

Building on Strong and Safe Foundations

2. Foundations

This chapter discusses the primary issues related to designing foundations for residential buildings in coastal areas: foundation design criteria, National Flood Insurance Program (NFIP) requirements on coastal construction in A and V Zones, the performance of various foundation types, and foundation construction.

2.1 Foundation Design Criteria

Foundations on the Gulf Coast should be designed in accordance with the 2003 or 2006 edition of the IBC or IRC; both contain up-to-date wind provisions and are consistent with NFIP flood provisions. In addition, any locally adopted building ordinances must be addressed. Foundations should be designed and constructed to:

- Properly support the elevated home and resist all loads expected to be imposed on the home and its foundation during a design event
- Prevent flotation, collapse, and lateral movement of the building

In addition, the foundation should be constructed with flood-resistant materials below the Base Flood Elevation (BFE).

2.2 Foundation Design in Coastal Areas

Building in a coastal environment is different from building in an inland area because:

- Storm surge, wave action, and erosion in coastal areas make coastal flooding more damaging than inland flooding.
- Design wind speeds are higher in coastal areas and thus require buildings and their foundations to be able to resist higher wind loads.

Foundations in coastal areas must be constructed such that the top of the lowest floor (in A Zones) or the bottom of the lowest horizontal structural members (in V Zones) of the buildings are elevated above the BFE, while withstanding flood forces, high winds, erosion and scour, and floodborne debris. Deeply embedded pile or other open foundations are required for V Zones because they allow waves and floodwaters to pass beneath elevated buildings. Because of the increased flood, wave, floodborne debris, and erosion hazards in V Zones, NFIP design and construction requirements are more stringent in V Zones than in A Zones.

NFIP Minimum Elevation Requirements for New Construction*

A Zone: Elevate top of lowest floor to or above BFE

V Zone: Elevate bottom of lowest horizontal structural member supporting the lowest floor to or above BFE

In both V and A Zones, many property owners have decided to elevate one full story above grade, even if not required, to allow below-building parking. See Fact Sheet No. 2 of FEMA 499 for more information about NFIP minimum requirements and recommended best practices in A and V Zones (see Appendix F).

Some coastal areas mapped as A Zones may also be subject to damaging waves and erosion (referred to as “Coastal A Zones”). Buildings in these areas that are constructed to minimum NFIP A Zone requirements may sustain major damage or be destroyed during the base flood. *It is strongly recommended that buildings in A Zones subject to breaking waves and erosion be designed and constructed with V Zone type foundations* (see Figure 2-1). Open foundations are often recommended instead of solid wall, crawlspace, slab, or shallow foundations, which can restrict floodwaters and be undermined easily. Figure 2-2 shows examples of building failures due to scour under a slab-on-grade foundation.

* For floodplain management purposes, “new construction” means structures for which the start of construction began on or after the effective date of the floodplain management regulation adopted by a community. Substantial improvements, repairs of substantial damage, and some enclosures must meet most of the same requirements as new construction.

