Recommended Residential Construction for the Gulf Coast

Building on Strong and Safe Foundations

FEMA 550 / July 2006

U.S. DEPARTMENT OF HOMELAND SECURITY FEMA

About the Cover

On August 29, 2005, Hurricane Katrina struck the Gulf Coast with recordbreaking storm surge that destroyed foundations and devastated homes from Louisiana east to Alabama. Katrina was so destructive that engineers assessing the carnage no longer looked for "success stories" (i.e., homes that were only moderately damaged), but rather searched for "survivor" homes that, while extensively damaged, still bore a slight resemblance to a residential building. Hurricane Katrina proved that, without strong foundations, homes on the coast can and will be destroyed.

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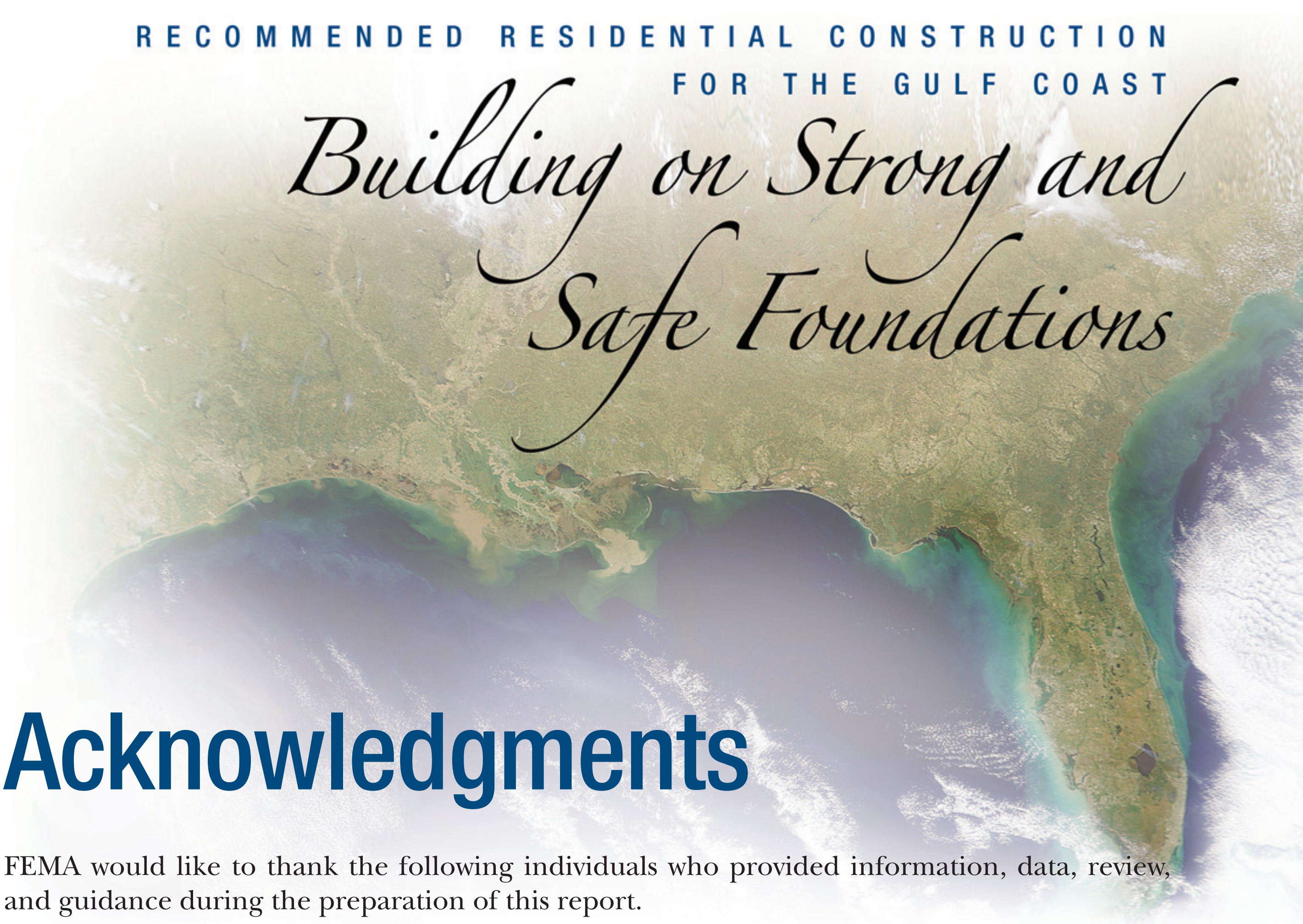
FEMA



RECOMMENDED RESIDENTIAL CONSTRUCTION FOR THE GULF COAST

Building on Strong and Safe Foundations

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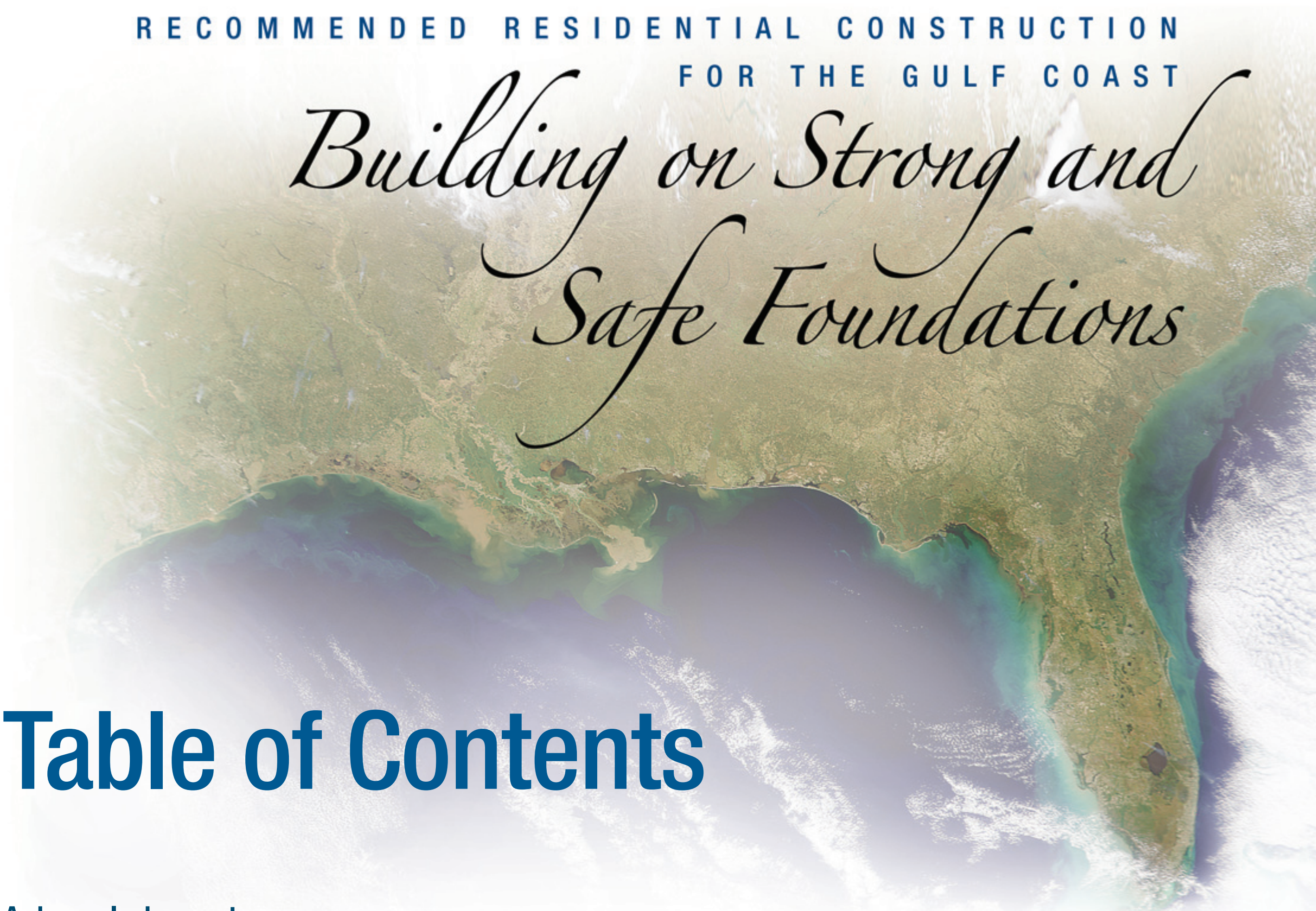

Building on Strong and Safe Foundations

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Building on Strong and Safe Foundations

Introduction

The purpose of this design manual is to provide recommended foundation designs and guidance for rebuilding homes destroyed by hurricanes in the Gulf Coast. In addition, the manual is intended to provide guidance in designing and building safer and less vulnerable homes to reduce the risk to life and property.

Past storms such as Hurricanes Andrew, Hugo, and Charley, and recent storms such as Katrina and Rita continue to show the vulnerability of our "built environment" (see Figure 1). While good design and construction cannot totally eliminate risk, every storm has shown that sound design and construction can significantly reduce the risk to life and damage to property. With that in mind, FEMA has developed this manual to help the community of homebuilders, contractors, and local engineering professionals in rebuilding homes destroyed by Hurricanes Katrina and Rita, and designing and building safer and less vulnerable new homes.

Figure 1.
Damage to residential properties as a result of Hurricane Katrina's winds and storm surge. Note the building that was knocked off its foundation (circled).

Intent of the Manual

The intent of the manual is to provide Gulf Coast homebuilders, contractors, and local engineering professionals with a series of recommended foundation designs that will help create safer and stronger buildings along the Gulf Coast. The use of these designs is intended to cover many of the home styles anticipated for the construction effort.

The foundations may differ somewhat from traditional construction techniques; however, they represent what are considered to be some of the better approaches to constructing strong and safe foundations in the hazardous areas along the Gulf Coast. The objectives used to guide the development of this manual are:

- To provide residential foundation designs that will require minimal engineering oversight
- To provide foundation designs that are flexible enough to accommodate many of the homes identified in *A Pattern Book for Gulf Coast Neighborhoods* prepared for the Mississippi Governor's Rebuilding Commission on Recovery, Rebuilding and Renewal (see Appendix B)
- To utilize model layouts so that many homes can be constructed without significant additional engineering efforts

The focus of this document is on the foundation of residential buildings. The assumption is that those who are designing and building new homes will be responsible for ensuring that the building itself is designed according to the latest building code (International Building Code [IBC], International Residential Code [IRC], and FEMA guidance) and any local requirements. The user of this manual is directed to other publications that also address disaster-resistant construction (see Appendix G).

Although the foundation designs are geared to the coastal environment subject to storm surge, waves, floating debris, and high winds, several are suitable for supporting homes on sites protected by levees and floodwalls. For protected sites, wave loads may be less than those in an exposed coastal environment and, therefore, the designs presented in this manual may be conservative for such areas.

CAUTION: Although sites inside levees are not exposed to wave loads, sites immediately adjacent to floodwalls and levees can be exposed to extremely high flood velocities and scour if a breach occurs. Design professionals should be consulted before using these foundation designs on sites close to floodwalls or levees to determine if they are appropriate.

This manual contains closed foundation designs for elevating homes up to 8 feet above ground level and open foundation designs for elevating homes up to 15 feet above ground level. These upper limits are a function of constructability limitations and overturning and stability issues for more elevated foundations. Eight-foot tall foundations are a practical upper limit for 8-inch thick reinforced concrete masonry unit (CMU) walls exposed to flood forces anticipated in non-coastal A zones. The upper limit of 15 feet for open foundations was established by estimating the amount a home needs to be elevated to achieve the 2005 Advisory Base Flood Elevations (ABFEs). The ABFEs published in the Hurricane Recovery Maps were compared to local topographic maps for the Gulf Coast. The comparison revealed that approximately 80 percent of the homes damaged by Hurricane Katrina could be elevated to the ABFEs on foundations that are 15 feet or less in height.

Using the Manual

The following information is needed to use this manual:

- Design wind speed and the Design Flood Elevation (DFE) at the site
- The flood zone(s) at the site
- Building layout
- Topographic elevation of existing building site
- Soil conditions for the site. Soil condition assumptions used in the load calculations are intentionally conservative. Users are encouraged to determine soil conditions at the site to potentially improve the cost-effectiveness of the design.

Most of the information can be obtained from the local building official or floodplain manager.

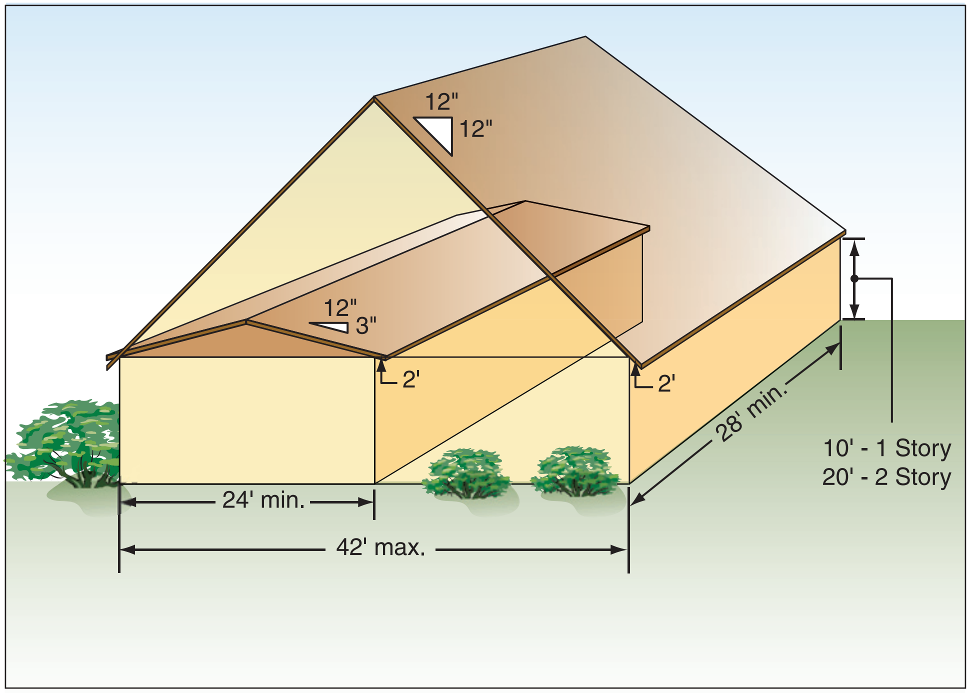
This document is not intended to supplant involvement from local design professionals. While the designs included can be used without modification (provided that the home to be elevated falls within the design criteria), consulting with local engineers should be considered. Local engineers may assist with the following:

- Incorporating local site conditions into the design

- Addressing and supporting unique features of the home
- Allowing use of value engineering to produce a more efficient design

These designs have been developed to support homes with a range of dimensions, weights, and roof pitches. Figure 2 schematically shows the diverse range of dimensions and roof pitches. Appendix C contains a complete list of criteria and assumptions used in these designs.

Figure 2. Schematic of range of home dimensions and roof pitches



This manual concentrates on foundations that resist the extreme hurricane wind and flooding conditions found throughout the Gulf Coast. For successful, natural hazard-resistant installations, both the foundation and the home it supports must be properly designed and constructed to take all loads on the structure into the ground through the foundation. Constructing the home to meet all the requirements of the IBC or the IRC is a minimum requirement to producing hazard-resistant homes. However, any model code must contain minimum requirements and best practice approaches for improved resistance to natural hazards.

To gain the benefits of a "best practices" approach, readers are directed to publications such as FEMA 499, *Home Builder's Guide to Coastal Construction Technical Fact Sheet Series*, and FEMA 55, *Coastal Construction Manual*. A more complete list of available publications is contained in Appendix G.

Organization of the Manual

There are five chapters and seven appendices in this manual. The intent is to cover the essential information in the chapters and provide all the details in the appendices. Chapter 1 provides a description of the different types of hazards that must be considered in the design of a residential building foundation in the Gulf Coast area. The primary issues related to designing foundations for residential buildings are described in Chapter 2. Chapter 3 provides guidance on how to determine the magnitude of the loads placed on a building by a particular natural hazard event or a combination of events. The different foundation types and methods of construction foundation for a residential building are discussed in Chapter 4. Chapter 5 and Appendix A present foundation designs to assist the homebuilders, contractors, and local engineering professionals in developing a safe and strong foundation.

In addition to Chapters 1 through 5 and Appendix A, the following appendices are presented herein:

- Appendix B presents examples of how the foundation designs in this manual can be used with some of the houses in the publication *A Pattern Book for Gulf Coast Neighborhoods*.
- Appendix C provides a list of assumptions used in developing the foundation design presented in this manual.
- Appendix D provides detailed calculations on how to design the foundation of residential buildings. Two examples, one for open foundations and the other for closed foundations, are presented.
- Appendix E provides cost information that the homebuilders can use to estimate the cost of installing the foundation systems proposed in this manual.
- Appendix F includes a list of fact sheets contained in FEMA 499 that are referenced in this manual.
- Appendix G presents a list of references and other FEMA publications that can be of assistance to the users of this manual.
- Appendix H contains a glossary of terms used in the manual.
- Appendix I defines abbreviations and acronyms used in the manual.

Limitations of the Manual

This manual has been provided to assist in the reconstruction efforts after Hurricane Katrina. Builders, architects, or engineers using this manual assume responsibility for the resulting designs and their performance during a natural hazard event.

The foundation designs and analyses presented in this manual were based on the American Society of Civil Engineers (ASCE) 7-02 and the 2003 version of the IRC. While FEMA 550 was being developed, ASCE released its 2005 edition of ASCE 7 (ASCE 7-05) and the International Code Council (ICC) issued their 2006 editions of the IBC and IRC. The ASCE 7 revisions did not affect the load calculations controlling the designs and there were no substantive flood provision changes to the IRC that affect foundation designs in coastal areas.

1. Types of Hazards

This chapter discusses the following types of hazards that must be considered in the design of a residential building foundation for the Gulf Coast: high winds, storm surge, and associated flood effects, including hydrostatic forces, hydrodynamic forces, waves, floodborne debris, and erosion and scour.

1.1 High Winds

Hurricanes are the basis for design wind speeds for the Gulf Coast. High winds during a hurricane can create extreme positive and negative forces on a building; the net result is that wind forces simultaneously try to push over the building and lift it off its foundation. If the foundation is not strong enough to resist these forces, the home may slide, overturn, collapse, or incur substantial damage (Figure 1-1).

The most current design wind speeds are provided by the American Society of Civil Engineers (ASCE) document *Minimum Design Loads for Buildings and Other Structures* (ASCE 7). ASCE 7 is typically updated every 3 years. The 2002 edition ASCE 7-02 is referenced by the following model building codes: the 2003 editions of the International Building Code (IBC), the International Residential Code (IRC), and the NFPA 5000, *Building Construction and Safety Code*, published by the National Fire Protection Association (NFPA).

NOTE: Hurricanes are classified into five categories according to the Saffir-Simpson Scale, which uses wind speed and central pressure as the principal parameters to categorize storm damage potential. Hurricanes can range from Category 1 to the devastating Category 5 (Figure 1-2).

Hurricanes can produce storm surge that is higher or lower than what the wind speed at landfall would predict. Katrina's surge was roughly that of a Category 5, although its winds at landfall were only a Category 3. A hurricane that is a Category 3 or above is generally considered a major hurricane.

Design wind speeds given by ASCE 7 are 3-second gust speeds, not the sustained wind speeds associated with the Saffir-Simpson hurricane classification scale. Figure 1-3 shows the design wind speeds for portions of the Gulf Coast region based on 3-second gusts (measured at 33 feet above the ground in Exposure C).

Figure 1-1. Wind damage to roof structure and gable end wall from Hurricane Katrina (2005) (Pass Christian, Mississippi)

Saffir-Simpson Scale (Category/Damage)

Category 1 Hurricane – Winds 74 to 95 mph, sustained (91 to 116 mph, 3-second gust)

No real damage to buildings. Damage to unanchored mobile homes. Some damage to poorly constructed signs. Also, some coastal flooding and minor pier damage. Examples: Hurricanes Irene (1999) and Allison (1995).

Category 2 Hurricane – Winds 96 to 110 mph, sustained (117 to 140 mph, 3-second gust)

Some damage to building roofs, doors, and windows. Considerable damage to mobile homes. Flooding damages piers, and small crafts in unprotected moorings may break. Some trees blown down. Examples: Hurricanes Bonnie (1998), Georges (FL and LA 1998), and Gloria (1985).

Category 3 Hurricane – Winds 111 to 130 mph, sustained (141 to 165 mph, 3-second gust)

Some structural damage to small residences and utility buildings. Large trees blown down. Mobile homes and poorly built signs destroyed. Flooding near the coast destroys smaller structures with larger structures damaged by floating debris. Terrain may be flooded far inland. Examples: Hurricanes Keith (2000), Fran (1996), Opal (1995), Alicia (1983), Betsy (1965), and Katrina at landfall (2005).

Category 4 Hurricane – Winds 131 to 155 mph, sustained (166 to 195 mph, 3-second gust)

More extensive curtainwall failures with some complete roof structure failure on small residences. Major erosion of beach areas. Terrain may be flooded far inland. Examples: Hurricanes Hugo (1989), Donna (1960), and Charley (2004).

Category 5 Hurricane – Winds greater than 155 mph, sustained (195 mph and greater, 3-second gust)

Complete roof failure on many residences and industrial buildings. Some complete building failures with small utility buildings blown over or away. Flooding causes major damage to lower floors of all structures near the shoreline. Massive evacuation of residential areas may be required. Examples: Hurricanes Andrew (1992), Camille (1969), and the unnamed Labor Day storm (1935).

Note: Saffir-Simpson wind speeds (sustained 1-minute) were converted to 3-second gust wind speed utilizing the Durst Curve contained in ASCE 7-02, Figure C6-2.

Figure 1-2. Saffir-Simpson Scale

1.2 Storm Surge

Storm surge is water that is pushed toward the shore by the combined force of the lower barometric pressure and the wind-driven waves advancing to the shoreline. This advancing surge combines with the normal tides to create the hurricane storm tide, which in many areas can increase the sea level by as much as 20 to 30 feet. Figure 1-4 is a graphical depiction of how wind-driven waves are superimposed on the storm tide. This rise in water level can cause severe flooding in coastal areas, particularly when the storm tide coincides with high tides (see Figure 1-5). Because much of the United States' densely populated Gulf Coast coastlines lie less than 20 feet above sea level, the danger from storm surge is great. In addition, because of the shape and the bathymetery of the Gulf of Mexico, storm surges along the Gulf Coast can be greater than anywhere else in the United States (see Figure 1-6).

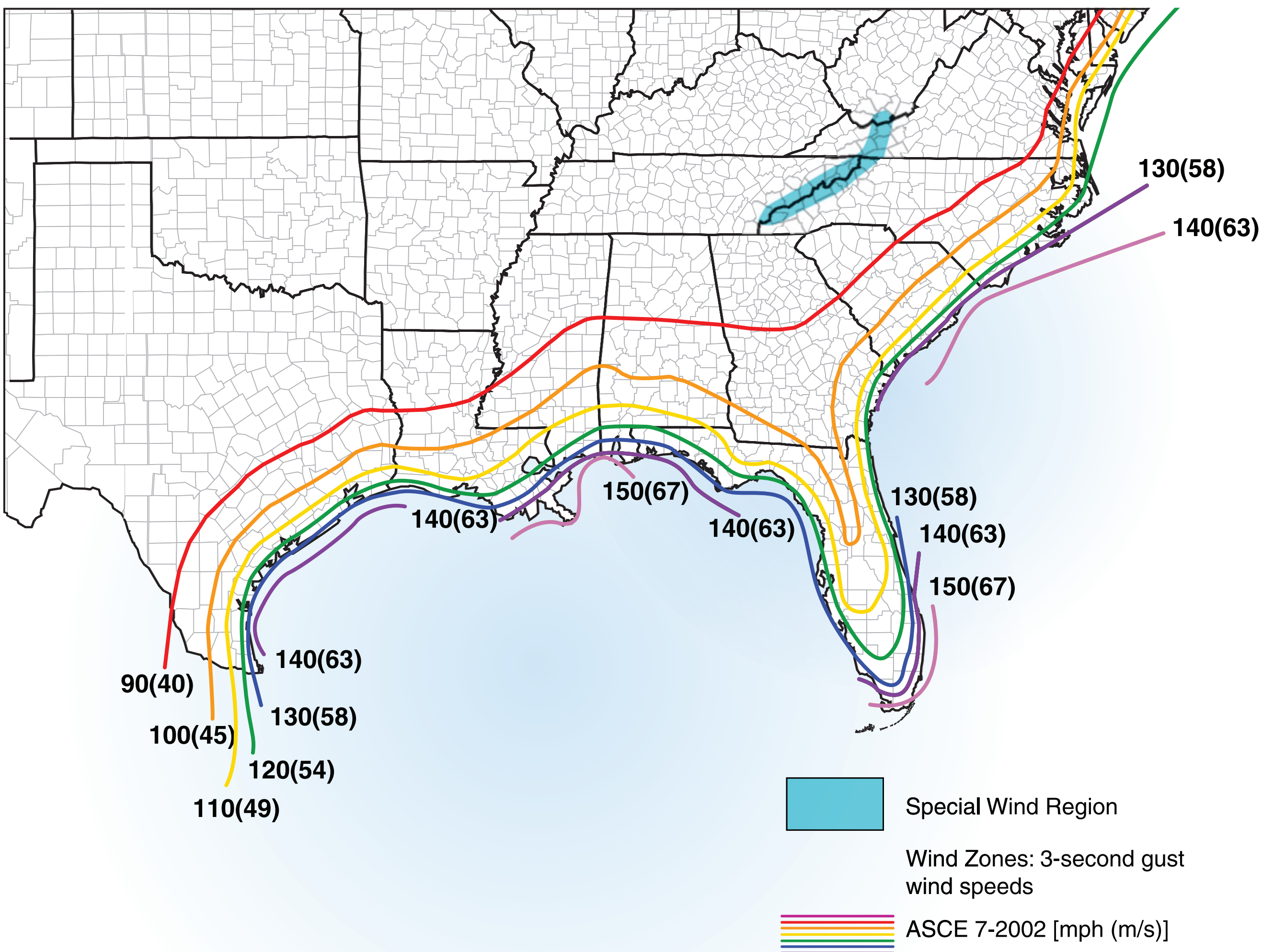


Figure 1-3.
Design wind speed map for portions of the Gulf Coast. Contours are 3-second gust wind speeds (in miles per hour [meters per second]) for Exposure Category C, 33 feet height.

SOURCE: ASCE 7-02

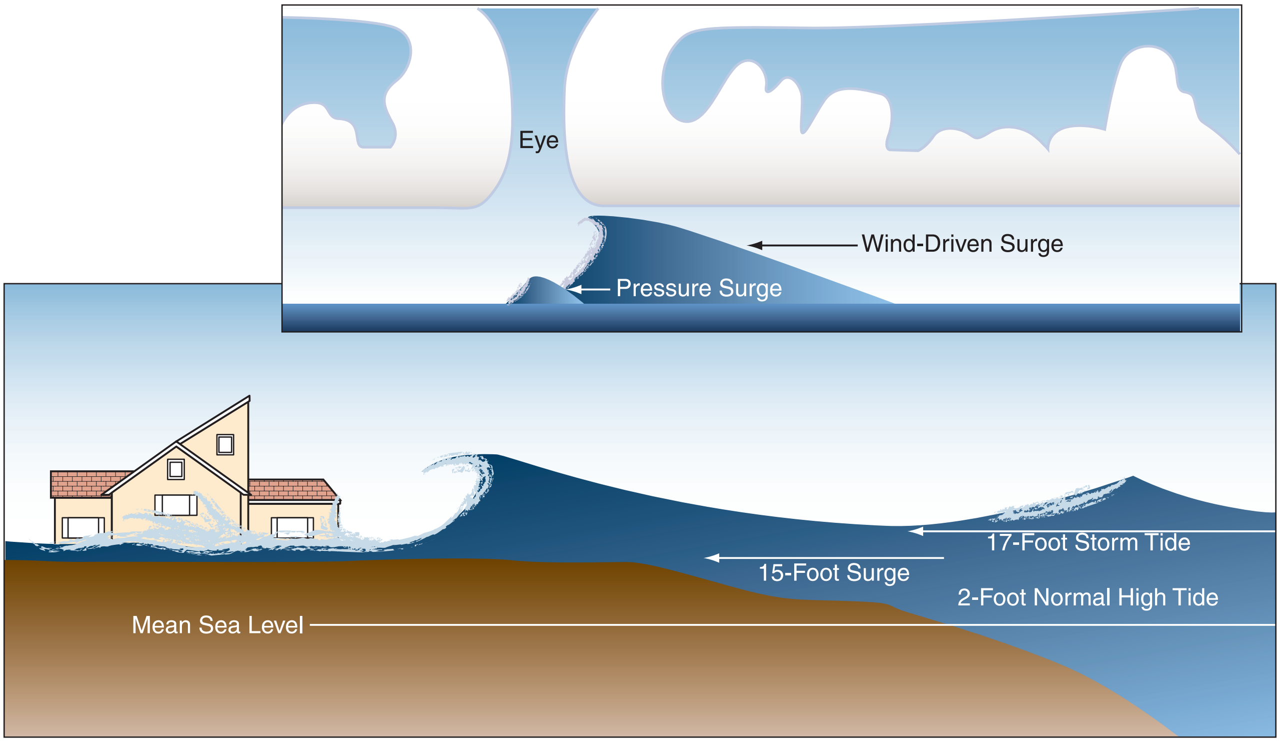


Figure 1-4.
Graphical depiction of a hurricane moving ashore. In this example, a 15-foot surge added to the normal 2-foot tide creates a total storm tide of 17 feet.

Figure 1-5.
Storm tide and waves from Hurricane Dennis on July 10, 2005, near Panacea, Florida

SOURCE: U.S. GEOLOGICAL SURVEY (USGS) *SOUND WAVES MONTHLY* NEWSLETTER. PHOTOGRAPH COURTESY OF *THE FORGOTTEN COASTLINE* (COPYRIGHT 2005)

