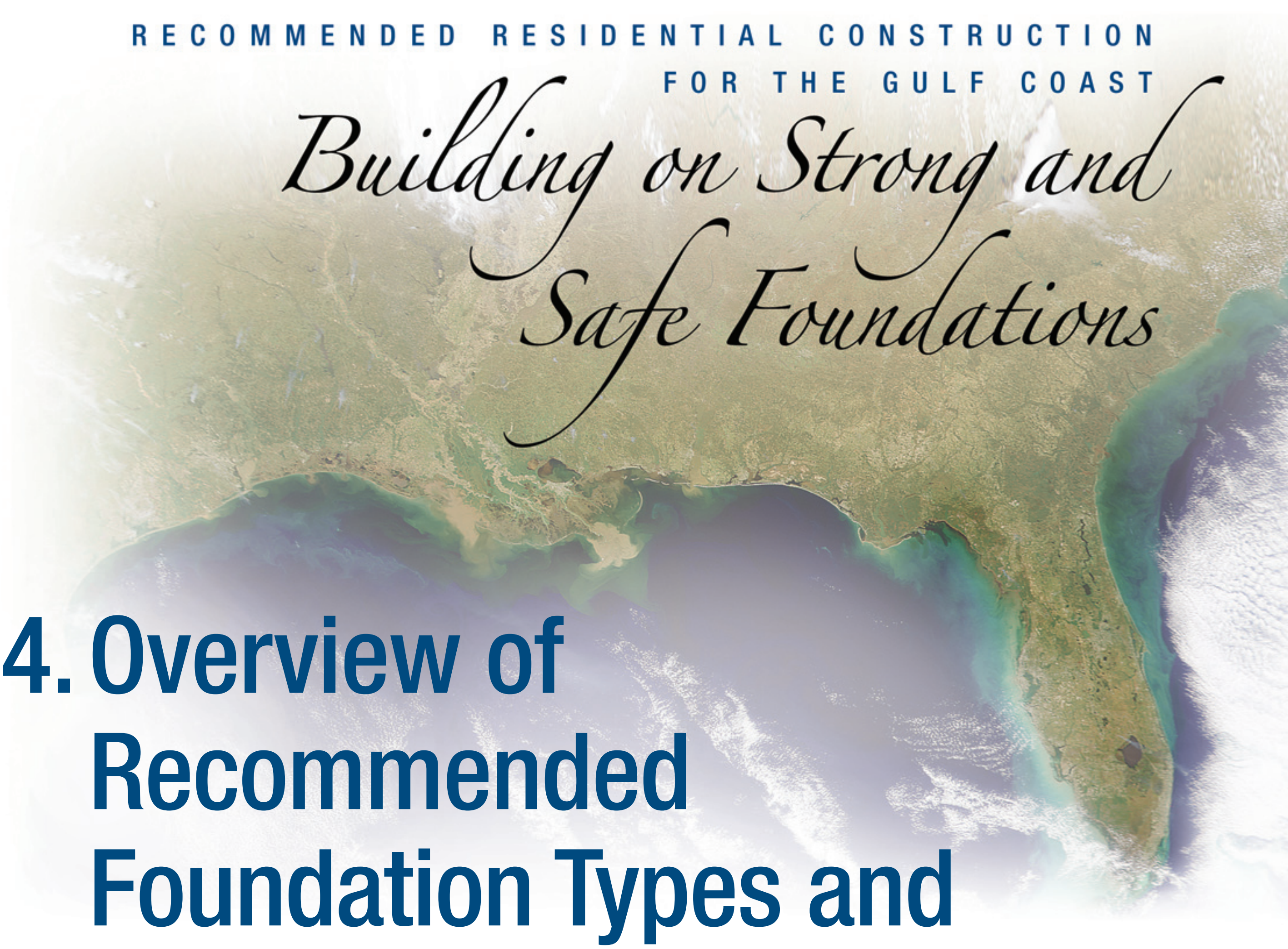


RECOMMENDED RESIDENTIAL CONSTRUCTION
FOR THE GULF COAST

Building on Strong and Safe Foundations

4. Overview of Recommended Foundation Types and Construction for the Gulf Coast

Chapters 1 through 3 discussed foundation design loads and calculations and how these issues can be influenced by coastal natural hazards. This chapter will tie all of these issues together with a discussion of foundation types and methods of constructing a foundation for a residential structure.

4.1 Critical Factors Affecting Foundation Design

Foundation construction types are dependent upon the following critical factors:

- Design wind speed
- Elevation height required by the BFE and local ordinances
- Flood zone
- Soil parameters

Soil parameters are very important but, for the purpose of creating standardized foundation designs in this report, soil parameters have been fixed. This section will only discuss the first three critical factors mentioned above.

4.1.1 Wind Speed

A design wind speed is a factor that determines the foundation size and strength (see also Section 1.1). The wind speed map shown in Figure 3-1 shows the design winds along most of the Mississippi and Louisiana Gulf Coast areas to be between 120 and 150 mph.

To determine forces on the building and foundation, the wind speed is critical. Wind speed creates wind pressures that act upon the building. These pressures are proportional to the square of the wind speed, so a doubling of the wind speed increases the wind pressure by a factor of four. The pressure applied to an area of the building will develop forces that must be resisted. To transfer these forces from the building to the foundation, properly designed load paths are required. For the foundation to be properly designed, all forces including uplift, compression, and lateral must be taken into account.

4.1.2 Elevation

The required height of the foundation depends on three factors: the DFE, the site elevation, and the flood zone. The flood zone dictates whether the lowest habitable finished floor must be placed at the DFE or, in the case of homes in the V Zone, the bottom of the lowest horizontal member must be placed at the DFE. While not required by the NFIP, V Zone criteria are recommended for Coastal A Zones. Stated mathematically,

$$H = DFE - G + Erosion$$

or

$$H = BFE - G + Erosion + Freeboard$$

Where

H = Required foundation height (in ft)

DFE = Design Flood Elevation

BFE = Base Flood Elevation

G = Non-eroded ground elevation

Erosion = Short-term plus long-term erosion

Freeboard = Locally adopted or owner desired freeboard

The height to which a home should be elevated is one of the key factors in determining which pre-engineered foundation to use. Elevation height is dependent upon several factors, including the BFE, local ordinances requiring freeboard, and the desire of the homeowner to elevate the lowest horizontal structural member above the BFE (see also Chapter 2). This manual provides designs for closed foundations up to 8 feet above ground level and open foundations up to 15 feet above ground level. Custom designs can be developed for open and closed foundations to position the homes above those elevation levels. Foundations for homes that need to be elevated higher than 15 feet should be designed by a licensed professional engineer.

