Fact Sheet 3.1: Foundations

The mitigation objective of this Fact Sheet is to decrease the likelihood of foundation damage or failure from a flood or hurricane that could restrict using the building or parts of the building for extended periods.

Building foundations can be grouped by general characteristics of open, closed/continuous, shallow and deep. Foundations generally have two of these characteristics, e.g., open and deep or continuous and shallow. These characteristics play a large part in how the foundation performs during a flood or hurricane. The text box below provides additional information about foundation characteristics, and Figure 3.1.1 illustrates these foundation characteristics.

Definitions

Closed Foundations—Closed foundations restrict or divert the flow of floodwaters. Closed foundations include basements, crawl spaces where the lowest floor is built above ground, stem walls with soil-supported concrete floor slabs, and soil-supported monolithic slab-on-grade foundations where portions of the slab often are thickened to support the structure above.

Open Foundations—Columns, piers and piles support raised buildings and allow floodwaters to pass underneath the structure. Open foundations are typically less vulnerable to flood damage than closed foundations.

Shallow Foundations—Shallow foundations are supported by soils that are relatively close to the surface of the surrounding grade. Shallow foundations include crawl space foundations, stem walls, monolithic slab-on-grade, discrete pad footings, and mat-style foundations. Column and pier foundations also can be shallow. Shallow foundations are vulnerable to moving floodwaters and can be undermined by scour and erosion.

Deep Foundations—Deep foundations are supported by soils or bedrock that are significantly below the surface of the surrounding grade. Deep foundations include piles, drilled shafts and caissons. Deep foundations naturally resist scour and erosion.

Structure Attributes

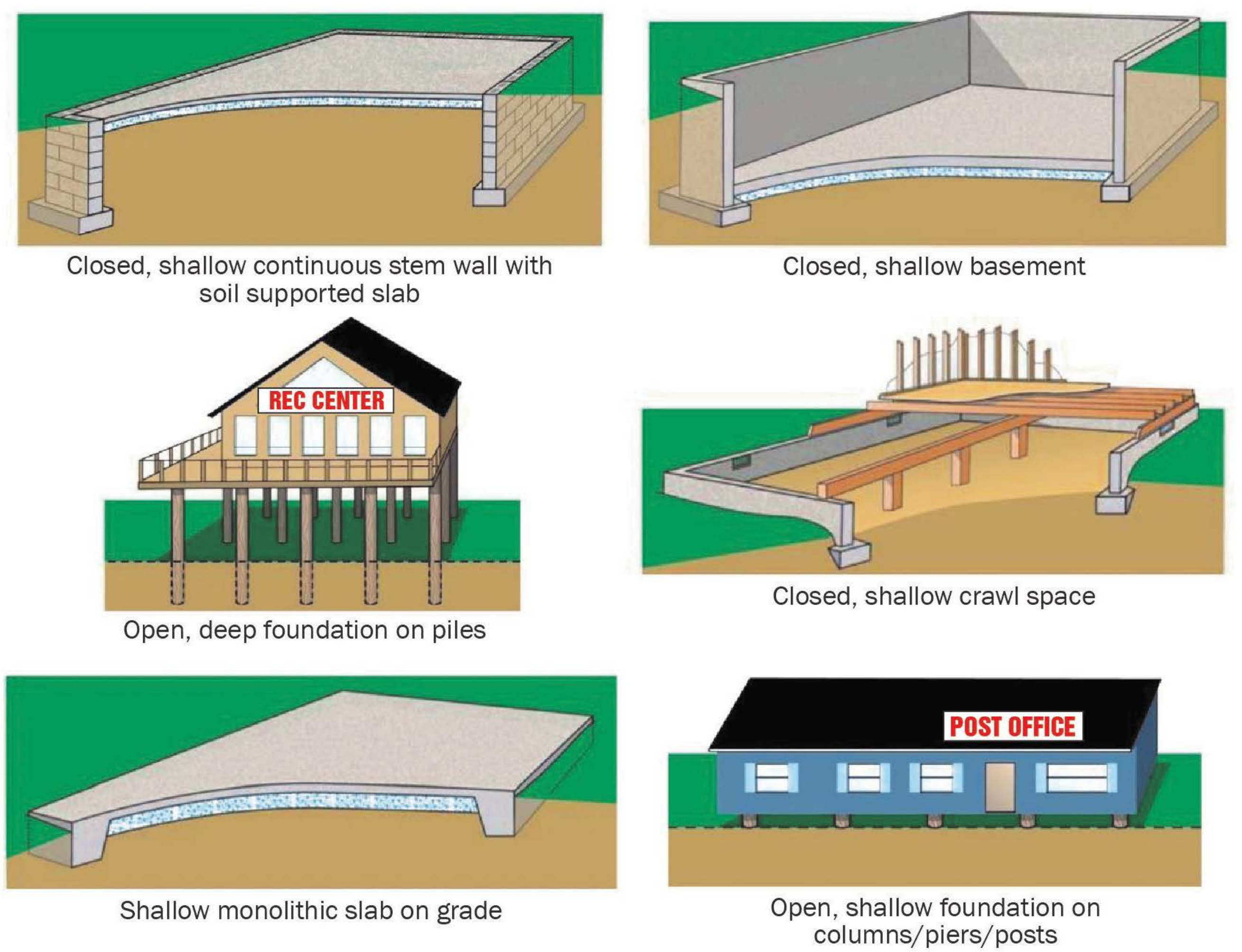


Figure 3.1.1. Foundation characteristics.