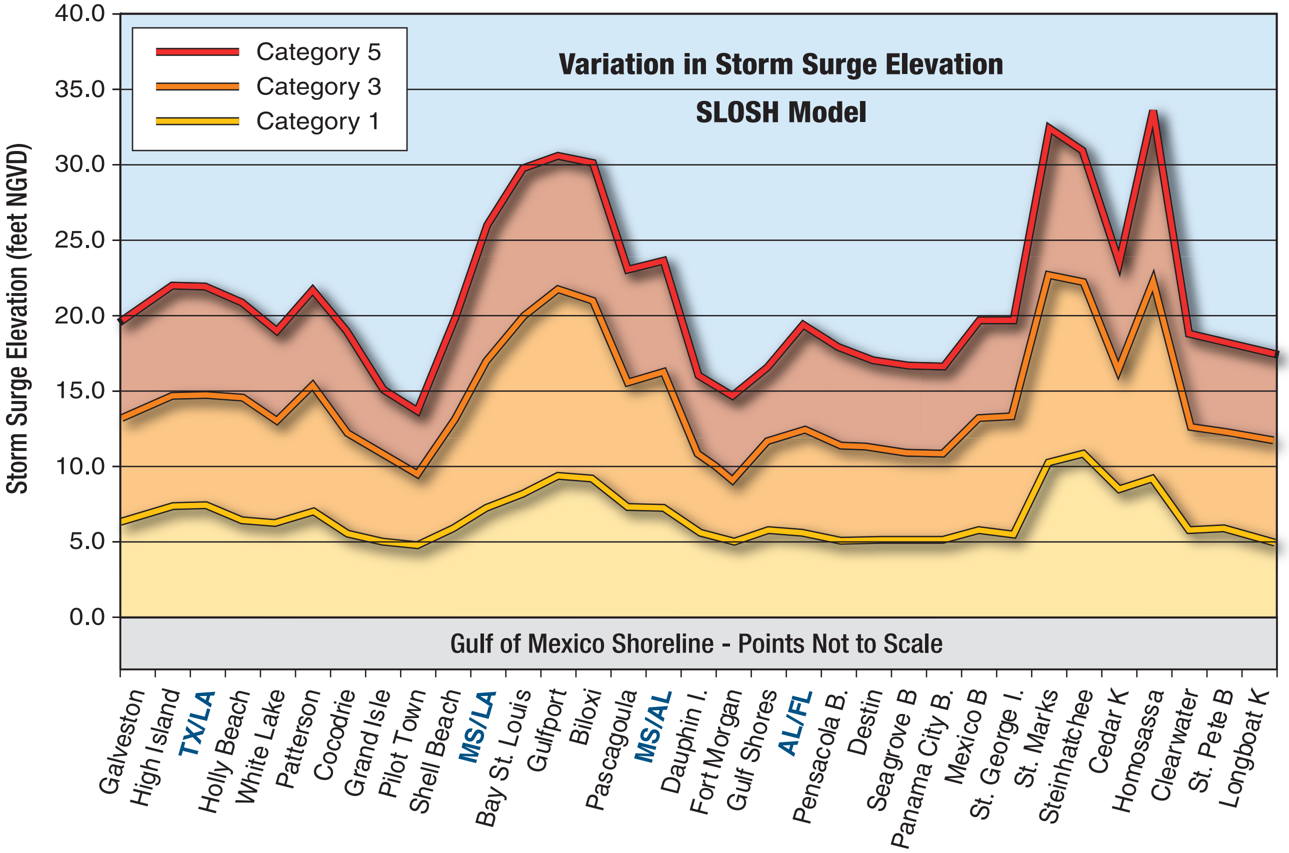


Figure 1-6.
Comparison of storm surge levels along the shorelines of the Gulf Coast for Category 1, 3, and 5 storms

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

1.3 Flood Effects

Although coastal flooding can originate from a number of sources, Gulf Coast hurricanes and weaker tropical storms not categorized as hurricanes are the primary cause of flooding (see Figure 1-2). The flooding can lead to a variety of impacts on coastal buildings and their foundations: hydrostatic forces, hydrodynamic forces, waves, floodborne debris forces, and erosion and scour.

1.3.1 Hydrostatic Forces

Horizontal hydrostatic forces against a structure are created when the level of standing or slowly moving floodwater on opposite sides of the structure are not equal. Flooding can also cause vertical hydrostatic forces, resulting in flotation. Rapidly rising floodwaters can also cause structures to float off of their foundations (see Figure 1-7). If floodwaters rise slowly enough, water can seep into a structure to reduce buoyancy forces. While slowly rising floodwaters reduce the adverse effects of buoyancy, any flooding that inundates a home can cause extreme damage.

Figure 1-7.
Building floated off of foundation (Plaquemines Parish, Louisiana)

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

1.3.2 Hydrodynamic Forces

Moving floodwaters create hydrodynamic forces on submerged foundations and buildings. These hydrodynamic forces can destroy solid walls and dislodge buildings with inadequate connections or load paths. Moving floodwaters can also move large quantities of sediment and debris that can cause additional damage. In coastal areas, moving floodwaters are usually associated with one or more of the following:

- Storm surge and wave runup flowing landward through breaks in sand dunes, levees, or across low-lying areas (see Figure 1-8)

Figure 1-8.
Aerial view of damage to one of the levees caused by Hurricane Katrina (photo taken on August 30, 2005, the day after the storm hit, New Orleans, Louisiana).

SOURCE: FEMA NEWS PHOTO/ JOCELYN AUGUSTINO

- Outflow (flow in the seaward direction) of floodwaters driven into bay or upland areas by a storm
- Strong currents along the shoreline driven by storm waves moving in an angular direction to the shore

High-velocity flows can be created or exacerbated by the presence of manmade or natural obstructions along the shoreline and by "weak points" formed by shore-normal (i.e., perpendicular to the shoreline) roads and access paths that cross dunes, bridges, or shore-normal canals, channels, or drainage features. For example, evidence after Hurricane Opal (1995) struck Navarre Beach, Florida, suggests that flow was channeled in between large, engineered buildings. The resulting constricted flow accelerated the storm surge and caused deep scour channels across the island. These channels eventually undermined pile-supported houses between large buildings while also washing out roads and houses farther landward (see Figure 1-9).

Figure 1-9.
During Hurricane Opal (1995), this house was in an area of channeled flow between large buildings. As a result, the house was undermined and washed into the bay behind a barrier island.

SOURCE: *COASTAL CONSTRUCTION MANUAL* (FEMA 55)

1.3.3 Waves

Waves can affect coastal buildings in a number of ways. The most severe damage is caused by breaking waves (see Figures 1-10 and 1-11). The height of these waves can vary by flood zone: V Zone wave heights can exceed 3 feet, while Coastal A Zone wave heights are between 1.5 and 3 feet. The force created by waves breaking against a vertical surface is often ten or more times higher than the force created by high winds during a storm event. Waves are particularly damaging due to their cyclic nature and resulting repetitive loading. Because typical wave periods during hurricanes range from about 6 to 12 seconds, a structure can be exposed to 300 to 600 waves per hour, resulting in possibly several thousand load cycles over the duration of the storm.

Wave runup occurs as waves break and run up beaches, sloping surfaces, and vertical surfaces. Wave runup can drive large volumes of water against or around coastal buildings, creating hydrodynamic forces (albeit smaller than breaking wave forces), drag forces from the current, and localized erosion and scour. Wave runup under a vertical surface (such as a wall) will create an upward force by the wave action due to the sudden termination of its flow. This upward force is much greater than the force generated as a wave moves along a sloping surface. In some instances, the force is large enough to destroy overhanging elements such as decks or porches. Another negative effect of waves is reflection or deflection, occurring when a wave is suddenly redirected as it impacts a building or structure.

Figure 1-10. Storm waves breaking against a seawall in front of a coastal residence at Stinson Beach, California

SOURCE: *COASTAL CONSTRUCTION MANUAL* (FEMA 55)

Figure 1-11. Storm surge and waves overtopping a coastal barrier island in Alabama (Hurricane Frederic, 1979)

SOURCE: *COASTAL CONSTRUCTION MANUAL* (FEMA 55)

1.3.4 Floodborne Debris

Floodborne debris produced by coastal flood events and storms typically includes decks, steps, ramps, breakaway wall panels, portions of or entire houses, fuel tanks, vehicles, boats, pilings, fences, destroyed erosion control structures, and a variety of smaller objects (see Figure 1-12). In some cases, larger pieces of floodborne debris can strike buildings (e.g., shipping containers and barges), but the designs contained herein are not intended to withstand the loads from these larger debris elements. Floodborne debris is capable of destroying unreinforced masonry walls, light wood-frame construction, and small-diameter posts and piles (and the components of structures they support). Debris trapped by cross bracing, closely spaced pilings, grade beams, or other components is also capable of transferring flood and wave loads to the foundation of an elevated structure.

Figure 1-12.
Pier pilings were carried over 2 miles by the storm surge and waves of Hurricane Opal (1995) before coming to rest against this elevated house in Pensacola Beach, Florida.

SOURCE: *COASTAL CONSTRUCTION MANUAL* (FEMA 55)

1.3.5 Erosion and Scour

Erosion refers to the wearing and washing away of coastal lands, including sand and soil. It is part of the larger process of shoreline changes. Erosion occurs when more sediment leaves a shoreline area than enters from either manmade objects or natural forces. Because of the dynamic nature of erosion, it is one of the most complex hazards to understand and difficult to accurately predict at any given site along the coast.

Short-term erosion changes can occur from storms and periods of high wave activity, lasting over periods ranging from a few days to a few years. Because of the variability in direction and magnitude, short-term erosion effects can be orders of magnitude greater than long-term erosion. Long-term shoreline changes occur over a period of decades or longer and tend to average out the short-term erosion. Both short-term and long-term changes should be considered in the siting and design of coastal residential construction. Refer to Chapter 7 of FEMA 55 for additional guidance on assessing short- and long-term erosion.

Scour can occur when water flows at high velocities past an object embedded in or sitting on soil that can be eroded. Scour occurs around the object itself, such as a piling or foundation element, and contributes to the loss of support provided by the soil. In addition to any storm or flood-induced erosion that occurs in the general area, scour is generally limited to small, cone-shaped depressions. Localized scour is capable of undermining slabs, pilings, and grade beam structures, and, in severe cases, can lead to structural failure (see Figure 1-13). This document considers these effects on the foundation size and depth of embedment requirements.

Figure 1-13.
Extreme case of localized scour undermining a slab-on-grade house in Topsail Island, North Carolina, after Hurricane Fran (1996). Prior to the storm, the lot was several hundred feet from the shoreline and mapped as an A Zone on the FIRM. This case illustrates the need for open foundations in Coastal A Zones.

SOURCE: *COASTAL CONSTRUCTION MANUAL* (FEMA 55)

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.

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.

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).

* 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.

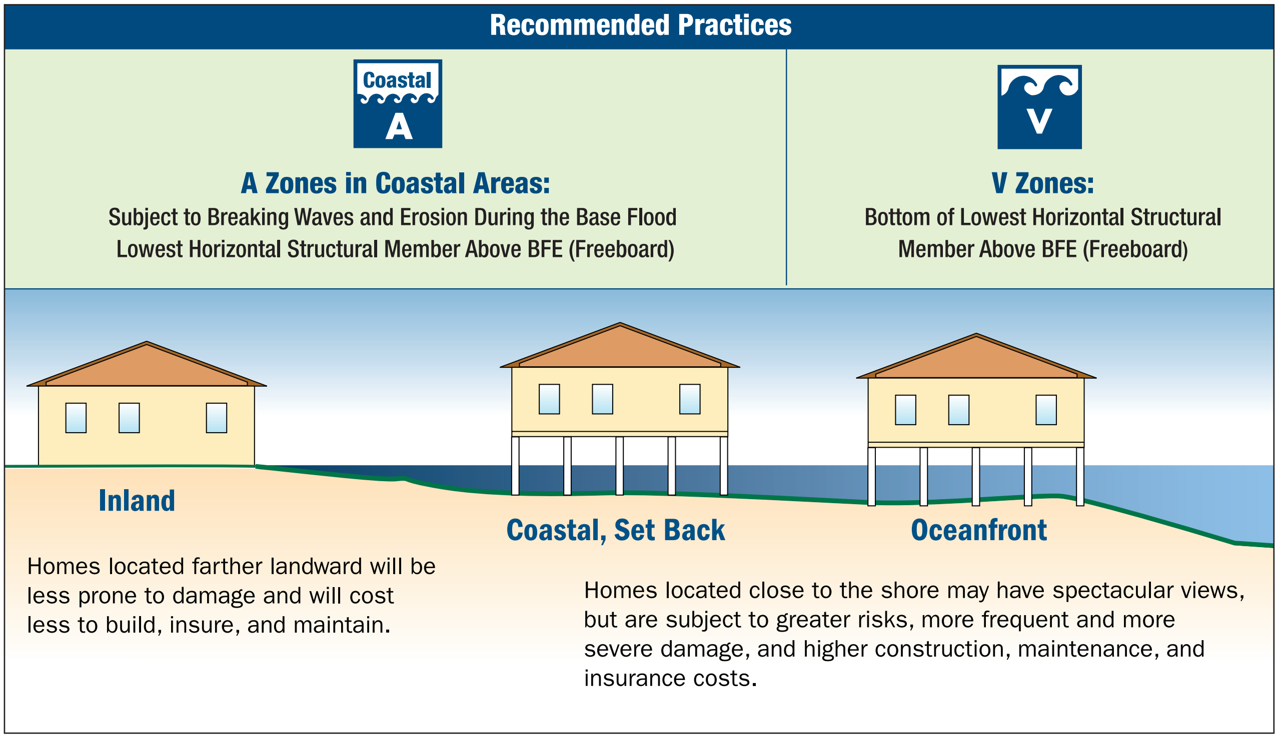


Figure 2-1.
Recommended open foundation practice for buildings in A Zones, Coastal A Zones, and V Zones

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 (crawlspace, stem wall, solid wall). Structural fill can also be used to elevate and support stem wall, crawlspace, 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)

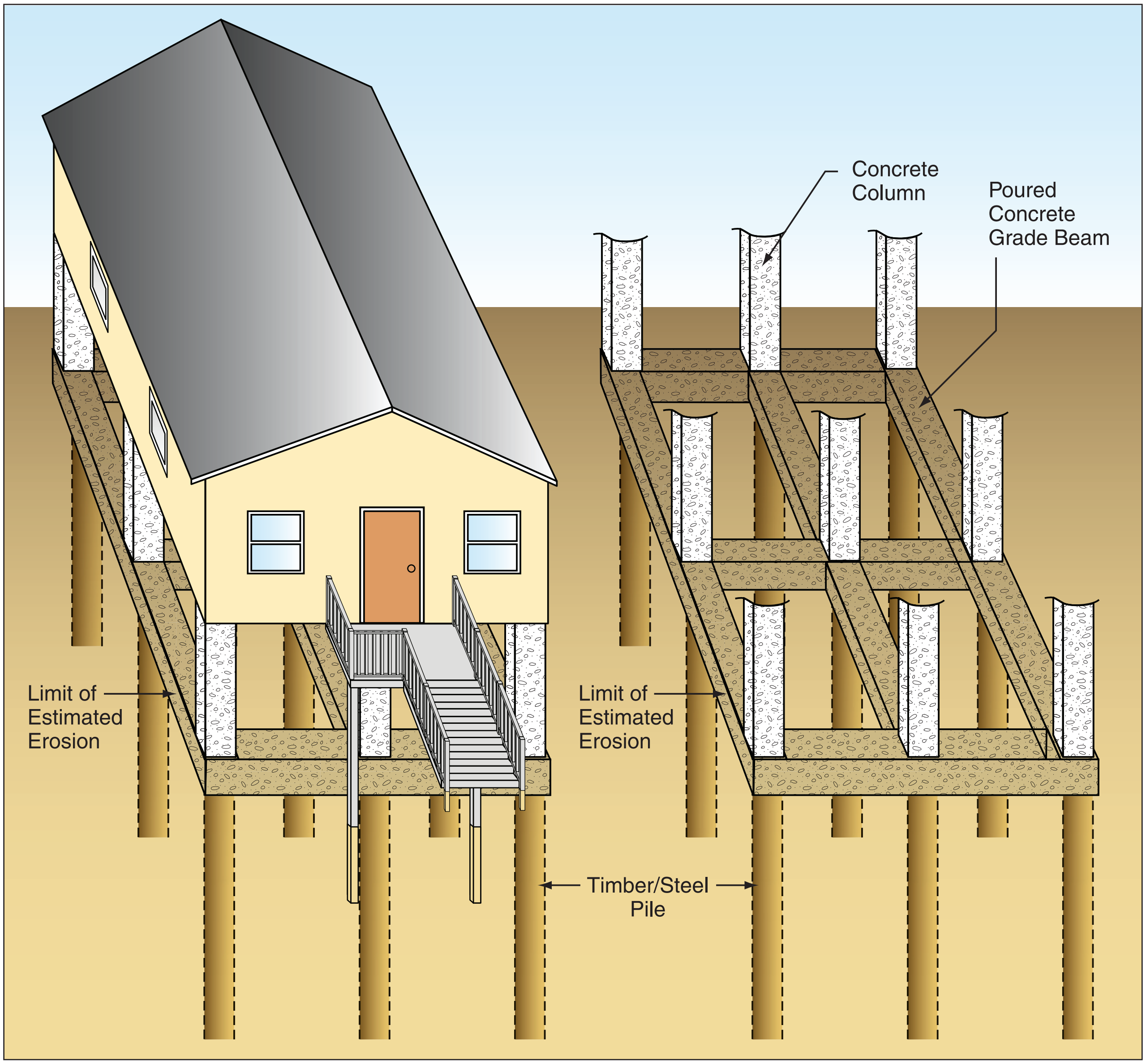


Figure 2-8. Isometric view of an open foundation with grade beam

2.3.2 Closed Foundations

A closed foundation is typically constructed using foundation walls, a crawlspace 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 crawlspace 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.

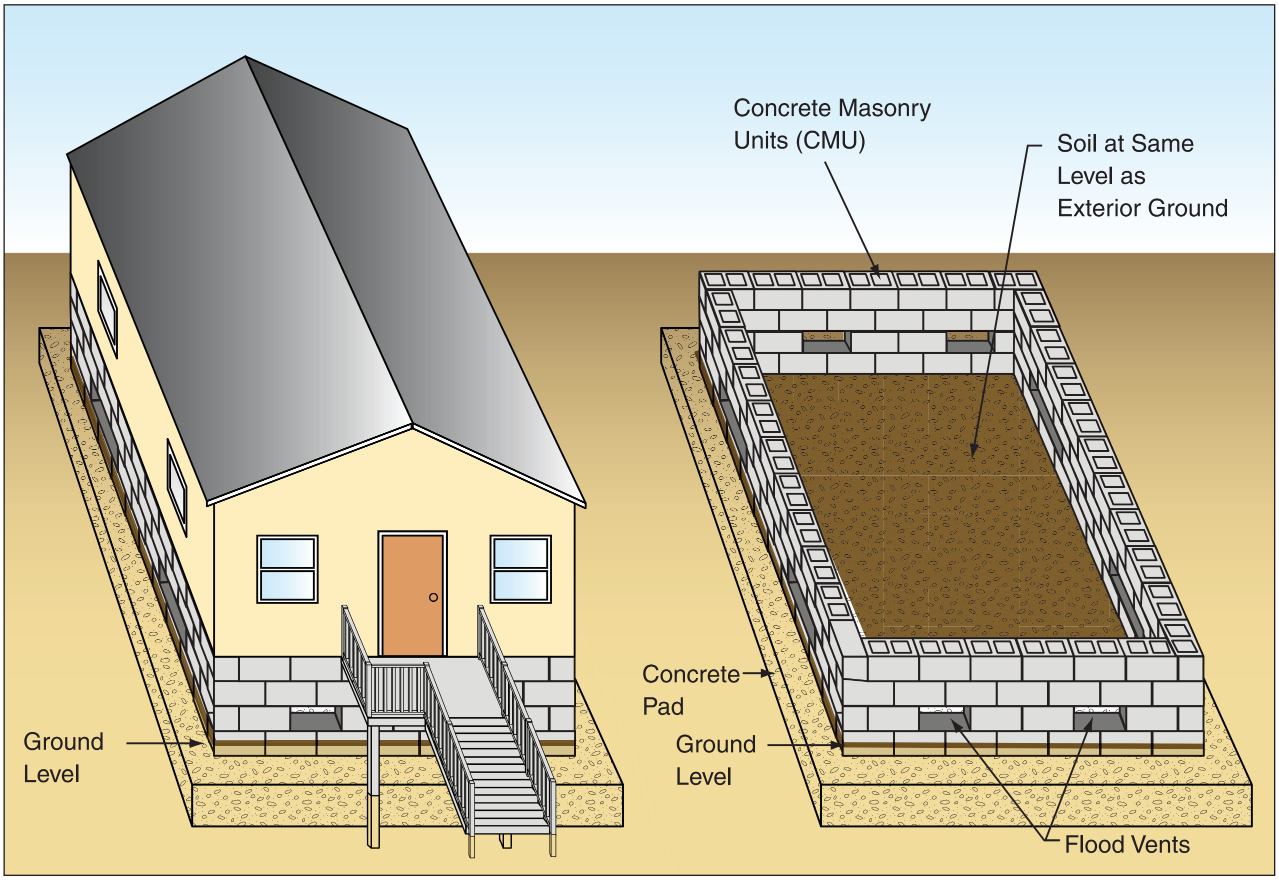


Figure 2-9. Isometric view of a closed foundation with crawlspace

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. Crawlspaces and stem walls are two types of foundations with perimeter walls.

Crawlspaces. 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

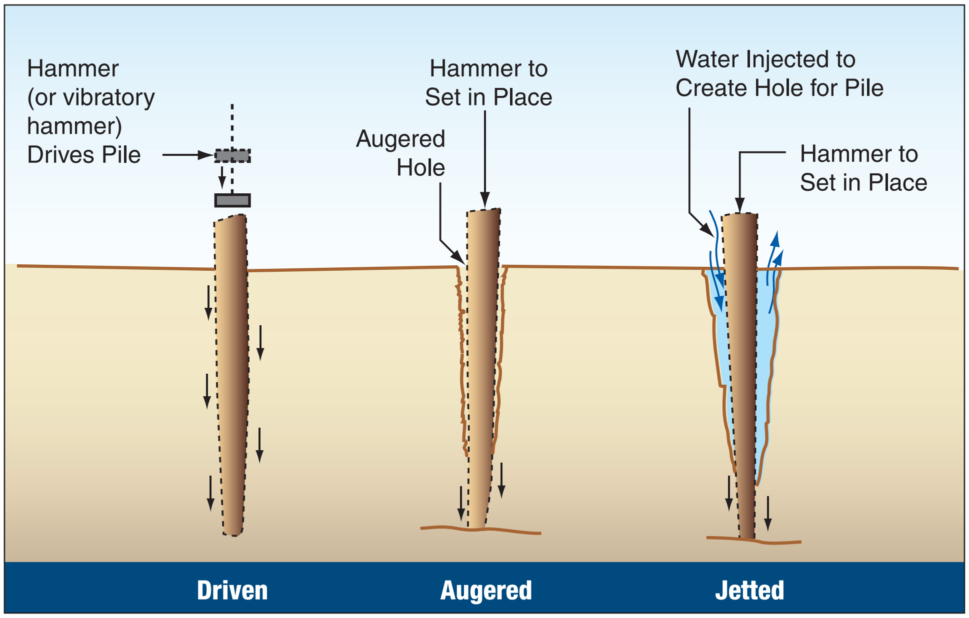
A common type of pile foundation is the elevated wood pile foundation, where the piles extend from deep in the ground to an elevation at or above the Design Flood Elevation (DFE). Horizontal framing members are used to connect the piles in both directions. This grid forms a platform on which the house 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.

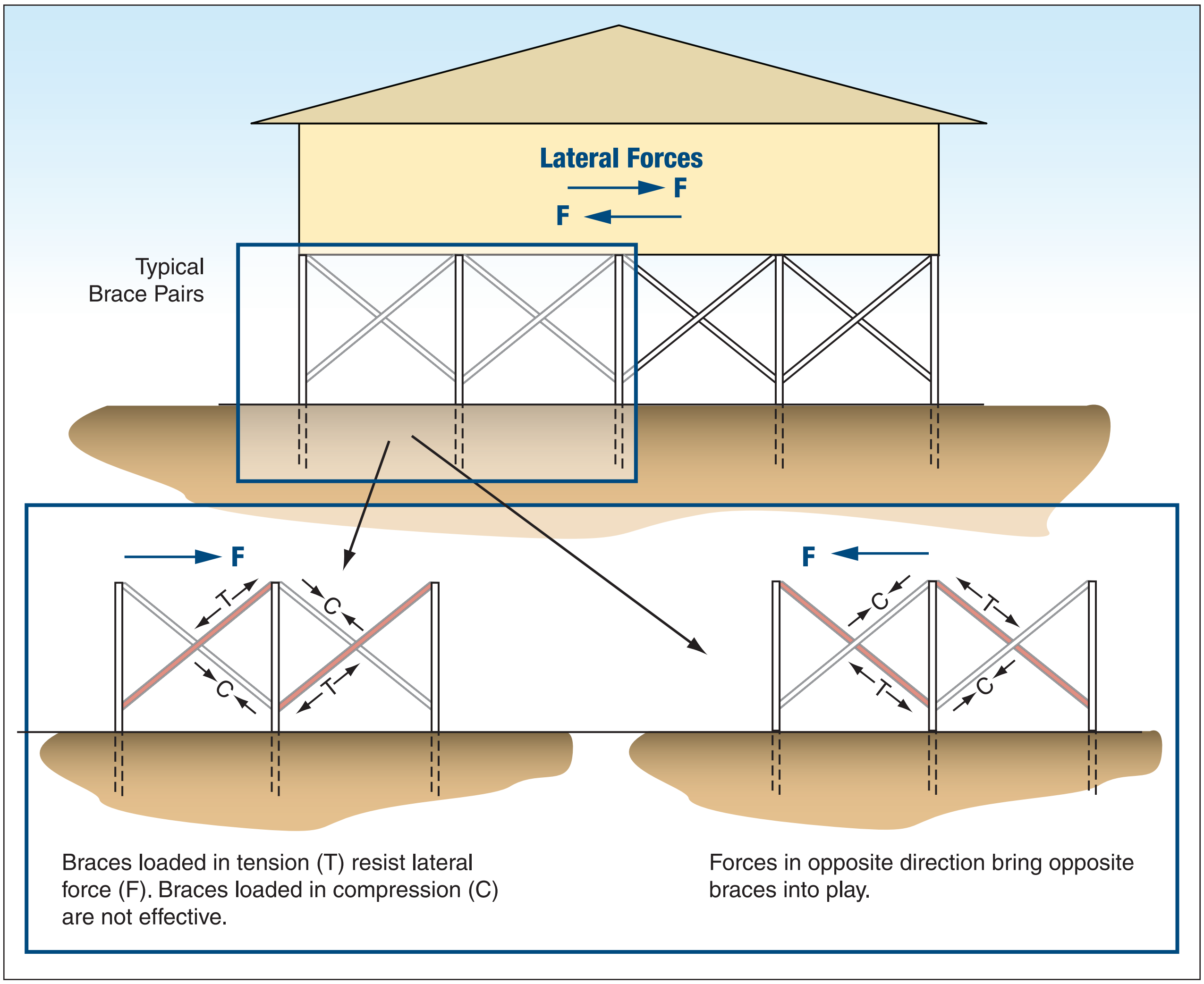


Figure 2-11. Diagonal bracing schematic

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.

Building on Strong and Safe Foundations

3. Foundation Design Loads

This chapter provides guidance on how to determine the magnitude of the loads placed on a building by a particular natural hazard event or a combination of events. The methods presented are intended to serve as the basis of a methodology for applying the calculated loads to the building during the design process.

The process for determining site-specific loads from natural hazards begins with identifying the building codes or engineering standards in place for the selected site (e.g., the International Building Code 2003 (IBC 2003) or ASCE 7-02, *Minimum Design Loads for Buildings and Other Structures),* if model building codes and other building standards do not provide load determination and design guidance for each of the hazards identified. In such instances, supplemental guidance such as FEMA 55 should be sought, the loads imposed by each of the identified hazards should be calculated, and the load combinations appropriate for the building site should be determined. The load combinations used in this manual are those specified by ASCE 7-02, the standard referenced by the IBC 2003. Either Allowable Stress Design (ASD) or Strength

Design methods can be used to design a building. For this manual, all of the calculations, analyses, and load combinations presented are based on ASD. The use of Strength Design methods will require the designer to modify the design values presented in this manual to accommodate Strength Design concepts. Assumptions utilized in this document can be found in Appendix C.

3.1 Wind Loads

Wind loads on a building structure are calculated using the methodology presented in ASCE 7-02, *Minimum Design Loads for Buildings and Other Structures*. This document is the wind standard referenced by the 2003 editions of the IBC and IRC. Equations used to calculate wind loads are presented in Appendix D.

The most important variable in calculating wind load is the design wind speed. Design wind speed can be obtained from the local building official or the ASCE 7-02 wind speed map (see Figure 3-1). The speeds shown in this figure are 3-second gust speeds for Exposure Category C at a 33-foot (10-meter) height. ASCE 7-02 includes scaling factors for other exposures and heights.

ASCE 7-02 specifies wind loads for structural components known as a Main Wind Force Resisting System (MWFRS). The foundation designs developed for this manual are based on MWFRS pressures calculated for Exposure Category C, the category with the highest anticipated wind loads for land-based structures.

ASCE 7-02 also specifies wind loads for components and cladding (C&C). Components and cladding are considered part of the building envelope, and ASCE 7-02 requires C&C to be designed to resist higher wind pressures than MWFRS.

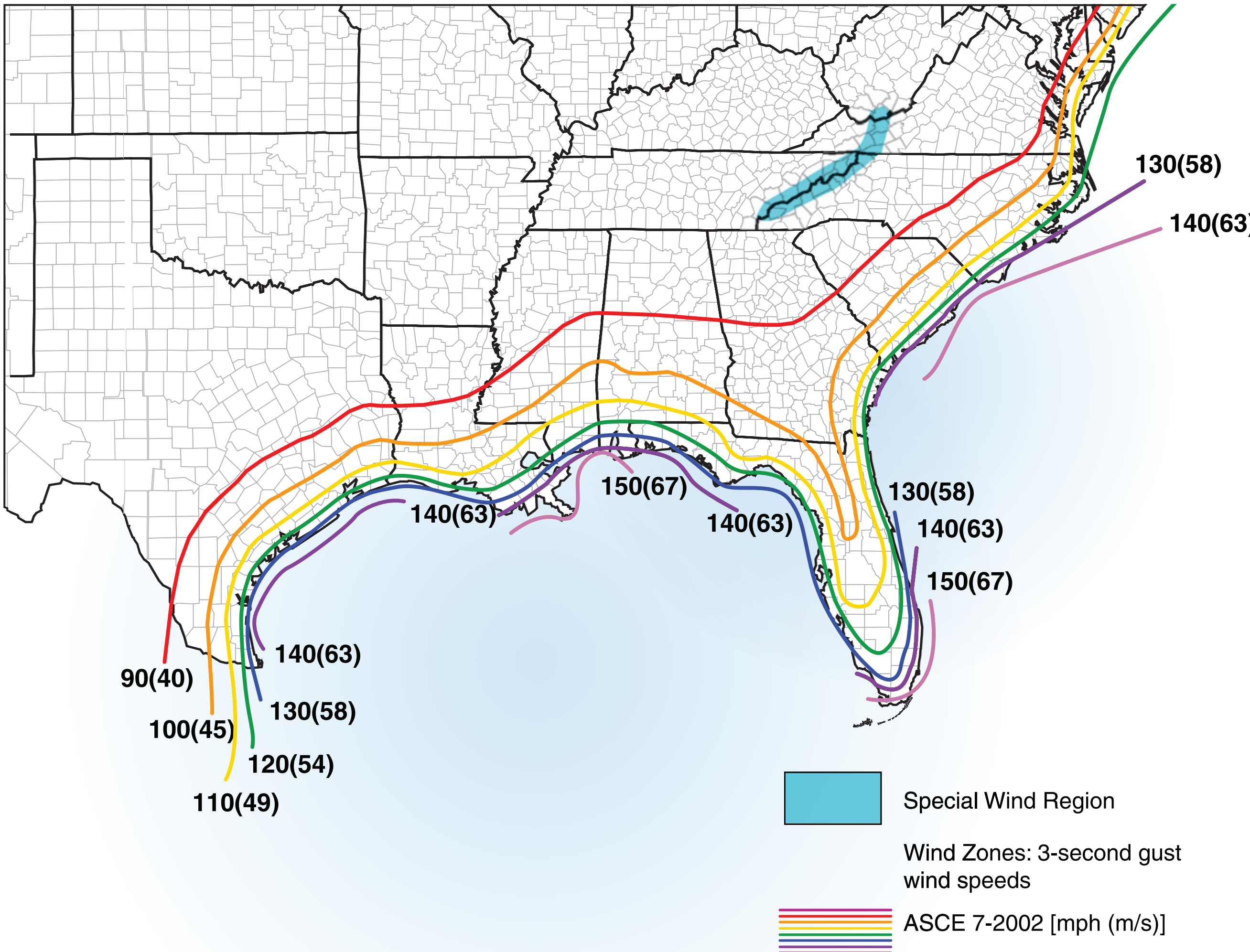


Figure 3-1. Wind speed (in mph) in the U.S. Gulf Coast area

SOURCE: ASCE 7-02

3.2 Flood Loads

This manual develops in more detail flood load calculations and incorporates the methodology presented in ASCE 7-02. Although wind loads can directly affect a structure and dictate the actual foundation design, the foundation is more affected by flood loads. ASCE 24 discusses floodproof construction. Loads developed in ASCE 24 come directly from ASCE 7-02, which is what the designs presented herein are based upon.

The effects of flood loads on buildings can be exacerbated by storm-induced erosion and localized scour, and by long-term erosion. Erosion and scour lower the ground surface around foundation members and can cause the loss of load-bearing capacity and resistance to lateral and uplift loads. Erosion and scour also increase flood depths and, therefore, increase depth dependent flood loads.

3.2.1 Design Flood and Design Flood Elevation (DFE)

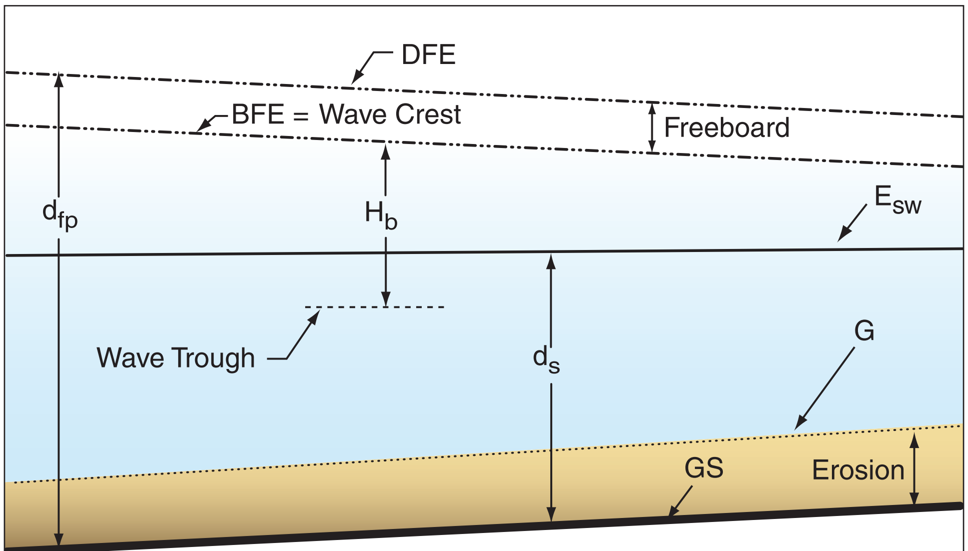
The design flood is defined by ASCE 7-02 as the greater of the following two flood events:

1. Base flood, affecting those areas identified as SFHAs on the community's FIRM, or
2. The flood corresponding to the area designated as a flood hazard area on a community's flood hazard map or otherwise legally designated.

The DFE is defined as the elevation of the design flood, including wave height and freeboard, relative to the datum specified on a community's flood hazard map. Figure 3-2 shows the parameters that determine or are affected by flood depth.

Figure 3-2.
Parameters that determine or are affected by flood depth

SOURCE: *COASTAL CONSTRUCTION MANUAL* (FEMA 55)



DFE = Design Flood Elevation in feet above datum

d_{fp} = Design flood protection depth in feet

BFE = Base Flood Elevation in feet above datum

Freeboard = Vertical distance in feet between BFE and DFE

H_b = Breaking wave height = $0.78d_s$ (note that 70 percent of wave height lies above E_{sw})

E_{sw} = Design stillwater flood elevation in feet above datum

d_s = Design stillwater flood depth in feet

G = Ground elevation, existing or pre-flood, in feet above datum

Erosion = Loss of soil during design flood event in feet (not including effects of localized scour)

GS = Lowest eroded ground elevation adjacent to building in feet above datum (including the effects of localized scour)

3.2.2 Design Stillwater Flood Depth (d_s)

Design stillwater flood depth (d_s) is the vertical distance between the eroded ground elevation and the stillwater flood elevation associated with the design flood. Determining the maximum design stillwater flood depth over the life of a building is the single most important flood load calculation that will be made; nearly all other coastal flood load parameters or calculations (e.g., hydrostatic load, design flood velocity, hydrodynamic load, design wave height, DFE, debris impact load, local scour depth) depend directly or indirectly on the design stillwater flood depth. The design stillwater flood depth (d_s) is defined as

$$d_s = E_{sw} - GS$$

Where

d_s = Design stillwater flood depth (ft)

E_{sw} = Design stillwater flood elevation (ft) above the datum (e.g., National Geodetic Vertical Datum [NGVD], North American Vertical Datum [NAVD]), including wave setup effects

GS = Lowest eroded ground elevation above datum (ft), adjacent to building, including the effects of localized sour around pilings

GS is not the lowest existing pre-flood ground surface; it is the lowest ground surface that will result from long-term erosion and the amount of erosion expected to occur during a design flood, excluding local scour effects. The process for determining GS is described in Chapter 7 of FEMA 55.

Values for E_{sw} are not shown on a FIRM, but they are given in the Flood Insurance Study (FIS) report, which is produced in conjunction with the FIRM for a community. FIS reports are usually available from community officials, from NFIP State Coordinating Agencies, and on the web at the FEMA Map Service Center (http://store.msc.fema.gov). Some states have FIS reports available on their individual web sites.

3.2.3 Design Wave Height (H_b)

The design wave height at a coastal building site will be one of the most important design parameters. Therefore, unless detailed analysis shows that natural or manmade obstructions will protect the site during a design event, wave heights at a site will be calculated from Equation 5-2 of ASCE 7-02 as the heights of depth-limited breaking waves (H_b), which are equivalent to 0.78 times the design stillwater flood depth:

$$H_b = 0.78d_s$$

Note: 70 percent of the breaking wave height ($0.7H_b$) lies above the stillwater flood level.

3.2.4 Design Flood Velocity (V)

Estimating design flood velocities in coastal flood hazard areas is subject to considerable uncertainty. Little reliable historical information exists concerning the velocity of floodwaters during coastal flood events. The direction and velocity of floodwaters can vary significantly throughout a coastal flood event, approaching a site from one direction during the beginning of the flood event before shifting to another (or several directions). Floodwaters can inundate some low-lying coastal sites from both the front (e.g., ocean) and the back (e.g., bay, sound, river). In a similar manner, flow velocities can vary from close to zero to high velocities during a single flood event. For these reasons, flood velocities should be estimated conservatively by assuming that floodwaters can approach from the most critical direction and that flow velocities can be high.

For design purposes, the *Commentary* of ASCE7-02 suggested a range of flood velocities from:

$V = d_s \div t$ (expected lower bound)

to

$V = (gd_s)^{0.5}$ (expected upper bound)

Where

d_s = Design stillwater flood depth

t = Time (1 second)

g = Gravitational constant (32.2 ft/sec^2)

Factors that should be considered before selecting the upper- or lower-bound flood velocity for design include:

- Flood zone
- Topography and slope
- Distance from the source of flooding
- Proximity to other buildings or obstructions

The upper bound should be taken as the design flood velocity if the building site is near the flood source, in a V Zone, in an AO Zone adjacent to a V Zone, in an A Zone subject to velocity flow and wave action, steeply sloping, or adjacent to other buildings or obstructions that will confine floodwaters and accelerate flood velocities. The lower bound is a more appropriate design flood velocity if the site is distant from the flood source, in an A Zone, flat or gently sloping, or unaffected by other buildings or obstructions.

3.3 Hydrostatic Loads

Hydrostatic loads occur when standing or slowly moving water comes into contact with a building or building component. These loads can act laterally (pressure) or vertically (buoyancy).

Lateral hydrostatic forces are generally not sufficient to cause deflection or displacement of a building or building component unless there is a substantial difference in water elevation on opposite sides of the building or component; therefore, the NFIP requires that floodwater openings be provided in vertical walls that form an enclosed space below the BFE for a building in an A Zone.

Lateral hydrostatic force is calculated by the following:

$$f_{stat} = \frac{1}{2} \gamma d_s^2$$

Where

f_{stat} = Hydrostatic force per unit width (lb/ft) resulting from flooding against vertical element

γ = Specific weight of water (62.4 lb/ft^3 for freshwater and 64 lb/ft^3 for saltwater)

Vertical hydrostatic forces during design flood conditions are not generally a concern for properly constructed and elevated coastal buildings. Buoyant or flotation forces on a building can be of concern if the actual stillwater flood depth exceeds the design stillwater flood depth.

Vertical (buoyancy) hydrostatic force is calculated by the following:

$$F_{Buoy} = \gamma \text{ (Vol)}$$

Where

F_{Buoy} = vertical hydrostatic force (lb) resulting from the displacement of a given volume of floodwater

Vol = volume of floodwater displaced by a submerged object (ft^3) = displaced area x depth of flooding

Buoyant force acting on an object must be resisted by the weight of the object and any other opposing force (e.g., anchorage forces) resisting flotation. In the case of a building, the live load on floors should not be counted on to resist buoyant forces.

3.4 Wave Loads

Calculating wave loads requires information about expected wave heights. For the purposes of this manual, the calculations will be limited by water depths at the site of interest. Wave forces can be separated into four categories:

- Non-breaking waves (can usually be computed as hydrostatic forces against walls and hydrodynamic forces against piles)
- Breaking waves (short duration but large magnitude forces against walls and piles)
- Broken waves (similar to hydrodynamic forces caused by flowing or surging water)
- Uplift (often caused by wave runup, deflection, or peaking against the underside of horizontal surfaces)

Of these four categories, the forces from breaking waves are the largest and produce the most severe loads. Therefore, it is strongly recommended that the breaking wave load be used as the design wave load.

Two breaking wave loading conditions are of interest in residential construction: waves breaking on small-diameter vertical elements below the DFE (e.g., piles, columns in the foundation of a building in a V Zone) and waves breaking against vertical walls below the DFE (e.g., solid foundation walls in A Zones, breakaway walls in V Zones).

3.4.1 Breaking Wave Loads on Vertical Piles

The breaking wave load (F_{brkp}) on a pile can be assumed to act at the stillwater flood level and is calculated by Equation 5-4 from ASCE 7-02:

$$F_{brkp} = (1/2)CD\gamma DH_b^2$$

Where

F_{brkp} = Net wave force (lb)

CD = Coefficient of drag for breaking waves = 1.75 for round piles or column, and 2.25 for square piles or columns

γ = Specific weight of water (lb/ft^3)

D = Pile or column diameter (ft) for circular section. For a square pile or column, 1.4 times the width of the pile or column (ft).

H_b = Breaking wave height (ft)

3.4.2 Breaking Wave Loads on Vertical Walls

The net force resulting from a normally incident breaking wave (depth limited in size, with $H_b = 0.78d_s$) acting on a rigid vertical wall, can be calculated by Equation 5-6 from ASCE 7-02:

$$F_{brkw} = 1.1C_p\gamma d_s^2 + 2.4\gamma d_s^2$$

Where

F_{brkw} = net breaking wave force per unit length of structure (lb/ft) acting near the stillwater flood elevation

C_p = Dynamic pressure coefficient ($1.6 < C_p < 3.5$) (see Table 3-1)

Table 3-1. Building Category and Corresponding Dynamic Pressure Coefficient (C_p)

Building Category	C_p
I – Buildings and other structures that represent a low hazard to human life in the event of a failure	1.6
II – Buildings not in Category I, III, and IV	2.8
III – Buildings and other structures that represent a substantial hazard to human life in the event of a failure	3.2
IV – Buildings and other structures designated as essential facilities	3.5

SOURCE: ASCE 7-02

γ = Specific weight of water (lb/ft^3)

d_s = Design stillwater flood depth (ft) at base of building where the wave breaks

This formula assumes the following:

- The vertical wall causes a reflected or standing wave against the seaward side of the wall with the crest of the wave, reaching a height of $1.2d_s$ above the design stillwater flood elevation, and
- The space behind the vertical wall is dry, with no fluid balancing the static component of the wave force on the outside of the wall (see Figure 3-3).

If free-standing water exists behind the wall (see Figure 3-4), a portion of the hydrostatic component of the wave pressure and force disappears and the net force can be computed using Equation 5-7 from ASCE 7-02:

$$F_{brkw} = 1.1C_p\gamma d_s^2 + 1.9\gamma d_s^2$$

Post-storm damage inspections show that breaking wave loads have destroyed virtually all wood-frame or unreinforced masonry walls below the wave crest elevation; only highly engineered, massive structural elements are capable of withstanding breaking wave loads. Damaging wave pressures and loads can be generated by waves much lower than the 3-foot wave currently used by FEMA to distinguish between A Zones and V Zones.

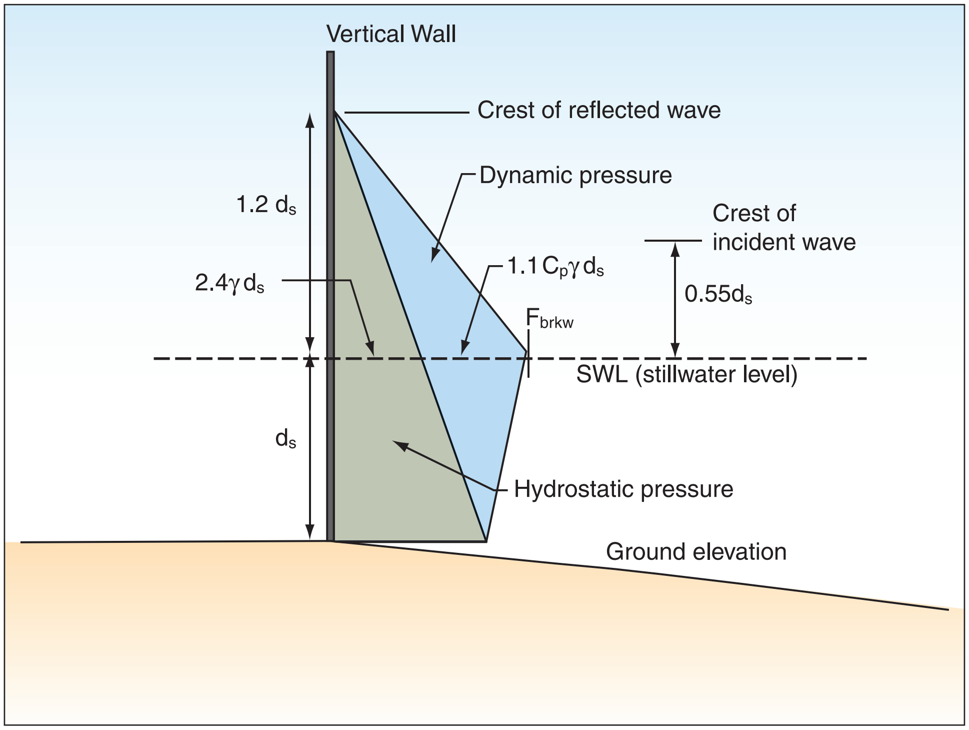


Figure 3-3. Normally incident breaking wave pressures against a vertical wall (space behind vertical wall is dry)

SOURCE: ASCE 7-02

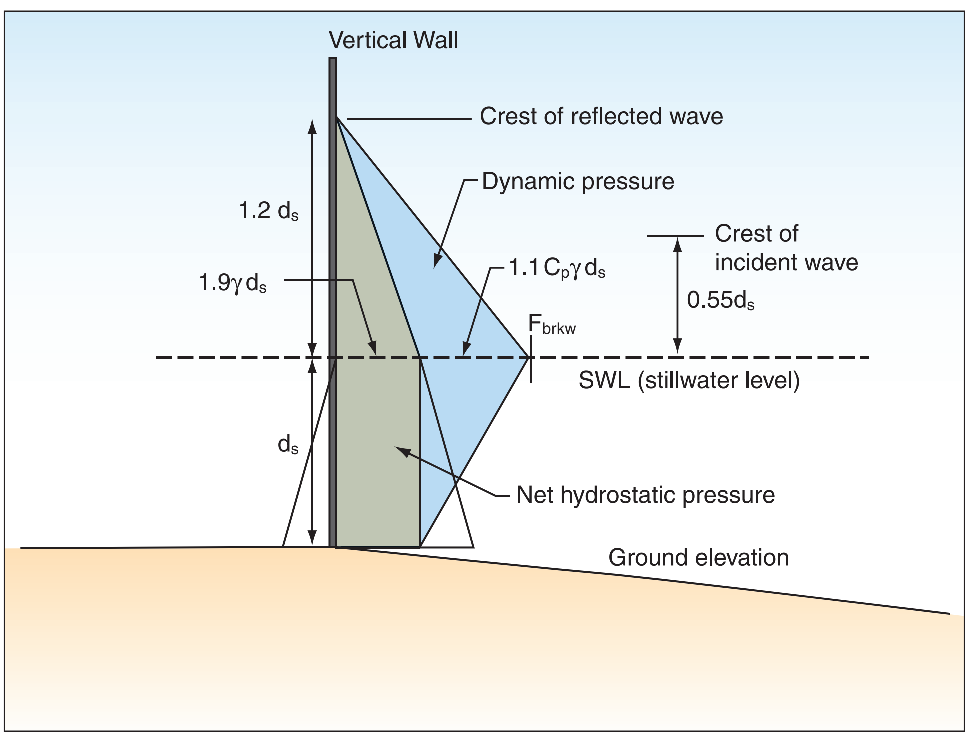


Figure 3-4. Normally incident breaking wave pressures against a vertical wall (stillwater level equal on both sides of wall)

SOURCE: ASCE 7-02

3.5 Hydrodynamic Loads

Water flowing around a building (or a structural element or other object) imposes additional loads on the building. The loads (which are a function of flow velocity and structural geometry) include frontal impact on the upstream face, drag along the sides, and suction on the downstream side. This manual assumes that the velocity of the floodwaters is constant (i.e., steady state flow).

One of the most difficult steps in quantifying loads imposed by moving water is determining the expected flood velocity. Refer to Section 3.2.4 for guidance concerning design flood velocities.

The following equation from FEMA 55 can be used to calculate the hydrodynamic load from flows with velocity greater than 10 ft/sec:

$$F_{dyn} = \tfrac{1}{2} C_d \rho V^2 A$$

Where

F_{dyn} = Hydrodynamic force (lb) acting at the stillwater mid-depth (halfway between the stillwater elevation and the eroded ground surface)

C_d = Drag coefficient (recommended values are 2.0 for square or rectangular piles and 1.2 for round piles)

ρ = Mass density of fluid (1.94 slugs/ft^3 for freshwater and 1.99 slugs/ft^3 for saltwater)

V = Velocity of water (ft/sec)

A = Surface area of obstruction normal to flow (ft^2)

Note that the use of this formula will provide the total force against a building of a given impacted surface area (A). Dividing the total force by either length or width would yield a force per unit length; dividing by "A" would yield a force per unit area.

The drag coefficient used in the previously stated equations is a function of the shape of the object around which flow is directed. If the object is something other than a round, square, or rectangular pile, the drag coefficient can be determined using Table 3-2.

Table 3-2. Drag Coefficient Based on Width to Depth Ratio

Width to Depth Ratio (w/d_s or w/h)	Drag Coefficient (C_d)
1 to 12	1.25
13 to 20	1.30
21 to 32	1.40
33 to 40	1.50
41 to 80	1.75
81 to 120	1.80
>120	2.00

Note: “h” refers to the height of an object completely immersed in water.

SOURCE: FEMA 55

Flow around a building or building component will also create flow-perpendicular forces (lift forces). If the building component is rigid, lift forces can be assumed to be small. But if the building component is not rigid, lift forces can be greater than drag forces. The formula for lift force is similar to the formula for hydrodynamic force except that the drag coefficient (C_d) is replaced with the lift coefficient (C_l). For the purposes of this manual, the foundations of coastal residential buildings can be considered rigid, and hydrodynamic lift forces can therefore be ignored.

3.6 Debris Impact Loads

Debris or impact loads are imposed on a building by objects carried by moving water. The magnitude of these loads is very difficult to predict, yet some reasonable allowance must be made for them. The loads are influenced by where the building is located in the potential debris stream:

- Immediately adjacent to or downstream from another building
- Downstream from large flotable objects (e.g., exposed or minimally covered storage tanks)
- Among closely spaced buildings

The following equation to calculate the magnitude of impact load is provided in the *Commentary* of ASCE 7-02:

$$F_i = (\pi W V C_i C_o C_D C_B R_{max}) \div (2g\Delta t)$$

Where

F_i = Impact force acting at the stillwater level (lb)

π = 3.14

W = Weight of debris (lb), suggest using 1,000 if no site-specific information is available

V = Velocity of object (assume equal to velocity of water) (ft/sec)

C_i = Importance coefficient (see Table C5.3 of ASCE 7-02)

C_o = Orientation coefficient = 0.8

C_D = Depth coefficient (see Table C5.5 and Figure C5-3 of ASCE 7-02)

C_B = Blockage coefficient (see Table C5.5 and Figure 5-4 of ASCE 7-02)

R_{max}= Maximum response ratio for impulsive load (see Table C5.6 of ASCE 7-02)

g = Gravitational constant (32.2 ft/sec^2)

Δt = Duration of impact (sec)

When the C coefficients and R_{max} are set to 1.0, the above equation reduces to

$$F_i = (\pi W V) \div (2g\Delta t)$$

This equation is very similar to the equation provided in ASCE 7-98 and FEMA 55. The only difference is the $\pi/2$ term, which results from the half-sine form of the impulse load.

The following uncertainties must be quantified before the impact of debris loading on the building can be determined using the above equation:

- Size, shape, and weight (W) of the waterborne object
- Flood velocity (V)
- Velocity of the object compared to the flood velocity
- Portion of the building that will be struck and most vulnerable to collapsing
- