0.5W + 1.0F_a$.

This material is taken directly from ASCE 7-10.

The guidance in ASCE 7-10 Section 2.3 for Strength Design indicates which load combinations the flood load should be applied to. In the portion of Zone A landward of the LiMWA, the flood load $F_a$ could be either hydrostatic or hydrodynamic loads. Both of 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, $F_o$ should be determined by the type of flooding expected. Hydrostatic forces will govern if the flooding is primarily 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 $F_{hyd}$) + $F_i$ (impact loads on that element acting at the stillwater level). The combination of these loads must be used to develop the required resistance that must be provided by the building element.

See Section 8.5.12 of FEMA P-55, Coastal Construction Manual (FEMA, 2011) for more guidance regarding incorporating flood loads into load combination equations.
5.2.14 Allowable Stress Method

When combining loads using the allowable stress method, the loads should be considered to act in the following combinations, whichever produces the most unfavorable effect on the building, foundation, or structural member being considered. This material is taken directly from ASCE 7-10.

1. $D$
2. $D + L$
3. $D + (L_r$ or $S$ or $R)$
4. $D + 0.75L + 0.75(L_r or S or R)$
5. $D + (0.6W + 0.7E)$
6a. $D + 0.75L + 0.75(0.6W) + 0.75(L_r or S or R)$
6b. $D + 0.75L + 0.75(0.7E) + 0.75S$
7. $0.6D + 0.6W$
8. $0.6D + 0.7E$

Exceptions:

1. In combinations (4) and (6), the companion load $S$ shall be taken as either the flat roof snow load ($p_f$) or the sloped roof snow load ($p_s$).

2. For non-building structures, in which the wind load is determined from force coefficients, $C_{fm}$ identified in Figures 29.5-1, 29.5-2, and 29.5-3 of ASCE 7-10, and the projected area contributing wind force to a foundation element exceeds 1,000 square feet on either a vertical or horizontal plane, it shall be permitted to replace $W$ with $0.9W$ in combination (7) for design of the foundation, excluding anchorage of the structure to foundation.

3. It shall be permitted to replace $0.6D$ with $0.9D$ in combination (8) for the design of Special Reinforced Masonry Shear Walls, where the walls satisfy the requirement of Section 14.4.2 of ASCE 7-10.

Where fluid loads $F$ are present, they shall be included in combinations (1) through (6) and (8) with the same factor as that used for dead load $D$.

Where load $H$ is present, it shall be included as follows:

1. Where the effect of $H$ adds to the primary variable load effect, include $H$ with a load factor of 1.0.
2. Where the effect of $H$ resists the primary variable load effect, include $H$ with a load factor of 0.6 where the load is permanent or a load factor of 0 for all other conditions.

The most unfavorable effects from both wind and earthquake loads should be considered, where appropriate, but they need not be assumed to act simultaneously. Refer to Sections 1.4 and 12.4 of ASCE 7-10 for specific definition of the earthquake load effect $E$. Increases in allowable stress shall not be used with the loads or
load combinations given in ASCE 7-10 unless it can be demonstrated that such an increase is justified by structural behavior caused by rate or duration of load.

Buildings and other structures should be designed so that the overturning moment due to lateral forces (wind or flood) acting singly or in combination does not exceed two-thirds of the dead load stabilizing moment unless the building or structure is anchored to resist the excess moment. The base shear due to lateral forces should not exceed two-thirds of the total resisting force due to friction and adhesion unless the building or structure is anchored to resist the excess sliding force. Stress reversals should be accounted for where the effects of design loads counteract one another in a structural member or joint.

When a structure is located in a flood zone, the following load combinations should be considered in addition to the basic combinations in Section 2.4.1 of ASCE 7-10:

- in Zone V or Coastal A Zone, \(1.5F_a\) should be added to load combinations (5), (6), and (7) and \(E\) should be set equal to zero in (5) and (6); and
- in Zone A in noncoastal areas, \(0.75F_a\) should be added to load combinations (5), (6), and (7) and \(E\) should be set equal to zero in (5) and (6).

ASCE 7-10 Section 2.4 for Allowable Stress Design indicates which load combinations the flood load should be applied to, as discussed above in Section 5.2.13. Additional details are also provided in Section 8.5.12 of FEMA P-55 (FEMA, 2011).

Analyzing the existing structure’s capacity to resist the expected loads is sometimes a long and tedious process, but it must be done to ensure that the structure will be able to withstand the additional loadings associated with various retrofitting measures.

The objective of this analysis is to verify that:

- the existing structure is able to withstand the anticipated loadings due to the retrofitting measure being considered; or
- the existing structure is unable to withstand the anticipated loadings due to the retrofitting measure being considered and requires reinforcement or other structural modification.

If these conditions are not met, then the retrofitting measure should be eliminated from consideration.

Using the information presented in this chapter, the designer should be able to conduct the analyses to implement the stated objective and identify the measures/modifications that must be designed.