Table 3.1.1 summarizes some common mitigation strategies that can improve building foundation performance. These strategies are discussed in the sections that follow.

Table 3.1.1. Common Mitigation Solutions

Solutions and Options	***Crawl Space***	***Stem Wall***	***Columns/ Piers***	***Piles***	***Basement***	***Slab-on-Grade***
Mitigation Solution: Relocate						
Option 1: Relocate the Building	✓	✓	✓	✓	✓	✓
Mitigation Solution: Elevate						
Option 1: Elevate the Foundation (freeboard)	✓		✓	✓		**NR***
Option 2: Convert or Abandon the First Floor		✓			✓	✓
Option 3: Raise the Interior Floor	✓	✓			✓	✓
Mitigation Solution: Floodproof						
Option 1: Wet Floodproof	✓				✓	
Option 2: Dry Floodproof		✓			**NR***	✓
Mitigation Solution: Retrofit the Structure						
Option 1: Anchor or Brace	✓	✓	✓	✓	✓	✓
Option 2: Improve Connections	✓	✓	✓	✓	✓	✓
Option 3: Underpin Footings	✓	✓			✓	✓

NR* = Not recommended for existing foundation type.

Mitigation Solution: Relocate

Relocation typically involves moving a building out of the hazard area. Due to the challenges of moving buildings over roadways, relocation is typically limited to small non-residential buildings where additional land outside the floodplain is available on the current site or on a nearby site. This mitigation measure can offer the best protection for retrofitting existing buildings from flood and coastal hazards. Still, it is often the most expensive mitigation solution.

Option 1: Relocate the Building

The following steps represent a typical relocation process:

1. Place large steel beams to temporarily support the structure and raise the building off its foundation.
2. Place the raised building on equipment capable of supporting the weight of the building. When relocation involves moving over roads, heavy-duty flatbed trailers often are used (Figure 3.1.2).

Figure 3.1.2. Relocation of a small flood-prone public building.

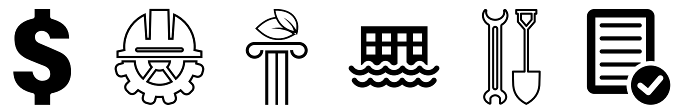
3. Haul the building to another part of the site or to a new site outside of the hazard area.
4. Lower the building onto a new foundation system.
5. Secure the building to the foundation to resist water and wind forces to which the building may be exposed.

When evaluating relocation as an option, consider the following items:

- Candidate buildings must be thoroughly evaluated for structural soundness.
- All structural members and connections must be strong enough to withstand the stresses of being lifted, transported and placed on a new foundation.
- Small, single-story, wood-frame structures that are supported by open foundations or placed over crawl spaces or basements are often the easiest buildings to relocate.

- Due to size and weight considerations, large, multi-story or heavy buildings like masonry structures are more challenging to relocate.
- Consider relocating critical facilities to an inland site to reduce storm exposure.
- Historic buildings can be susceptible to movement during relocation. If the building is historic, the move should be coordinated with the state historic preservation office.

CONSIDERATIONS:



Mitigation Solution: Elevate

Elevation involves raising a building to reduce its risk of flooding while keeping the building at or near its existing location. For buildings located in a Coastal High Hazard Zone, the lowest floor of a structure or lowest horizontal structural member must be raised to the design flood elevation (DFE). Where possible, provide greater risk reduction by raising the building more than required to reach the DFE. Like relocation, elevation is easiest with smaller or lighter buildings; larger buildings generally are more difficult to raise. Buildings that cannot be relocated may be candidates for elevation.

- Elevation involves most of the same steps as those required for relocation, except for transportation of the building. Elevation does not reduce risk to building foundations, so consider improving the foundation in addition to elevating the building. An example of a foundation improvement is replacing a closed-style foundation with an open-style foundation.
- Some general points to keep in mind when considering elevation as a mitigation strategy include:
- Shallow foundations, continuous wall foundations and open foundations can fail because of damage caused by erosion and the impact of debris carried by floodwaters.
- If portions of the original foundation (for example, footings) are used to support any new addition to the building, they must be capable of safely carrying the additional loads imposed by new construction and expected flood and wind forces.
- For Substantially Damaged critical facilities along the coast, choose an inland relocation site to elevate the critical facilities to reduce hazard exposure, so the facilities retain functionality in future hazard events.
- Slab-on-grade buildings are harder to elevate because there is no place to insert the lifting beams. Most grade slabs are not designed to function as raised floor systems. Raising them also can pose a risk to the building. In some cases, the building can be lifted off of and separated from the slab.

Option 1: Elevate the Foundation

This elevation option raises the entire structure of a small public building or portions of a large public building. When evaluating this mitigation strategy, consider the following:

- During the elevation process, most buildings are separated from their foundations, raised on hydraulic jacks, and held by temporary supports (cribbing), while a new or extended foundation is built below. Buildings with basements typically backfill the basement to grade. The new or extended foundation can consist of continuous walls or separate piers, posts, columns or piles.
- Buildings exposed to flooding from rivers or surface water flooding and buildings in NFIP Zone A may be raised on closed, shallow foundations with the top of the lowest floor at or above the DFE, in accordance with Zone A construction requirements.

- Elevation of slab-on-grade buildings is not advised since the slab was never intended to support a raised structure.
- Open, deep foundations using driven piles with the lowest horizontal part of the structure at or above the DFE, in accordance with Zone V construction requirements, as shown in Figure 3.1.3, are the only foundations compliant with coastal zone floodplain management and building code regulations.

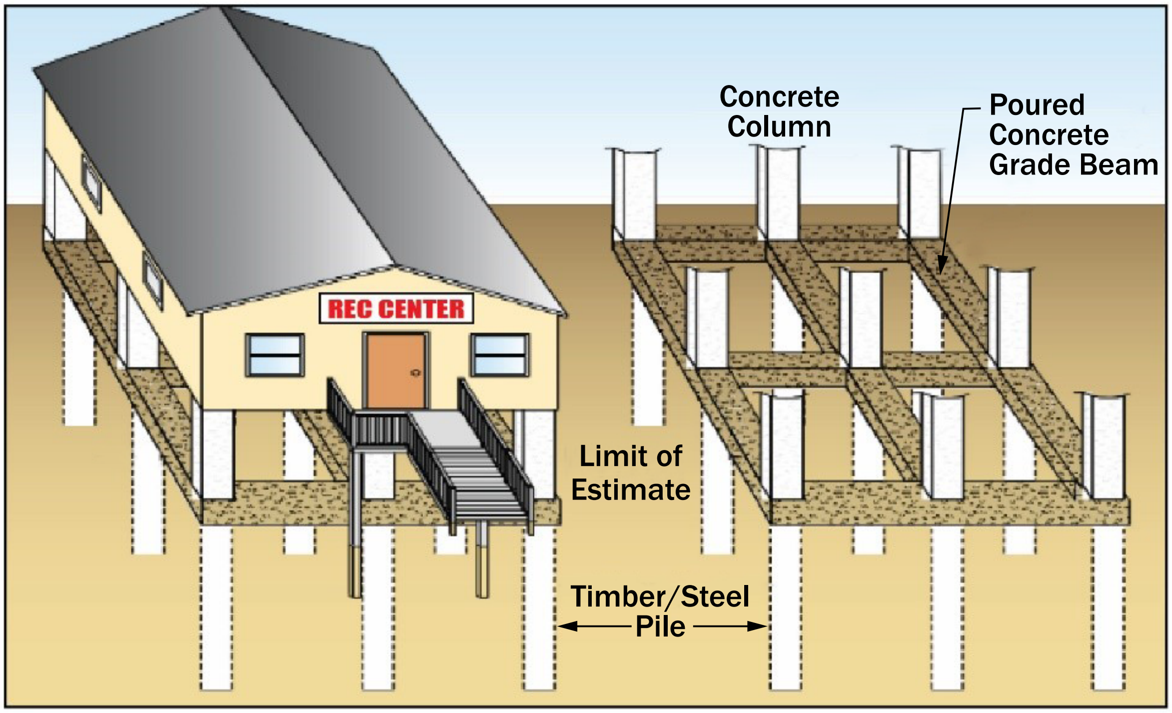
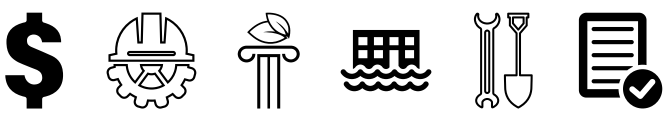


Figure 3.1.3. Elevation of small public building on piles in coastal flood zone.

CONSIDERATIONS:



Option 2: Convert or Abandon the First Floor

For small or large public buildings that are two or more stories high, and where the lowest floor is constructed with flood-resistant materials, elevation can be achieved by vacating the lowest story or converting its use in accordance with the NFIP or local ordinances.

Consider the following when evaluating this option:

- With conversion or abandonment, the building is not raised, but flood risks are reduced.
- Check the base flood elevation (BFE) against the potential for storm surge and design for the higher of the two levels.
- Install flood vents to allow floodwaters to enter the lowest level, equalizing flood levels inside and outside the building and reducing or relieving buoyancy and hydrostatic forces (Figure 3.1.4).

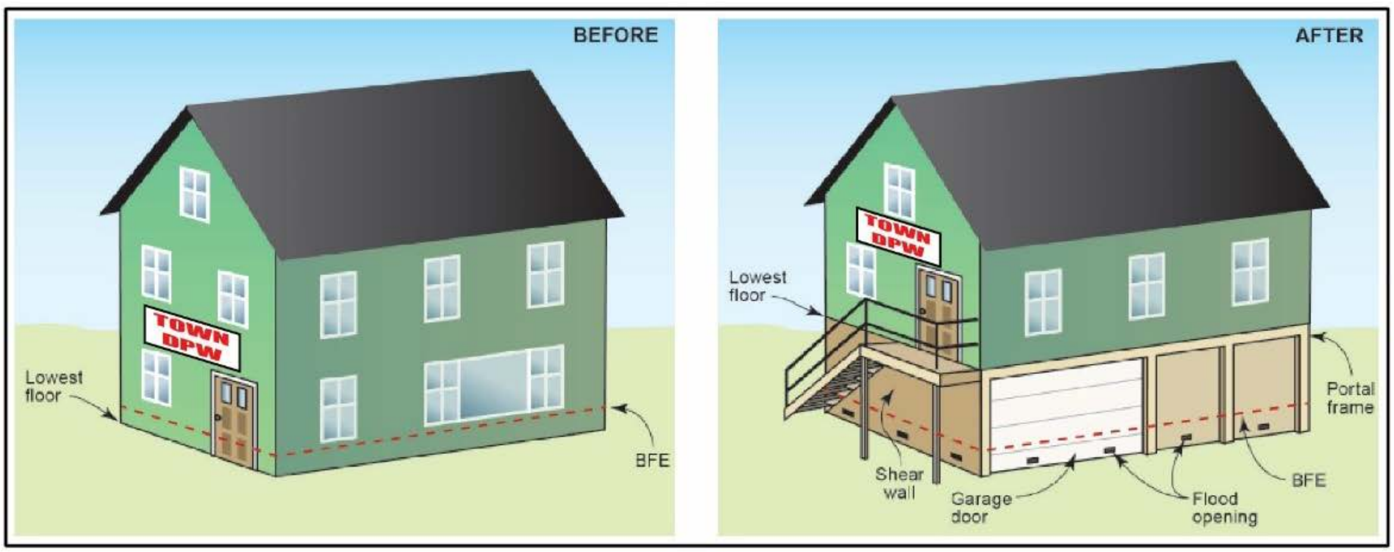
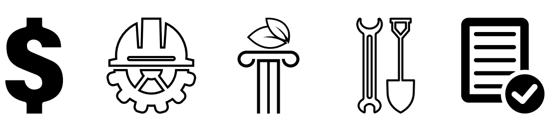


Figure 3.1.4. Abandoning the lowest floor can elevate usable space above the BFE.

- Consider building an additional story to replace a converted or abandoned first floor. This option is only viable for buildings that have the structural capacity to support the added story. The original foundation must safely carry the additional loads imposed by an additional story while also handling flood and wind loads.
- Damage caused by erosion and debris impacts can cause shallow foundations, continuous wall foundations and open foundations to fail.

CONSIDERATIONS:



Option 3: Raise the Interior Floor

For small or large public buildings where the first floor has enough ceiling height, raising the floor can achieve elevation. Basements can be filled to the potential maximum flood level if there is enough first-floor clearance for code compliance and building function, as shown in Figure 3.1.5. This measure is accomplished by constructing a new lowest floor with the bottom of its lowest horizontal structural member at or above the BFE within the existing structure. Any utility systems and associated equipment located below the lowest interior floor must be elevated to protect them from damage or loss of function. The area below the new first floor is filled in with soil or retrofitted with flood openings to allow automatic entry and exit of floodwaters.

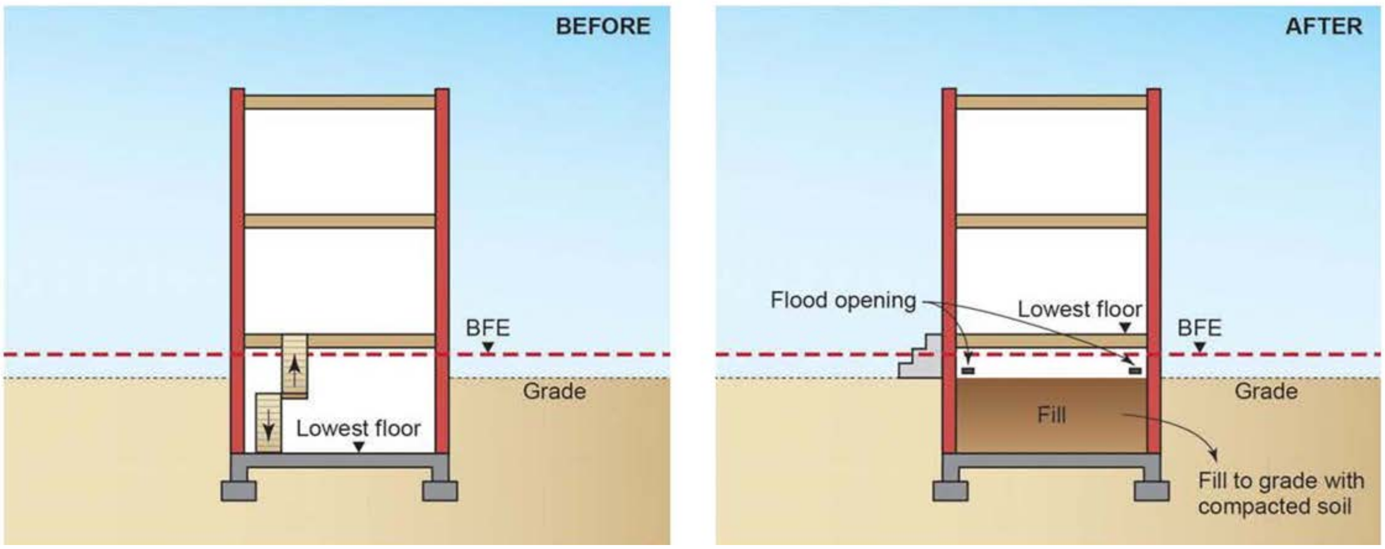
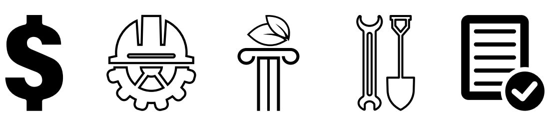


Figure 3.1.5. Constructing a raised floor or filling in a basement can elevate occupied space above the BFE.

CONSIDERATIONS:



Mitigation Solution: Floodproof

FEMA defines floodproofing as "… any combination of structural and non-structural additions, changes, or adjustments to structures which reduce or eliminate flood damage to real estate or improved real property, water and sanitary facilities, structures and their contents." Floodproofing is done to protect buildings and their contents from water damage caused by flooding.

Option 1: Wet Floodproof

Wet floodproofing involves modifying the unoccupied portions of buildings (such as crawl spaces or unfinished basements) to allow floodwaters to enter and exit, as shown in Figure 3.1.6. Wet floodproofing equalizes pressures exerted by non-moving flood waters on the inside and outside of the building.

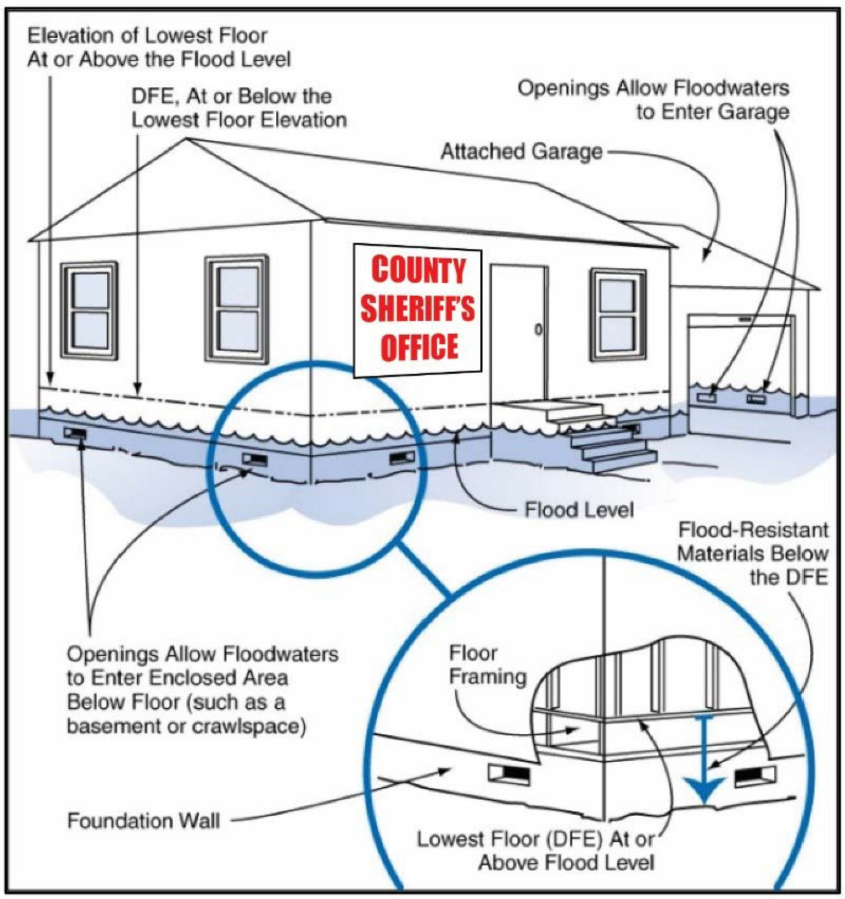
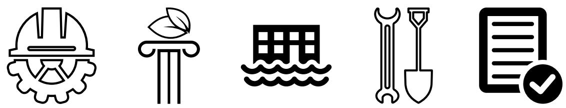


Figure 3.1.6. Wet floodproofing opening retrofit diagram for a small public building.

Crawl space foundation walls below the BFE are retrofitted with flood openings. Flood openings are installed on at least two sides of the foundation. The bottom of the opening is no higher than one foot above ground level. The recommended opening area must be at a ratio of at least one square inch of opening per one square foot of building area (floor space) to allow floodwaters to enter and exit underneath the structure to equalize flood pressure on the foundation walls. See NFIP Technical Bulletin 1, *Requirements for Flood Openings in Foundation Walls and Walls of Enclosures*, for additional information.

Materials that resist damage from water can be used to mitigate inhabited portions of buildings. See the latest editions of NFIP Technical Bulletin 1, *Requirements for Flood Openings in Foundation Walls and Walls of Enclosures* and NFIP Technical Bulletin 2, *Flood Damage-Resistant Materials Requirements.*

CONSIDERATIONS:



Option 2: Dry Floodproof

A dry-floodproofed building is watertight below the design flood elevation as required by ASCE 24 and state or local codes and standards. This mitigation method is designed to prevent floodwater entry and is best applied to small public buildings or sections of large public buildings with slab-on-grade foundations and reinforced masonry or concrete walls. Dry floodproofing can be a good option for all or part of public buildings subject to shallow flooding if building relocation or elevation is not technically feasible or cost-effective, as shown in Figure 3.1.7 and Figure 3.1.8.

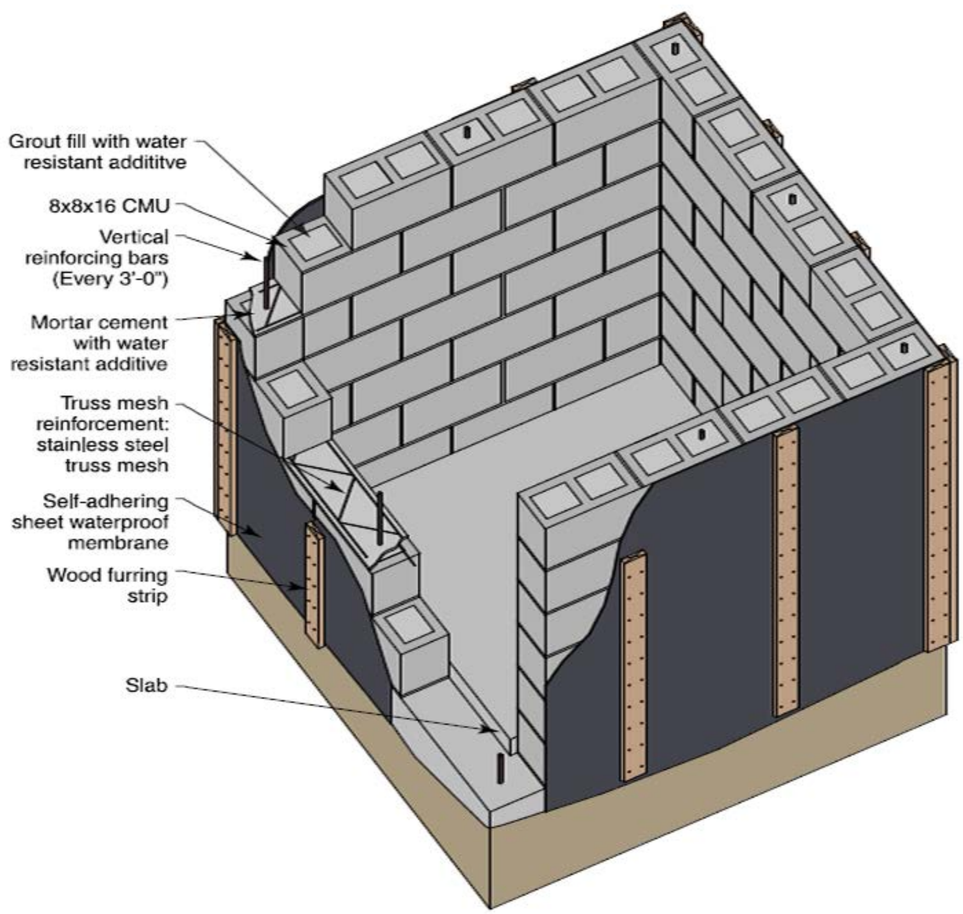


Figure 3.1.7. Dry floodproofing sealants diagram for a portion of a building.

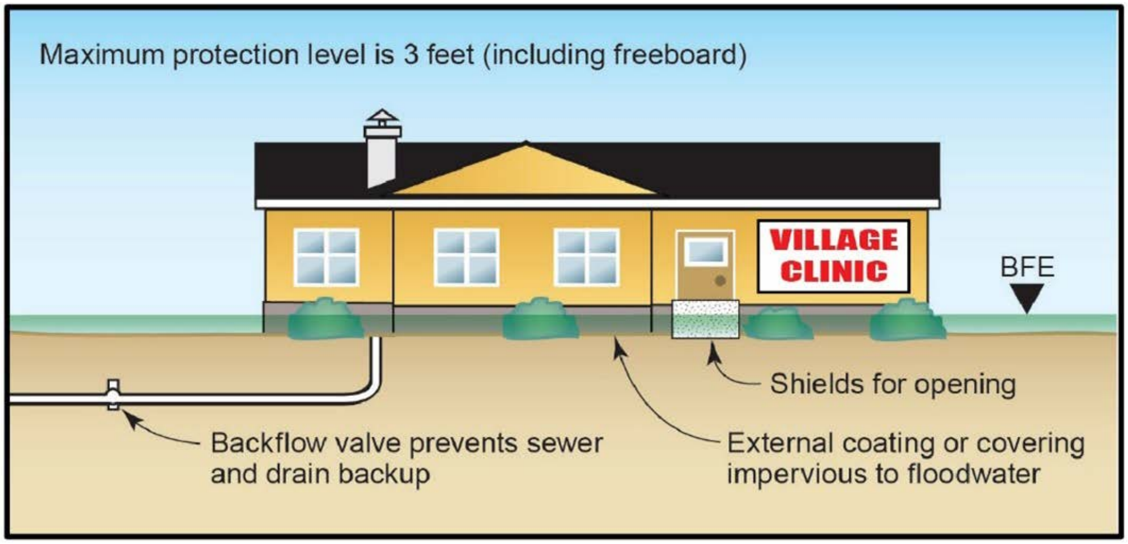


Figure 3.1.8. Dry floodproofing sealants and secondary drainage diagram.

Dry floodproofing mitigation methods may include:

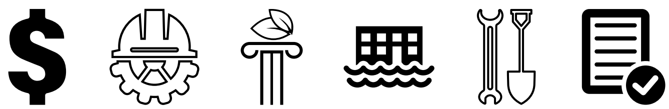
- Construct a flood wall or berm around all or part of the building to protect critical components.
- Seal the building's outside walls using technologies that include waterproof membranes to make the walls impermeable. This approach can potentially strengthen those walls.
- Increase the flood resistance in inside core areas to protect critical components. This approach may be used when dry floodproofing the entire building is either not needed or not feasible.
- Seal openings such as doors, windows, and utility penetrations, and seal walls and slabs to improve flood resistance. These building components are rarely designed to be watertight.
- Install flood shields to prevent water from entering through openings in outside walls.
- Install backflow valves to prevent floodwater flow into the building caused by blockages in the sewage system.
- Install internal drainage systems to remove water that may seep through small fissures and pathways in the protection system.

When evaluating dry floodproofing as a mitigation option, consider the following:

- Elevation or relocation, including elevating or relocating critical equipment, is preferred to floodproofing. However, where elevation or relocation are not possible, proper floodproofing can reduce risk.
- Before dry floodproofing a building, a registered design professional such as a structural engineer should determine if the building is structurally sound and can resist the design flood loads. It should also be confirmed that the dry-floodproofed building can resist other loads such as hydrodynamic loads and debris impacts during the design flood. Extensive structural reinforcement may be needed.

- Dry floodproofing should include passive mitigation that does not require human involvement, such as flood shields that close automatically when triggered by rising floodwater or doors that always seal when closed. It also may include active mitigation that does require human involvement, such as manual installation of door shields or preparation of supplemental drainage.
- Significant warning time (at least 12 hours) is needed to ensure dry floodproofing effectiveness. Flash floods, deep floods, or quickly moving water could prevent the use of dry floodproofing.
- Dry floodproofing the lowest floor of a mixed-use building is permitted if the lowest floor is used for non-residential purposes.

CONSIDERATIONS:



Mitigation Solution: Retrofit the Structure

For public buildings where existing foundations have been damaged but the structure remains intact, foundations can be retrofitted or repaired for improved performance to reduce future damages. When foundation damage is significant, consider replacing the foundation with a type more resistant to flood damage, like an open-style foundation.

Option 1: Anchor or Brace

Anchoring and bracing involve installing ground anchors or lateral bracing systems to improve resistance to horizontal pressures and uplift forces imposed by floods and hurricane winds. When evaluating this option, some considerations include:

- Steel ground anchors, micropiles or helical piles are drilled or bored next to or through the existing foundation (Figure 3.1.9), secured by grouting, and then connected to the existing building.

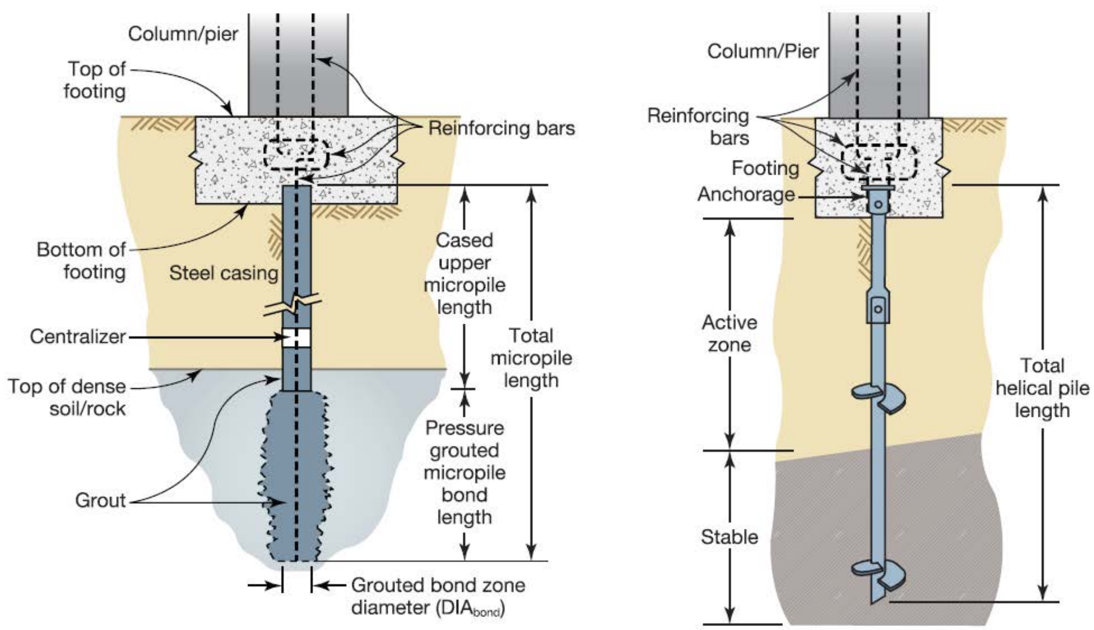
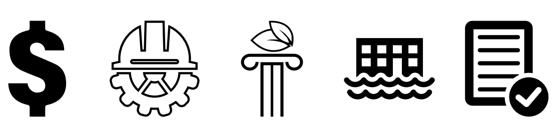


Figure 3.1.9. Grouted micropile (left) and helical pile (right) can strengthen existing building foundations.

- Open foundation bracing can include installation of diagonal cross bracing, knee bracing or grade beams.
- Designers should ensure that foundation bracing does not obstruct water flow or inhibit breakaway wall systems.

CONSIDERATIONS:



Option 2: Improve Connections

This option involves installing enhanced connectors and fasteners to link the foundation to the frame of the building to improve horizontal load resistance. When evaluating this mitigation option, consider the following:

- Use corrosion-resistant techniques to improve wood pile-to-beam connections, including the use of corrosion-resistant connectors and fasteners. Make small notches in piles or add engineered support brackets to handle minor wood pile-to-beam misalignments (Figure 3.1.10).

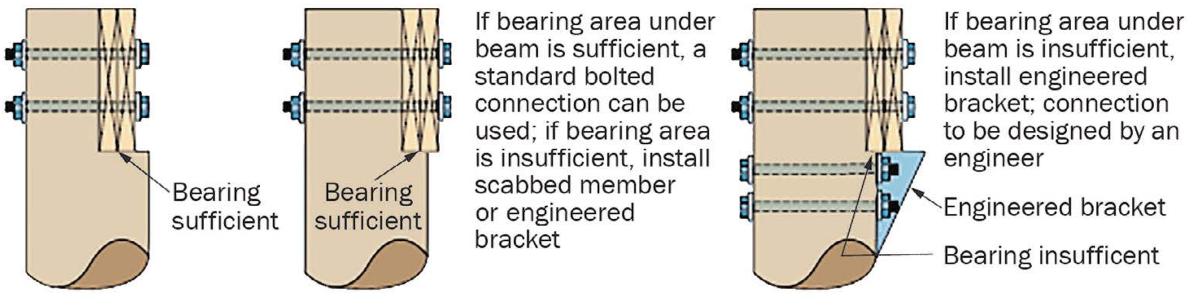


Figure 3.1.10. Improve connections—select approaches to address minor wood pile-to-beam misalignments.

- Install corrosion-resistant connectors and fasteners that are securely grouted to masonry piers or concrete pipes and anchored to the structural frame with enough strength to resist the full combined flood and wind uplift force.
- An engineer should design improved connections. Inspect the installation in the field to prevent the use of inadequate connectors or over-notching existing piles.

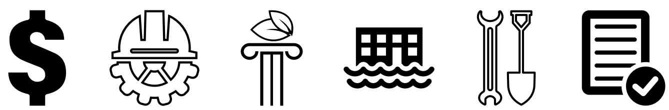
CONSIDERATIONS:

Option 3: Underpin Footings

Underpinning extends the foundation depth and/or breadth to rest on stronger soils or distributes the load more evenly across a larger area. Considerations when evaluating this option include:

- Underpin footings to mitigate pier footings or crawl space wall footings that have been undermined by storm-induced erosion and scour.
- Use jacks and temporary supports on either side of the footing to stabilize the structure.
- Restore soil support of the undermined footing by injecting grout, increasing the footing size/depth, or installing micropiles through the footing deep into the underlying soil.
- Consult a geotechnical engineer to determine if stronger soils are present to support the foundation loads. If soil strength is adequate, a structural engineer should design the underpinning system.

CONSIDERATIONS:



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Detailed technical information on retrofitting and floodproofing methods, considerations and general design practices can be found in these publications. Much of the residential information also applies to non-residential buildings as well.

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