4.1.3 Construction Materials

The use of flood-resistant materials below the BFE is also covered in FEMA NFIP Technical Bulletin 2 and FEMA 499 Fact Sheet No. 8 (see also Appendix F). This manual will cover the materials used in masonry and concrete foundation construction, and field preservative treatment for wood.

4.1.3.1 Masonry Foundation Construction

The combination of high winds, moisture, and salt-laden air creates a damaging recipe for masonry construction. All three can penetrate the tiniest cracks or openings in the masonry joints. This can corrode reinforcement, weaken the bond between the mortar and the brick, and create fissures in the mortar. Moisture resistance is highly influenced by the quality of the materials and the workmanship.

4.1.3.2 Concrete Foundation Construction

Cast-in-place concrete elements in coastal environments should be constructed with 3 inches or more of concrete cover over the reinforcing bars. The concrete cover physically protects the reinforcing bars from corrosion. However, if salt water penetrates the concrete cover and reaches the reinforcing steel, the concrete alkalinity is reduced by the salt chloride, thereby corroding the steel. As the corrosion forms, it expands and cracks the concrete, allowing the additional entry of water and further corrosion. Eventually, this process weakens the concrete structural element and its load carrying capacity.

Alternatively, epoxy-coated reinforcing steel can be used if properly handled, stored, and placed. Epoxy-coated steel, however, requires more sophisticated construction techniques and more highly trained contractors that are not usually involved with residential construction.

Concrete mix used in coastal areas must be designed for durability. The first step in this process is to start with the mix design. The American Concrete Institute (ACI) 318 manual recommends that a maximum water-cement ratio by weight of 0.40 and a minimum compressive strength of 4,000 pounds per square inch (psi) be used for concrete used in coastal environments. Since the amount of water in a concrete mix largely determines the amount that concrete will shrink and promote unwanted cracks, the water-cement ratio of the concrete mix is a critical parameter in promoting concrete durability. Adding more water to the mix to improve the workability increases the potential for cracking in the concrete and can severely affect its durability.

Another way to improve the durability of a concrete mix is with ideal mix proportions. Concrete mixes typically consist of a mixture of sand, aggregate, and cement. How these elements are proportioned is as critical as the water-cement ratio. The sand should be clean and free of contaminants. The aggregate should be washed and graded. The type of aggregate is also very important. Recent research has shown that certain types of gravel do not promote a tight bond with the paste. The builder or contractor should consult expert advice prior to specifying the concrete mix.

Addition of admixtures such as pozzolans (fly ash) is recommended for concrete construction along the coast. Fly ash when introduced in concrete mix has benefits such as better workability and increased resistance to sulfates and chlorates, thus reducing corrosion from attacking the steel reinforcing.

4.1.3.3 Field Preservative Treatment for Wood Members

In order to properly connect the pile foundation to the floor framing system, making field cuts, notches, and boring holes are some of the activities associated with construction. Since pressure-preservative-treated piles, timbers, and lumber are used for many purposes in coastal construction, the interior, untreated parts of the wood are exposed to possible decay and infestation. Although treatments applied in the field are much less effective than factory treatments, the potential for decay can be minimized. The American Wood Preservers' Association (AWPA) standard *Care of Pressure-Treated Wood Products* (AWPA 1991) describes field treatment procedures and field cutting restrictions for poles, piles, and sawn lumber.

Field application of preservatives should always be done in accordance with instructions on the label. When detailed instructions are not provided, dip soaking for at least 3 minutes can be considered effective for field applications. When this is impractical, treatment may be done by thoroughly brushing or spraying the exposed area. It should be noted that the material is more absorptive at the end of a member, or end grains, than it is for the sides or side grains. To safeguard against decay in bored holes, the holes should be poured full of preservative. If the hole passes through a check (such as a shrinkage crack caused by drying), it will be necessary to brush the hole; otherwise, the preservative would run into the check instead of saturating the hole.

Waterborne arsenicals, pentachlorophenol, and creosote are unacceptable for field applications. Copper napthenate is the most widely used field treatment. Its deep green color may be objectionable, but the wood can be painted with alkyd paints in dark colors after extended drying. Zinc napthenate is a clear alternative to copper napthenate. However, it is not quite as effective in preventing insect infestation, and it should not be painted with latex paints. Tributyltin oxide (TBTO) is available, but should not be used in or near marine environments, because the leachates are toxic to aquatic organisms. Sodium borate is also available, but it does not readily penetrate dry wood and it rapidly leaches out when water is present. Therefore, sodium borate is not recommended.

4.1.4 Foundation Design Loads

To provide flexibility in the home designs, tension connections have been specified between the tops of all wood piles and the grade beams. Depending on the location of shear walls, shear wall openings, and the orientation of floor and roof framing, some wood piles may not experience tension forces. Design professionals can analyze the elevated structure to identify compression only pilings to reduce construction costs. For foundation design and example calculations, see Appendix D.

Figure 4-1 illustrates design loads acting on a column. The reactions at the base of the elevated structure used in the foundation designs are presented in Tables 4-1a (one-story) and 4-1b (two-story). These reactions are the controlling forces for the range of building weights and dimensions listed in Appendix A and shown in Figure 2 of the Introduction. Design reactions have been included for the various design wind speeds and various building elevations above exterior grade. ASCE 7-02 Load Combination 4 ($D + 0.75L + 0.75L_r$) controls for gravity loading and Load Combination 7 controls for uplift and lateral loads. Load Combination 7 is $0.6D + W + 0.75F_a$ in non-Coastal A Zones and $0.6D + W + 1.5F_a$ in Coastal A and V Zones. Refer to Section 3.8 for the list of flood load combinations.

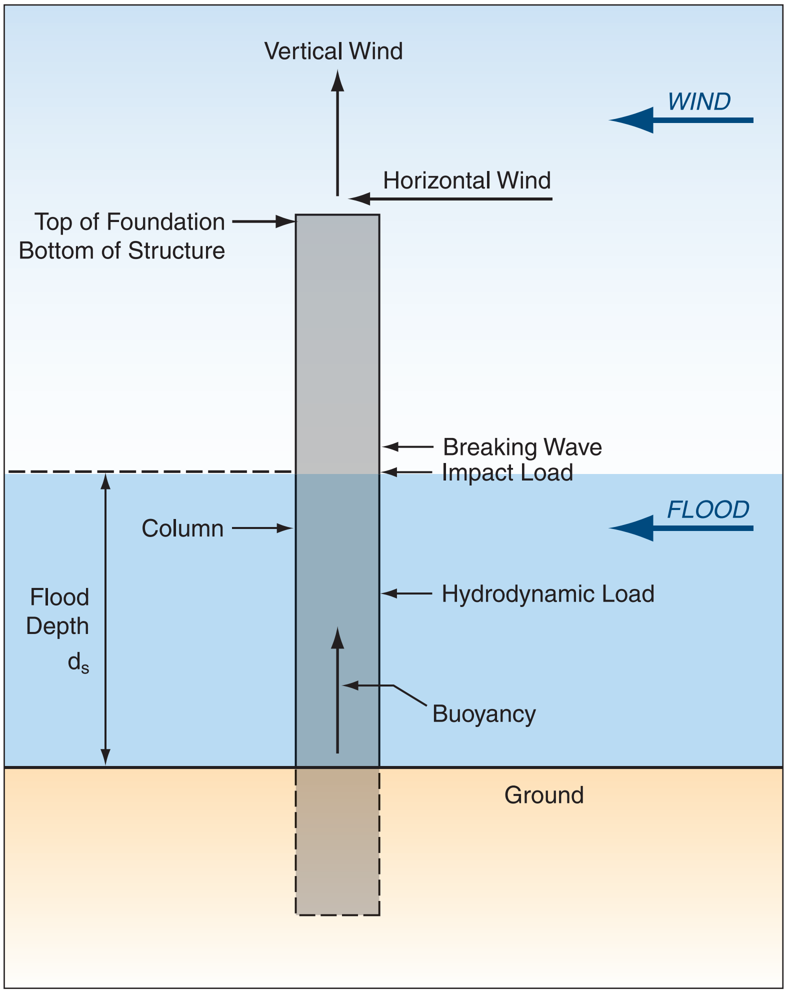


Figure 4-1.
Design loads acting on a column

Loads on the foundation elements themselves are more difficult to tabulate since they depend on the foundation style (open or enclosed), foundation dimensions, and foundation height. Table 4-2 provides reactions for the 18-inch square columns used in most of the open foundation designs.

Table 4-1a. Design Perimeter Wall Reactions (lb/lf) for One-Story Elevated Homes (Note: Reactions are taken at the base of the elevated home/top of the foundation element.)

V	120 mph		130 mph		140 mph		150 mph		(All V)
H	Horiz	Vert	Horiz	Vert	Horiz	Vert	Horiz	Vert	Gravity
5 ft	770	-175	903	-259	1,048	-350	1,203	-448	1,172
6 ft	770	-175	903	-259	1,048	-350	1,203	-448	1,172
7 ft	770	-175	903	-259	1,048	-350	1,203	-448	1,172
8 ft	804	-202	944	-291	1,095	-388	1,257	-490	1,172
10 ft	804	-202	944	-291	1,095	-388	1,257	-490	1,172
12 ft	804	-202	944	-291	1,095	-388	1,257	-490	1,172
14 ft	832	-224	977	-317	1,133	-417	1,300	-525	1,172
15 ft	843	-226	989	-319	1,147	-419	1,317	-527	1,172

lb = pound
lf = linear foot
V = wind speed
H = height of foundation above grade

Table 4-1b. Design Perimeter Wall Reactions (lb/lf) for Two-Story Elevated Homes (Note: Reactions are taken at the base of the elevated home/top of the foundation element.)

V	120 mph		130 mph		140 mph		150 mph		(All V)
H	Horiz	Vert	Horiz	Vert	Horiz	Vert	Horiz	Vert	Gravity
5 ft	1,149	-145	1,348	-255	1,564	-374	1,795	-502	1,608
6 ft	1,149	-145	1,348	-255	1,564	-374	1,795	-502	1,608
7 ft	1,149	-145	1,348	-255	1,564	-374	1,795	-502	1,608
8 ft	1,182	-168	1,387	-282	1,609	-406	1,847	-539	1,608
10 ft	1,191	-171	1,397	-286	1,629	-410	1,860	-543	1,608
12 ft	1,191	-171	1,397	-286	1,620	-410	1,860	-543	1,608
14 ft	1,191	-171	1,397	-286	1,620	-410	1,860	-543	1,608
15 ft	1,210	-175	1,420	-291	1,647	-416	1,890	-550	1,608

lb = pound
lf = linear foot
V = wind speed
H = height of foundation above grade

Table 4-2. Flood Forces (in pounds) on an 18-inch Square Column

Flood Depth	Hydrodynamic	Breaking Wave	Impact	Buoyancy
5 ft	1,000	684	3,165	465
6 ft	1,440	985	3,476	577
7 ft	1,960	1,340	3,745	650
8 ft	2,560	1,750	4,004	743
10 ft	4,001	2,735	4,476	939
12 ft	5,761	3,938	4,903	1,115
14 ft	7,841	5,360	5,296	1,300
15 ft	9,002	6,155	5,482	1,394

4.2 Recommended Foundation Types for the Gulf Coast

Table 4-3 provides five open (deep and shallow) foundation types and two closed foundations discussed in this manual. Appendix A provides the foundation design drawings for the cases specified.

Table 4-3. Recommended Foundation Types Based on Zone

Foundation		Case	V Zones	A Zones in Coastal Areas	
				Coastal A Zone	A Zone
Open Foundation (deep)	Timber pile	A	✔	✔	✔
	Steel pipe pile with concrete column and grade beam	B	✔	✔	✔
	Timber pile with concrete column and grade beam	C	✔	✔	✔
Open Foundation (shallow)	Concrete column and grade beam	D	NR	✔	✔
	Concrete column and grade beam with slab	G	NR	✔	✔
Closed Foundation (shallow)	Reinforced masonry – crawlspace	E	✘	NR	✔
	Reinforced masonry – stem wall	F	✘	NR	✔

✔ = Acceptable

NR = Not Recommended

✘ = Not Permitted

The foundation designs contained in this manual are based on soils having a bearing capacity of 1,500 pounds per square foot (psf). The 1,500-psf bearing capacity value corresponds to the presumptive value contained in the 2003 IBC for cohesive soil. Cohesive soils are fine-grained soils (or soils with a high clay content) with cohesive strength. These types of soils include clay, sandy clay, silty clay, clayey silt, silt, and sandy silt.

The size of the perimeter footings and grade beams are generally not controlled by bearing capacity (uplift and lateral loads typically control footing size and grade beam dimensions). Refining the designs for soils with greater bearing capacities may not significantly reduce construction costs. However, the size of the interior pad footings for the crawlspace foundation (Table 4-3, E: Closed Foundation, Reinforced Masonry - Crawlspace) depends greatly on the soil's bearing capacity. Design refinements can reduce footing sizes in areas where soils have greater bearing capacities. The following discussion of the foundation designs listed in Table 4-3 is also presented in Appendix A. Figures 4-2 through 4-8 are based on Appendix A.

4.2.1 Open Foundation: Timber Pile (Case A)

This pre-engineered, timber pile foundation uses conventional, tapered, treated piles and steel rod bracing to support the elevated structure. No concrete, masonry, or reinforcing steel is needed (see Figure 4-2). Often called a "stilt" foundation, the driven timber pile system is suitable for moderate elevations if the homebuilder prefers to minimize the number of different construction trades used. Once the piles are driven, the wood guides and floor system are attached to the piles; the remainder of the house is constructed off the floor platform.

The recommended design for Case A that is presented in this manual accommodates home elevations up to 10 feet above grade. With customized designs and longer piles, the designs can be modified to achieve higher elevations. However, elevations greater than 10 feet will likely be prevented by pile availability, the pile strength required to resist lateral forces, and the pile embedment required to resist scour and erosion. A construction approach that can improve performance is to extend the piles above the first floor diaphragm to the second floor or roof diaphragm. Doing so allows the foundation and the elevated home to function more like a single, integrated structural frame. Extending the piles stiffens the structure, reduces stresses in the pilings, and reduces lateral deflections. Post disaster assessments of pile supported homes indicate that extending piles in this fashion improves survivability. Licensed professional engineers should be consulted to analyze the pile foundations and design the appropriate connections.

One drawback of the timber pile system is the exposure of the piles to floodborne debris. During a hurricane event, individual piles can be damaged or destroyed by large, floating debris. With the home in place, damaged piles are difficult to replace. Two separate ways of addressing this potential problem is to use piles with a diameter larger than is called for in the foundation design or to use a greater number of piles to increase structural redundancy.

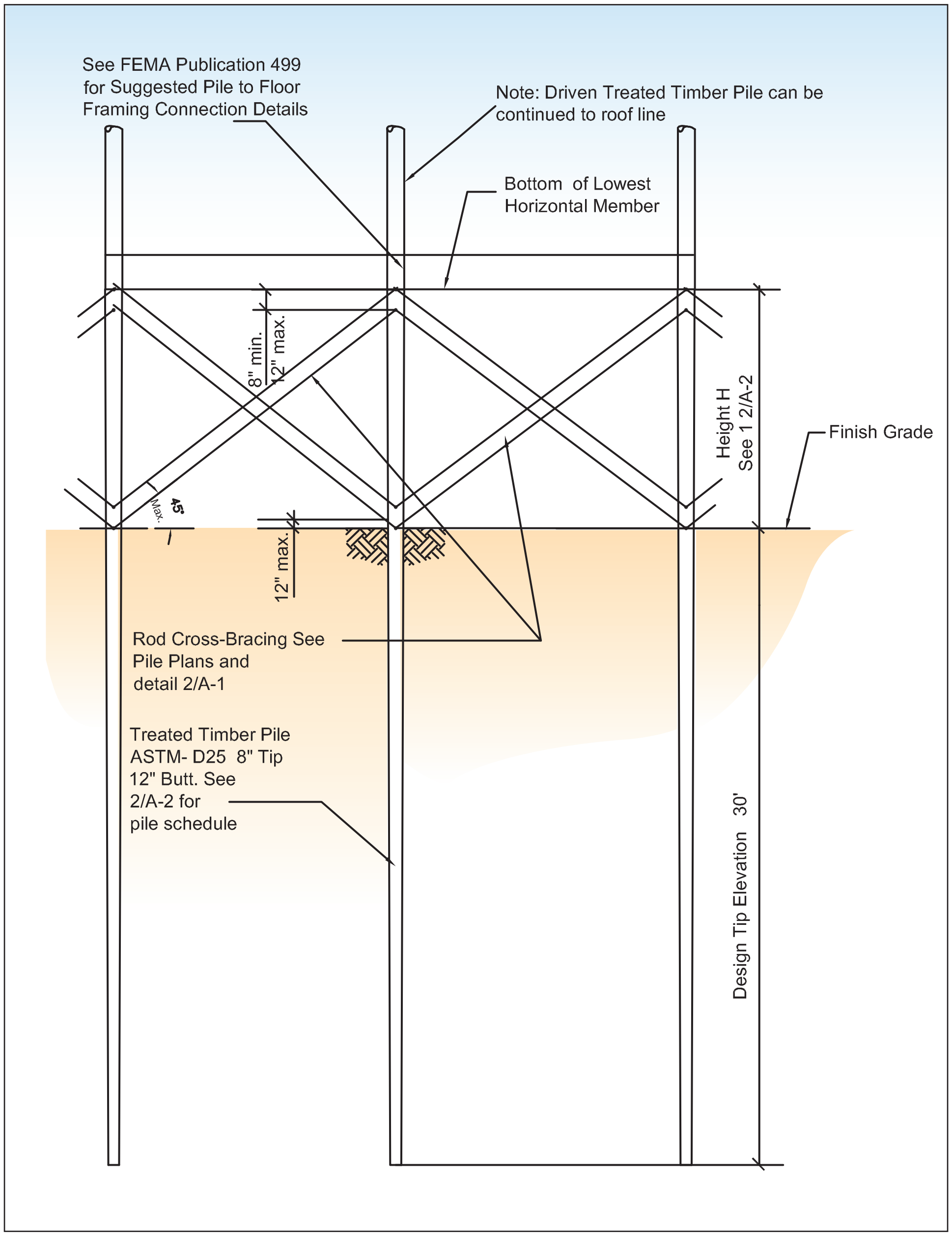
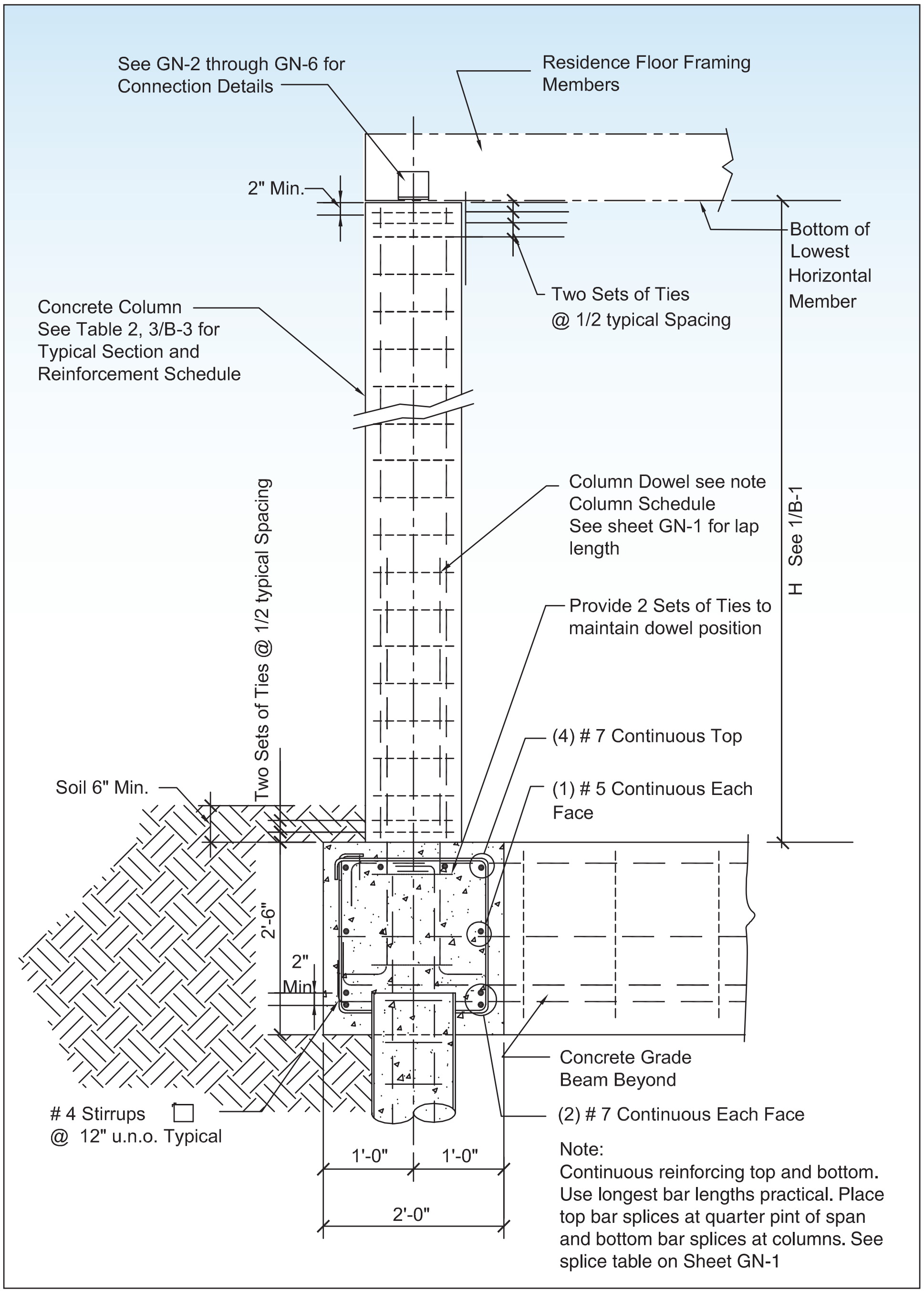


Figure 4-2. Profile of Case A foundation type (see Appendix A for additional drawings)

4.2.2 Open Foundation: Steel Pipe Pile with Concrete Column and Grade Beam (Case B)

This foundation incorporates open-ended steel pipe piles; this style is somewhat unique to the Gulf Coast region where the prevalence of steel pipe pilings used to support oil platforms has created local sources for these piles. Like treated wood piles, steel pipe piles are driven but have the advantage of greater bending strength and load carrying capacity (see Figure 4-3). The open steel pipe pile foundation is resistant to the effects of erosion and scour. The grade beam can be undermined by scour without compromising the entire foundation system.

Figure 4-3. Profile of Case B foundation type (see Appendix A for additional drawings)



The number of piles required depends on local soil conditions. Like other soil dependent foundation designs, consideration should be given to performing soil tests on the site so the foundation design can be optimized. With guidance from engineers, the open-ended steel pipe pile foundation can be designed for higher elevations. Additional piles can be driven for increased resistance to lateral forces, and columns can be made larger and stronger to resist the increased bending moments that occur where the columns join the grade beam. Because only a certain amount of steel can be installed to a given cross-section of concrete before the column sizes and the flood loads become unmanageable, a maximum elevation of 15 feet exists for the use of this type of foundation.

4.2.3 Open Foundation: Timber Pile with Concrete Column and Grade Beam (Case C)

This foundation is similar to the steel pipe pile with concrete column and grade beam foundation (Case B). Elevations as high as 15 feet can be achieved for wind speeds up to 150 mph for both one- and two-story structures. However, because wood piles have a lower strength to resist the loads than steel piles, approximately twice as many timber piles are needed to resist loads imposed on the house and the exposed portions of the foundation (see Figure 4-4).

While treated to resist rot and damage from insects, wood piles may become vulnerable to damage from wood destroying organisms in areas where they are not constantly submerged by groundwater. If constantly submerged, there is not enough oxygen to sustain fungal growth and insect colonies; if only periodically submerged, the piles can have moisture levels and oxygen levels sufficient to sustain wood destroying organisms. Consultation with local design professionals in the area familiar with the use and performance of driven treated wood piles will help quantify this potential risk. Grade beams can be constructed at greater depths or alternative pile materials can be selected if wood destroying organism damage is a major concern.

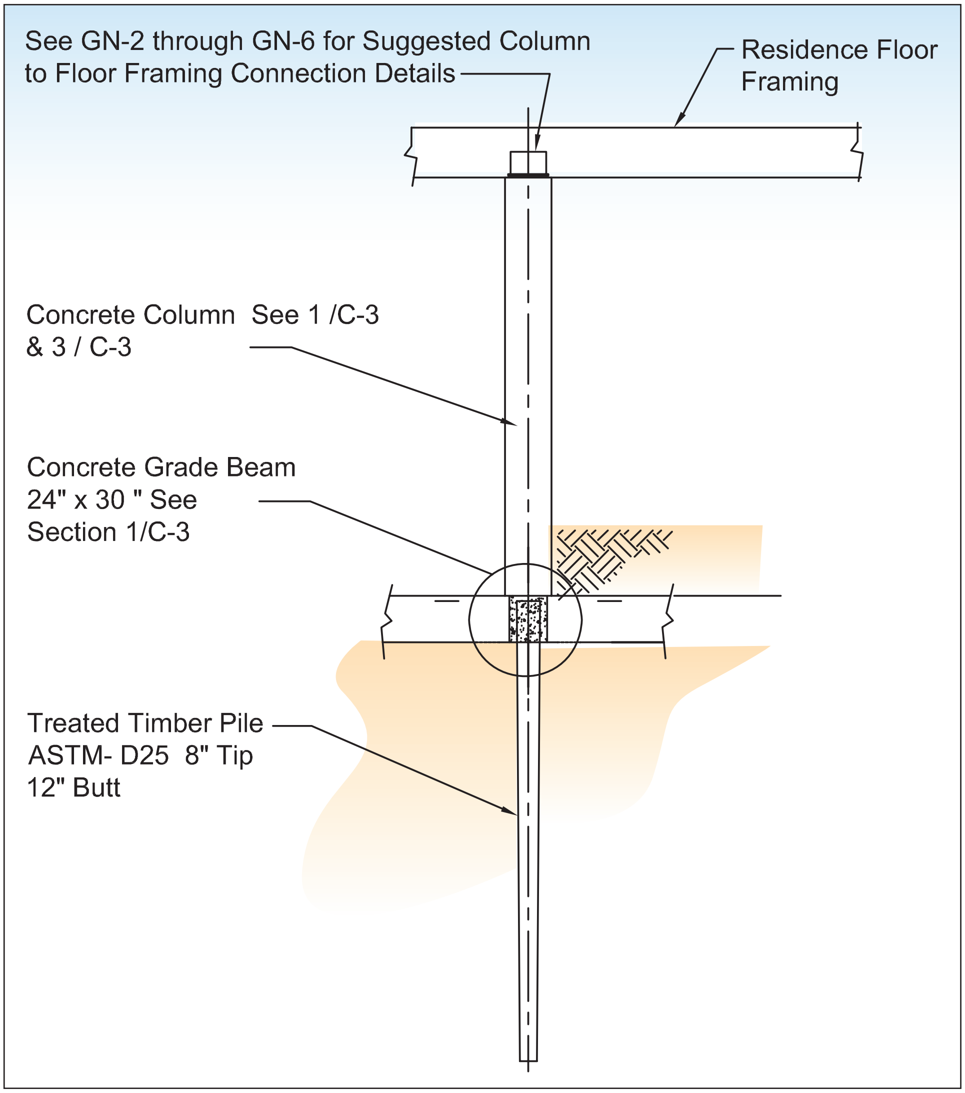


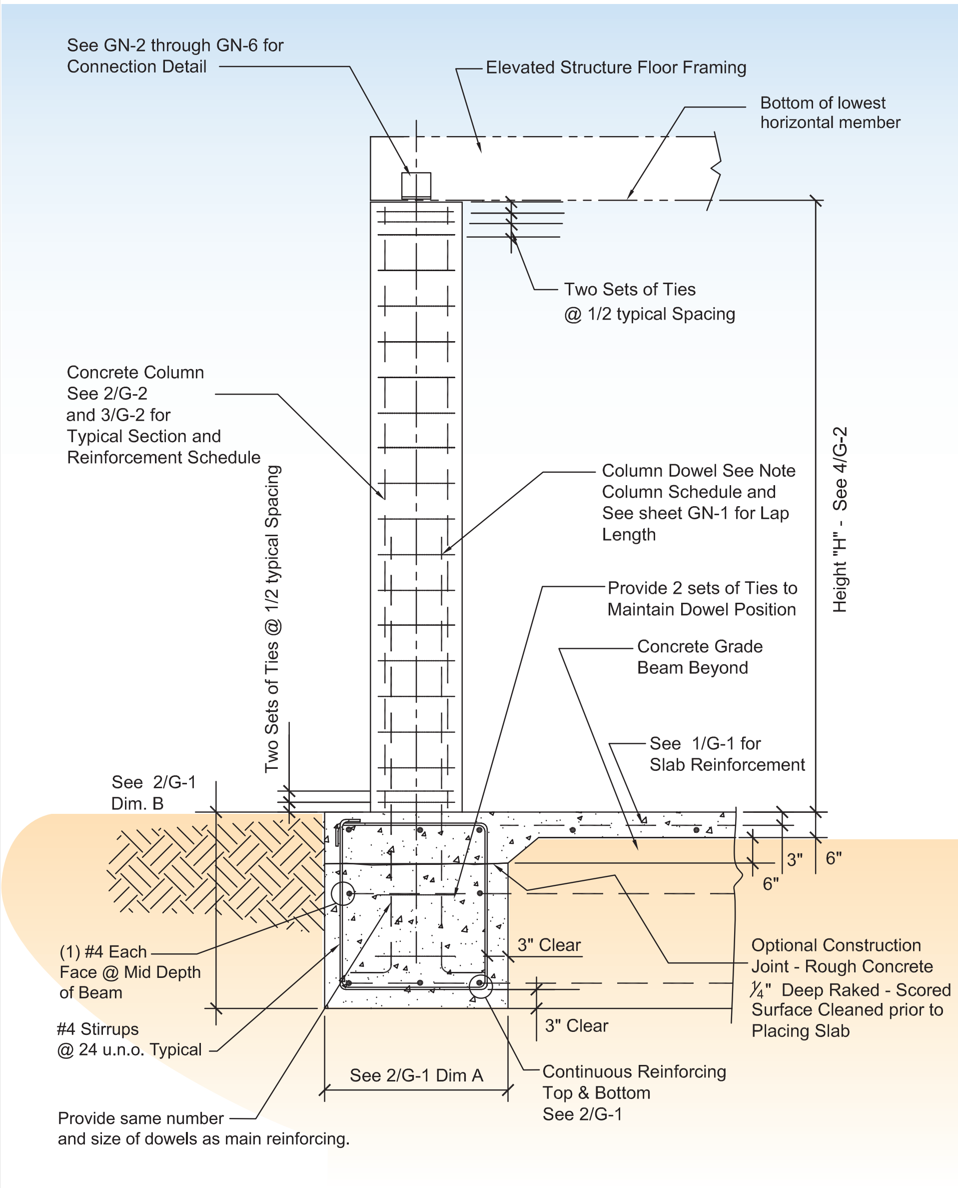
Figure 4-4. Profile of Case C foundation type (see Appendix A for additional drawings)

4.2.4 Open Foundation: Concrete Column and Grade Beam with Slabs (Cases D and G)

These open foundation types make use of a rigid mat to resist lateral forces and overturning moments. Frictional resistance between the grade beams and the supporting soils resist lateral loads while the weight of the grade beam and the above grade columns resist uplift. Case G (foundation with slab) contains additional reinforcement to tie the on-grade slab to the grade beams to provide additional weight to resist uplift (see Figure 4-5). With the integral slab, elevations up to 15 feet above grade are achievable. Without the slab (as for Case D), the designs as detailed are limited to 10-foot elevations (see Figure 4-6).

Unlike the deep driven pile foundations, both shallow grade beam foundation styles can be undermined by erosion and scour if exposed to waves and high flow velocities. Neither style of foundation should be used where anticipated erosion or scour would expose the grade beam.

**Figure 4-5.
Profile of Case G foundation type (see Appendix A for additional drawings)**



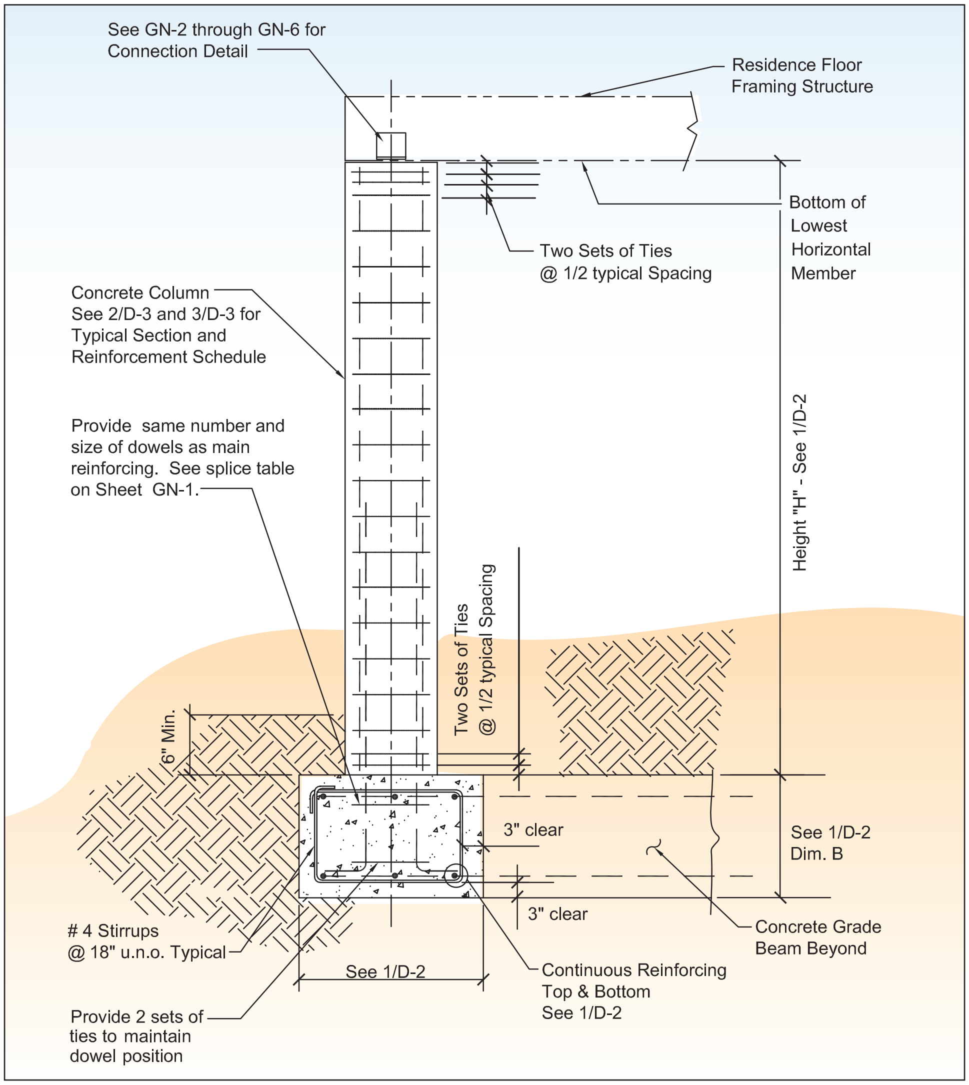


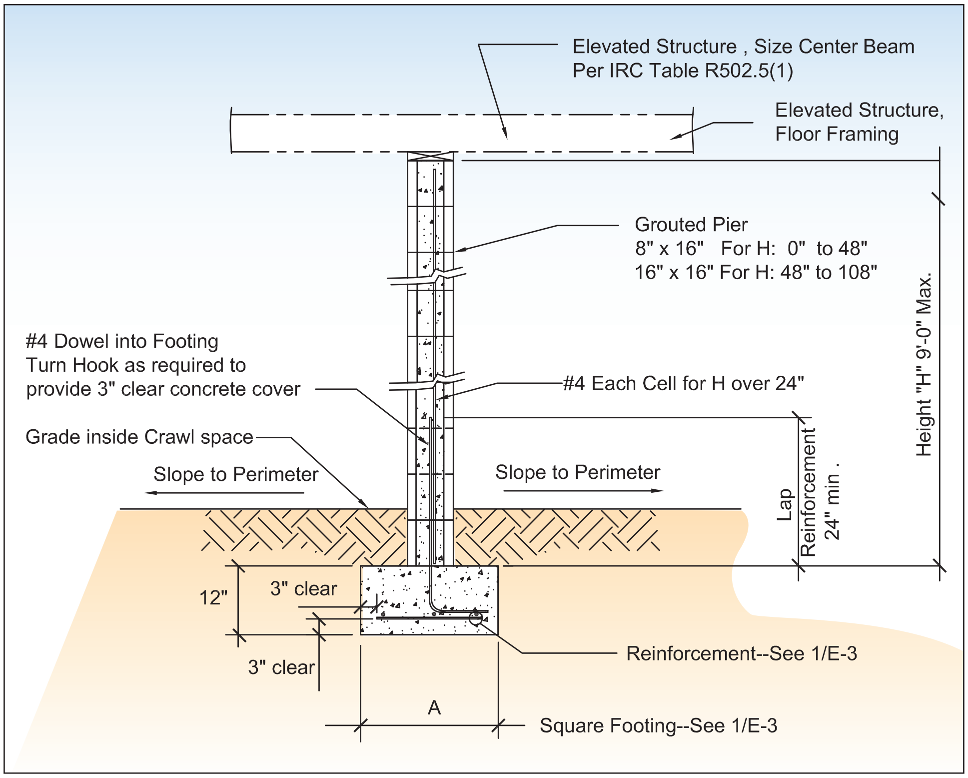
Figure 4-6. Profile of Case D foundation type (see Appendix A for additional drawings)

4.2.5 Closed Foundation: Reinforced Masonry – Crawlspace (Case E)

The reinforced masonry with crawlspace type of foundation utilizes conventional construction similar to foundations used outside of SFHAs. Footings are cast-in-place reinforced concrete; walls are constructed with reinforced masonry (see Figure 4-7). The foundation designs presented in Appendix A permit elevated homes to be raised to 8 feet. Higher elevations are achievable with larger or more closely spaced reinforcing steel or with walls constructed with thicker masonry.

The required strength of a masonry wall is determined by breaking wave loads for wall heights 3 feet or less, by non-breaking waves and hydrodynamic loads for taller walls, and by uplift for all walls. Perimeter footing sizes are controlled by uplift and must be relatively large for short foundation walls. The weight of taller walls contributes to uplift resistance and allows for smaller perimeter footings. Solid grouting of perimeter walls is recommended for additional weight and improved resistance to water infiltration.

**Figure 4-7.
Profile of Case E foundation type (see Appendix A for additional drawings)**



Interior footing sizes are controlled by gravity loads and by the bearing capacity of the supporting soils. Since the foundation designs are based on relatively low bearing capacities, obtaining soils tests for the building site may allow the interior footing sizes to be reduced.

The crawlspace foundation walls incorporate NFIP required flood vents, which must allow floodwaters to flow into the crawlspace. In doing so, hydrostatic, hydrodynamic, and breaking wave loads are reduced. Crawlspace foundations are vulnerable to scour and flood forces and should not be used in Coastal A Zones; the NFIP prohibits their use in V Zones.

4.2.6 Closed Foundation: Reinforced Masonry – Stem Wall (Case F)

The reinforced masonry stem walls (commonly referred to as chain walls in portions of the Gulf Coast) type of foundation also utilizes conventional construction to contain fill that supports the floor slab. They are constructed with hollow masonry block with grouted and reinforced cells (see Figure 4-8). Full grouting is recommended to provide increased weight, resist uplift, and improve longevity of the foundation.

The amount and size of the reinforcement are controlled primarily by the lateral forces created by the retained soils and by surcharge loading from the floor slab and imposed live loads. Because the retained soils can be exposed to long duration flooding, loads from saturated soils should be considered in the analyses. The lateral forces on stem walls can be relatively high and even short cantilevered stem walls (those not laterally supported by the floor slab) need to be heavily reinforced. Tying the top of the stem walls into the floor slab provides lateral support for the walls and significantly reduces reinforcement requirements. Because backfill needs to be placed before the slab is poured, walls that will be tied to the floor slab need to be temporarily braced when the foundation is backfilled until the slab is poured and cured.

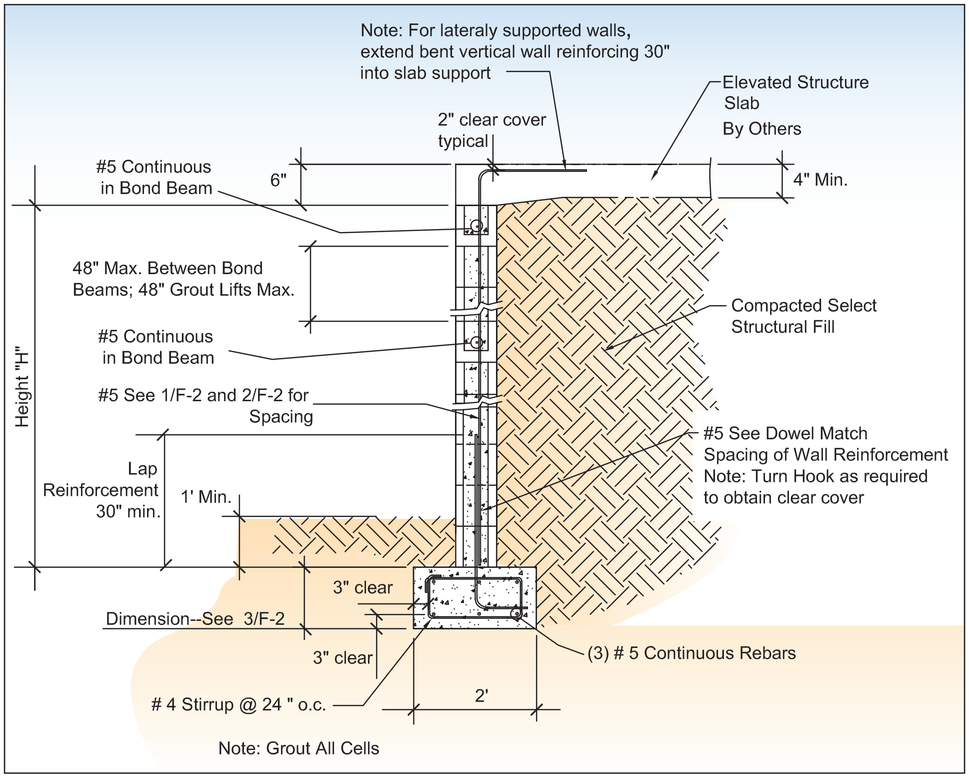


Figure 4-8. Profile of Case F foundation type (see Appendix A for additional drawings)

NOTE: Stem wall foundations are vulnerable to scour and should not be used in Coastal A Zones without a deep footing. The NFIP prohibits the use of this foundation type in V Zones.