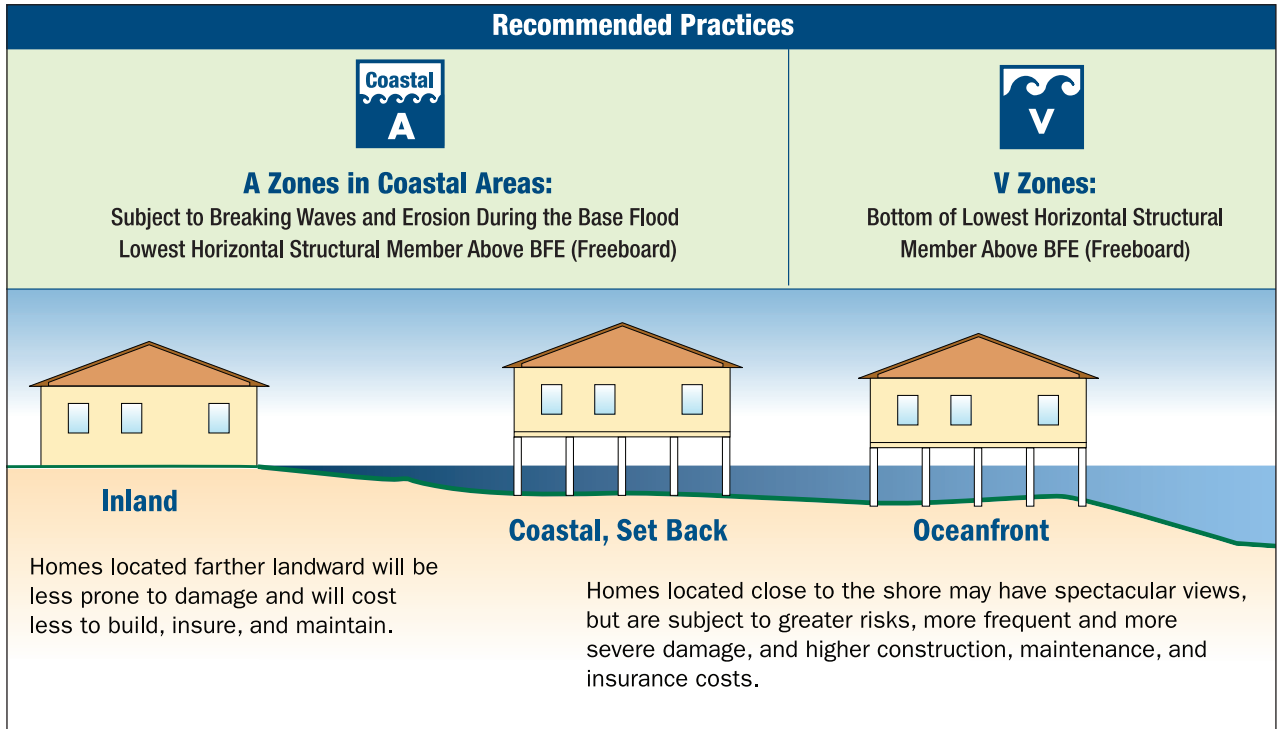


Figure 2-1. Recommended open foundation practice for buildings in A Zones, Coastal A Zones, and V Zones

SOURCE: COASTAL CONSTRUCTION MANUAL (FEMA 55)



Figure 2-2 Slab-on-grade foundation failure due to erosion and scour undermining and closeup of the foundation failure from Hurricane Dennis, 2005 (Navarre Beach, Florida).

2.3 Open and Closed Foundations in Coastal Areas

There are many designs that can be used to elevate buildings above the BFE: open foundations (pile, pier, column) and closed foundations (crawl space, stem wall, solid wall). Structural fill can also be used to elevate and support stem wall, crawl space, solid wall, slab-on-grade, pier, and column foundations in areas not subject to damaging wave action and scour. Only open foundations with base members or elements (pilings or beams) located below expected erosion and scour are allowed in V Zones; as a “best practices” approach, open foundations are recommended, but are not NFIP required, in Coastal A Zones. Table 2-1 shows the recommended type of foundation depending on the coastal area. Additional information concerning foundation performance can be found in FEMA 499, Fact Sheet No. 11 (see Appendix F).

Table 2-1. Foundation Type Dependent on Coastal Area

Foundation Type	V Zone	Coastal A Zone	A Zone
Open	✓	✓	✓
Closed	✗	NR	✓

✓ = Acceptable NR = Not Recommended ✗ = Not Permitted

2.3.1 Open Foundations

Open foundations are required in V Zones and recommended in Coastal A Zones. This type of foundation allows water to pass beneath an elevated building through the foundation and reduces lateral flood loads on the structure. Open foundations also have the added benefit of being less susceptible to damage from floodborne debris because debris is less likely to be trapped.

2.3.1.1 Piles

Pile foundations consist of deeply placed vertical piles installed under the elevated structure. The piles support the elevated structure by remaining solidly placed in the soil. Because pile foundations are set deeply, they are inherently more tolerant to erosion and scour. Piles rely primarily on the friction forces that develop between the pile and the surrounding soils (to resist gravity and uplift forces) and the compressive strength of the soils (to resist lateral movement). The soils at the ends of the piles also contribute to resist gravity loads.

Piles are typically treated wood timbers, steel pipes, or pre-cast concrete. Other materials like fiber reinforced polyester (FRP) are available, but are rarely used in residential construction. Piles can be used with or without grade beams. When used without grade beams, piles extend to the lowest floor of the elevated structure. Improved performance is achieved when the piles extend beyond the lowest floor to the roof (or an upper floor level) above. Doing so provides resistance to rotation (also called “fixity”) in the top of the pile and improves stiffness of the pile foundation. Occasionally, wood framing members are installed at the base of a wood piling (see Figure 2-3). These members are not true grade beams but rather are compression struts. They provide lateral support for portions of the piling near grade and reduce the potential for column buckling; however, due to the difficulties of constructing moment connections with wood, the compression struts provide very little resistance to rotation.



Figure 2-3.
Compression strut at base of a wood piling. Struts provide some lateral support for the piling, but very little resistance to rotation.

SOURCE: *COASTAL CONSTRUCTION MANUAL* (FEMA 55)

Critical aspects of a pile foundation include the pile size, installation method, and embedment depth, bracing, and their connections to the elevated structure (see FEMA 499 Fact Sheet Nos. 12 and 13 in Appendix F). Pile foundations with inadequate embedment will not have the structural capacity to resist sliding and overturning (see Figure 2-4). Inadequate embedment and improperly sized piles greatly increase the probability for structural collapse. However, when properly sized, installed, and braced with adequate embedment into the soil (with consideration for erosion and scour effects), a building's pile foundation performance will allow the building to remain standing and intact following a design flood event (see Figure 2-5).



Figure 2-4.
Near collapse due to insufficient pile embedment (Dauphin Island, Alabama)

SOURCE: *HURRICANE KATRINA IN THE GULF COAST* (FEMA 549)

When used with grade beams, the piles and grade beams work in conjunction to elevate the structure, provide vertical and lateral support for the elevated home, and transfer loads imposed on the elevated home and foundation to the ground below.

Figure 2-5.
Successful pile
foundation following
Hurricane Katrina
(Dauphin Island,
Alabama)

SOURCE: *HURRICANE KATRINA IN THE GULF COAST* (FEMA 549)



Pile foundations with grade beams must be constructed with adequate strength to resist all lateral and vertical loads. Failures experienced during Hurricane Katrina often resulted from inadequate connections between the columns and footings or grade beams below (see Figure 2-6). Pile and grade beam foundations should be designed and constructed so that the grade beams act only to provide fixity to the foundation system and not to support the lowest elevated floor. If grade beams support the lowest elevated floor of the home, they become the lowest horizontal structural member and significantly higher flood insurance premiums would result. Also, if the grade beams support the structure, the structure would become vulnerable to erosion and scour. Grade beams must also be designed to span between adjacent piles and the piles must be capable of resisting both the weight of the grade beams when undermined by erosion and scour, and the loads imposed on them by forces acting on the structure.

Figure 2-6.
Column connection
failure (Belle Fontaine
Point, Jackson County,
Mississippi)

SOURCE: *HURRICANE KATRINA IN THE GULF COAST* (FEMA 549)



2.3.1.2 Piers

Piers have different design criteria in various locations around the country. As used in the Gulf Coast for residential construction, piers are generally placed on footings to support the elevated structure. Without footings, piers function as short piles and rarely have sufficient capacity to resist uplift and gravity loads.

The type of footing used in pier foundations greatly affects the foundation's performance (see Figure 2-7). When exposed to lateral loads, discrete footings can rotate so piers placed on discrete footings are only suitable when wind and flood loads are relatively low. Piers placed on continuous concrete grade beams or concrete strip footings provide much greater resistance to lateral loads because the grade beams/footings act as an integral unit and are less prone to rotation. Footings and grade beams must be reinforced to resist the moment forces that develop at the base of the piers due to the lateral loads on the foundation and the elevated home (see Figure 2-8).

Since pier foundation footings or grade beams are limited in depth of placement, they are appropriate only where there is limited potential for erosion or scour. The maximum estimated depth for long- and short-term erosion and localized scour should not extend below the bottom of the footing or grade beam.



Figure 2-7. Performance comparison of pier foundations. Piers on discrete footings (foreground) failed by rotating and overturning while piers on more substantial footings (in this case a concrete mat) survived (Pass Christian, Mississippi)

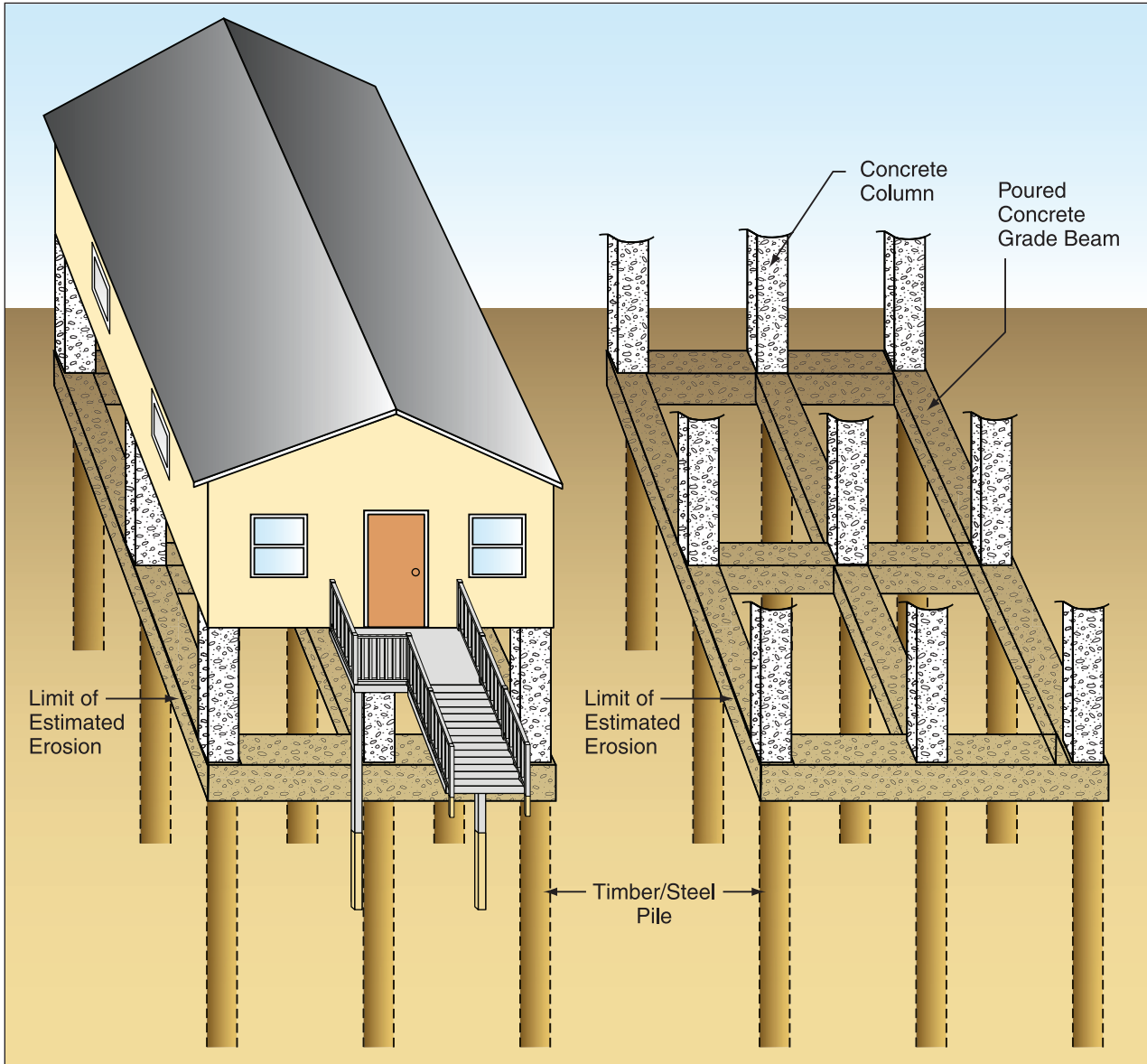


Figure 2-8. Isometric view of an open foundation with grade beam

2.3.2 Closed Foundations

A closed foundation is typically constructed using foundation walls, a crawspace foundation, or a stem wall foundation (usually filled with compacted soil). A closed foundation does not allow water to pass easily through the foundation elements below the elevated building. Thus, these types of foundations are said to obstruct the flow. These foundations also present a large surface area upon which waves and flood forces act; therefore, they are prohibited in V Zones and not recommended for Coastal A Zones. If foundation or crawspace walls enclose space below the BFE, they must be equipped with openings that allow floodwaters to flow in and out of the area

enclosed by the walls (see Figure 2-9 for an isometric view). The entry and exit of floodwater will equalize the water pressure on both sides of the wall and reduce the likelihood of the wall collapsing (see FEMA 499 Fact Sheet No. 15 in Appendix F). Two types of closed foundations are discussed in this manual, perimeter walls and slab-on-grade.

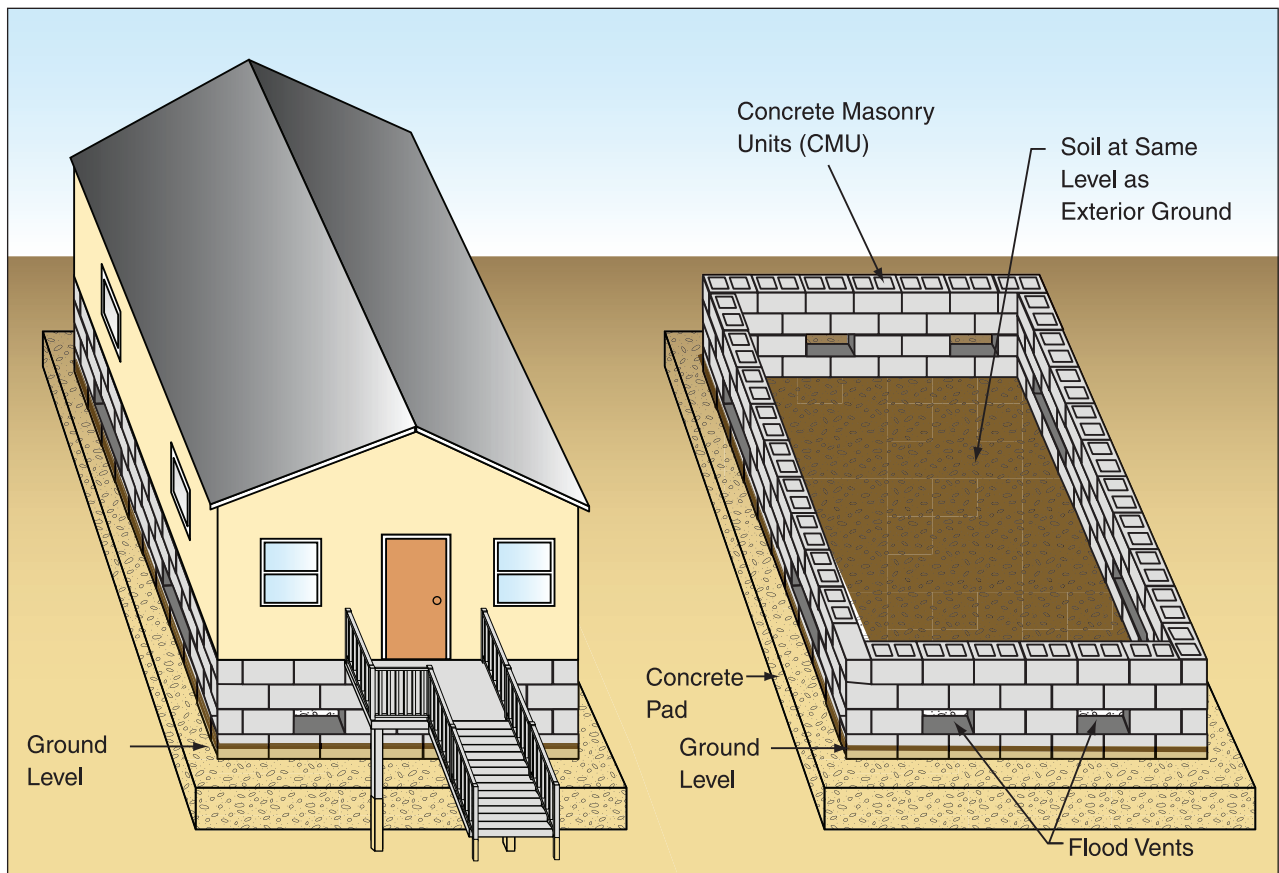


Figure 2-9. Isometric view of a closed foundation with crawlspace

2.3.2.1 Perimeter Walls

Perimeter walls are conventional walls (typically masonry or wood frame) that extend from the ground up to the elevated building. They typically bear on shallow footings. Crawlspace and stem walls are two types of foundations with perimeter walls.

Crawlspace. Crawlspace foundations are typically low masonry perimeter walls, some requiring interior piers supporting a floor system if the structure is wide. These foundations are usually supported by shallow footings and are prone to failure caused by erosion and scour.

This type of foundation is characterized by a solid perimeter foundation wall around a structure with a continuous spread footing with reinforced masonry or concrete piers. All crawlspace foundation walls in the Special Flood Hazard Area (SFHA) must be equipped with flood openings. These openings are required to equalize the pressure on either side of the wall (see FEMA 499 Fact Sheet Nos. 15 and 26 in Appendix F). However, even with flood vents, hydrodynamic and wave forces in Coastal A Zones can damage or destroy these foundations.

Stem Walls. Stem walls (i.e., a solid perimeter foundation wall on a continuous spread footing backfilled to the underside of the floor slab) are similar to crawlspace foundations, but the interior that would otherwise form the crawlspace is filled with soil or gravel that supports a floor slab. Stem wall foundations have been observed to perform better than crawlspace foundations in Coastal A Zones (but only where erosion and scour effects are minor). Flood openings are not required in filled stem wall foundations.

2.3.2.2 Slab-on-Grade

A slab-on-grade foundation is concrete placed directly on-grade (to form the slab) with generally thickened, reinforced sections around the edges and under loadbearing walls. The slab itself is typically 4 inches thick where not exposed to concentrated loads and 8 to 12 inches thick under loadbearing walls. The thickened portions of slab-on-grade foundations are typically reinforced with deformed steel bars to provide structural support; the areas not thickened are typically reinforced with welded wire fabrics (WWF) for shrinkage control. While commonly used in residential structures in A Zones, slab-on-grade foundations are prone to erosion and prohibited in V Zones, and are not recommended for Coastal A Zones.

Slab-on-grade foundations can be used with structural fill to elevate buildings. Fill is usually placed in layers called “lifts” with each lift compacted at the site. Because fill is susceptible to erosion, it is prohibited for providing structural support in V Zones. Structural fill is not recommended for Coastal A Zones, but may be appropriate for non-Coastal A Zones.

2.4 Introduction to Foundation Design and Construction

This section introduces two main issues related to foundation design and construction: site characterization and types of foundation construction. Construction materials and methods (field preservation treatment, substitutions, inspection points) are addressed in Chapter 4.

2.4.1 Site Characterization

The foundation design chosen should be based on the characteristics that exist at the building site. A site characteristic study should include the following:

- The type of foundations that have been installed in the area in the past. A review of the latest Flood Insurance Rate Map (FIRM) is recommended to ensure that construction characteristics have not been changed.

- The proposed site history, which would indicate whether there are any buried materials, or the site has been regraded.
- How the site may have been used in the past, from a search of land records for past ownership.
- A Soil Investigation Report, which should include:
 - Soil borings sampled from the site or taken from test pits
 - A review of soil borings from the immediate area adjacent to the site
 - Information from the local office of the Natural Resource Conservation Service (formerly the Soil Conservation Service) and soil surveys published for each county

One of the parameters derived from a soil investigation report is the bearing capacity, which measures the ability of soils to support gravity loads without soil shear failure or excessive settlement. Measured in pounds per square foot (psf), soil bearing capacity typically ranges from 1,000 psf for relatively weak soils to over 10,000 psf for bedrock.

Frequently, designs are initially prepared on a presumed bearing capacity. It is then the homebuilder's responsibility to verify actual site conditions. The actual soil bearing capacity should be determined. If soils are found to have higher bearing capacity, the foundation can be constructed as designed or the foundation can be revised to take advantage of the better soils.

Allowable load bearing values of soils given in Section 1804 of the 2003 IBC can be used when other data are not available. However, soils can vary significantly in bearing capacity from one site to the next. A geotechnical engineer should be consulted when any unusual or unknown soil condition is encountered.

2.4.2 Types of Foundation Construction

2.4.2.1 Piles

A common type of pile foundation is the elevated wood pile foundation, where the piles extend from deep in the ground to an elevation at or above the Design Flood Elevation (DFE). Horizontal framing members are used to connect the piles in both directions. This grid forms a platform on which the house is built (see FEMA 499 Fact Sheet No. 12 in Appendix F).

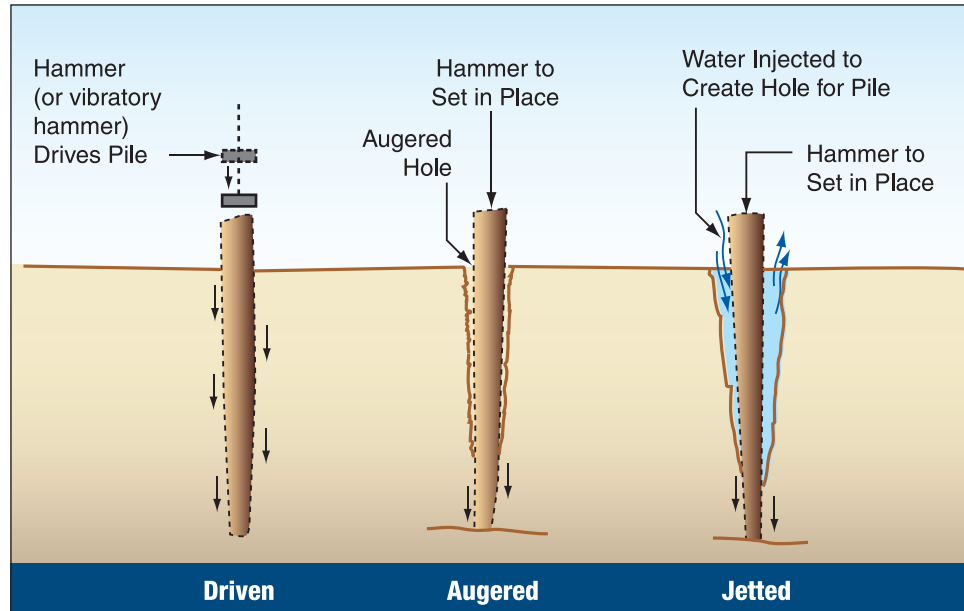
The method of installation is a major consideration in the structural integrity of pile foundations. The ideal method is to use a pile driver. In this method, the pile is held in place with leads while a single-acting, double-acting diesel or air-powered hammer drives the pile into the ground (see Figure 2-10).

If steel piles are used, only the hammer driving method mentioned above should be used. For any pile driving, the authority having jurisdiction or the engineer-of-record may require that a driving log is kept for each pile. The log will tabulate the number of blows per foot as the driving progresses. This log is a key factor used in determining the pile capacity.

Figure 2-10.

Pile installation methods

SOURCE: *COASTAL CONSTRUCTION MANUAL* (FEMA 55)



Another method for driving piles is the drop hammer method. It is a lower cost alternative to the pile driver. A drop hammer consists of a heavy weight raised by a cable attached to a power-driven winch and then dropped onto the pile.

A less desirable but frequently used method of inserting piles into sandy soil is “jetting,” which involves forcing a high-pressure stream of water through a pipe that advances with the pile. The water creates a hole in the sand as the pile is driven until the required depth is reached. Unfortunately, jetting loosens the soil both around the pile and the tip. This results in a lower load capacity due to less frictional resistance. Jetted piles are not appropriate for the design provided in this manual unless capacity is verified by a geotechnical engineer.

Holes for piles may be excavated by an auger if the soil has sufficient clay or silt content. Augering can be used by itself or in conjunction with pile driving. If the hole is full-sized, the pile is dropped in and the void backfilled. Alternatively, an undersized hole can be drilled and a pile driven into it. When the soil conditions are appropriate, the hole will stay open long enough to drop or drive in a pile. In general, this method may not have as much capacity as those methods previously mentioned. Like jetted piles, augered piles are not appropriate for the designs provided in this manual unless the method for compressing the soil is approved by a geotechnical engineer.

2.4.2.2 Diagonal Bracing of Piles

The foundation design may include diagonal bracing to stiffen the pile foundation in one or more directions. When installed properly, bracing lowers the point where lateral loads are applied to the piles. The lowering of load application points reduces the bending forces that piles must resist (so piles in a braced pile foundation do not need to be as strong as piles in an unbraced pile foundation) and also reduces lateral movement in the building. Outside pilings are sufficiently designed to withstand external forces, because bracing will not assist in countering

these forces. A drawback to bracing, however, is that the braces themselves can become obstructions to moving floodwaters and increase a foundation's exposure to wave and debris impact.

Because braces tend to be slender, they are vulnerable to compression buckling. Therefore, most bracing is considered tension-only bracing. Because wind and, to a lesser extent, flood loads can act in opposite directions, tension-only bracing must be installed in pairs. One set of braces resists loads from one direction while the second set resists loads from the opposite direction. Figure 2-11 shows how tension only bracing pairs resist lateral loads on a home.

The braced pile design can only function when all of the following conditions are met:

- The home must be constructed with a stiff horizontal diaphragm such as a floor system that transfers loads to laterally braced piles.
- Solid connections, usually achieved with bolts, must be provided to transmit forces from the brace to the pile or floor system.

The placement of the lower bolted connection of the diagonal to the pile requires some judgment. If the connection is placed too high above grade, the pile length below the connection is not braced and the overall bracing is less strong and stiff. If the connection is placed too close to grade, the bolt hole is more likely to be flooded or infested with termites. Because the bolt hole passes through the untreated part of the pile, flooding and subsequent decay or termite infestation will weaken the pile at a vulnerable location. Therefore, the bolt hole should be treated with preservative after drilling and prior to bolt placement.

The braced wood pile designs developed for this manual use steel rods for bracing. Steel rods were used because:

- Steel has greater tensile strength than even wide dimensional lumber.
- There are fewer obstructions to waves and floodborne debris.
- The rod bracing can easily be tensioned with turnbuckles and can be adjusted throughout the life of the home.
- A balanced double shear connection is two to three times stronger than a wood to wood connection made with 2-inch thick dimensional lumber.

Alternative bracing should only be installed when designed by a licensed engineer.

2.4.2.3 Knee Bracing of Piles

Knee braces involve installing short diagonal braces between the upper portions of the pilings and the floor system of the elevated structure. The braces increase the stiffness of an elevated pile foundation and can be effective at resisting the lateral forces on a home. While knee braces do not stiffen a foundation as much as diagonal bracing, they do offer some advantages over diagonal braces. For example, knee braces present less obstruction to waves and debris, are shorter than diagonal braces, and are usually designed for both tension and compression loads.

Unlike diagonal braces, knee braces do not reduce bending moments in the piles (they can actually increase bending moments) and will not reduce the diameter of the piles required to resist lateral loads.

The entire load path into and through the knee brace must be designed with sufficient capacity. The connections at each end of each knee brace must have sufficient capacity to handle both tension and compression and to resist axial loads in the brace. The brace itself must have sufficient cross-sectional area to resist compression and tensile loads. Due to the complexity of knee bracing, they have not been used in the foundation designs included in Appendix A of this document.

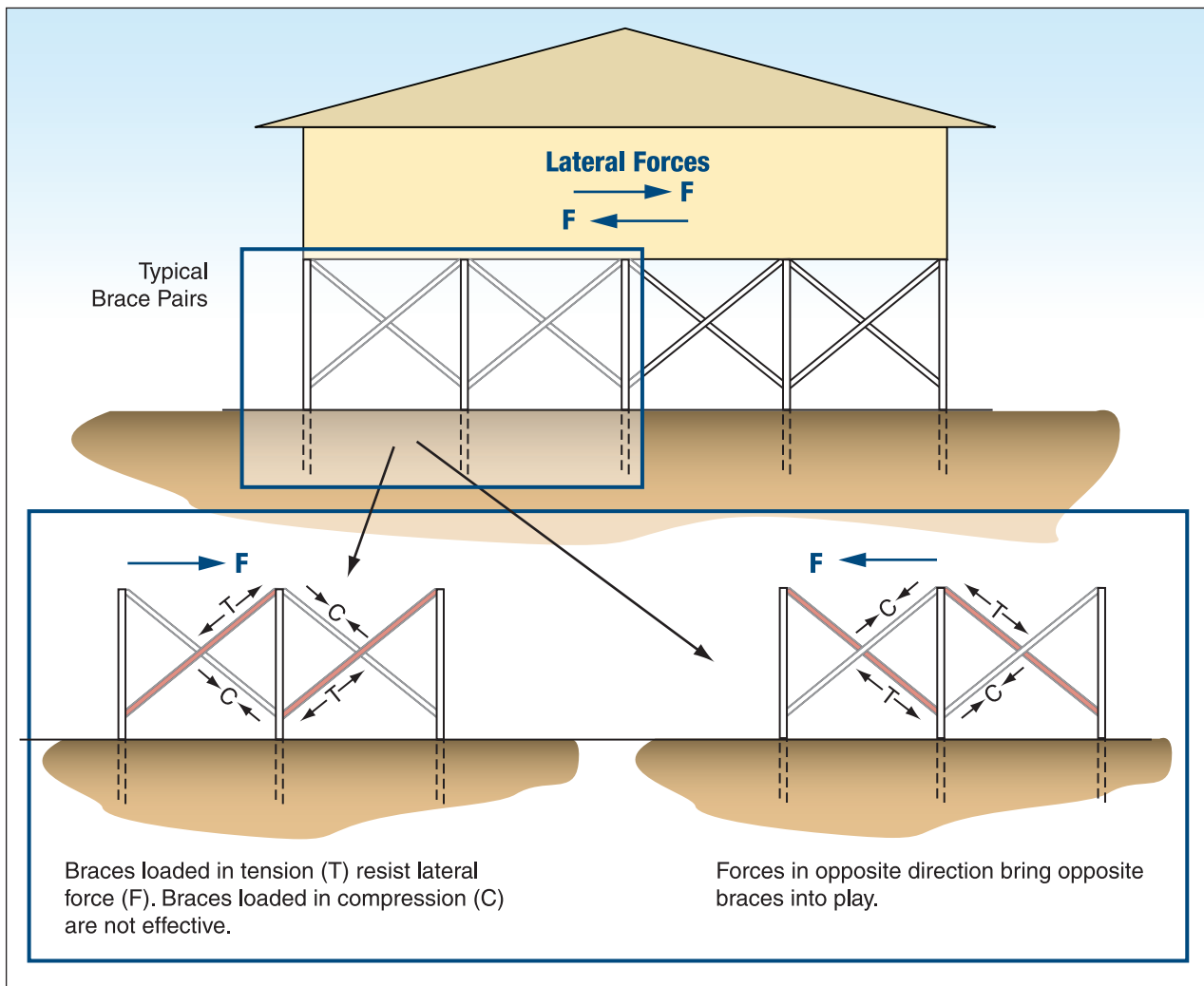


Figure 2-11. Diagonal bracing schematic

2.4.2.4 Wood-Pile-to-Wood-Girder Connections

Wood piles are often notched to provide a bearing surface for a girder. However, a notch should not reduce more than 50 percent of the pile cross-section (such information is typically provided by a designer on contract documents). For proper load transfer, the girder should bear on the surface of the pile notch.

Although connections play an integral role in the design of structures, they are typically regarded as the weakest link. The connection between a wood pile and the elevated structure should be designed by an engineer (see FEMA 499 Fact Sheet No. 13 in Appendix F).

2.4.2.5 Grade Beams in Pile/Column Foundations

Grade beams are sometimes used in conjunction with pile and column foundations to generate more stiffness. They generate stiffness by forcing the piles to move as a group rather than individually and by providing fixity (i.e., resistance to rotation) at the ends of the piles. Typically, they extend in both directions and are usually made of reinforced concrete. The mix design, the amount and placement of reinforcement, the cover, and the curing process are important parameters in optimizing durability. To reduce the effect of erosion and scour on foundations, grade beams must be designed to be self-supporting foundation elements. The supporting piers should be designed to carry the weight of the grade beams and resist all loads transferred to the piers.

In V Zones, grade beams must be used only for lateral support of the piles. If, during construction, the floor is made monolithic with the grade beams, the bottom of the beams become the lowest horizontal structural member. This elevation must be at or above the BFE.

If grade beams are used with wood piles, the possibility of rot occurring must be considered when designing the connection between the grade beam and the pile. The connection must not encourage water retention. The maximum bending moment in the piles occurs at the grade beams, and decay caused by water retention at critical points in the piles could induce failure under high wind or flood forces.

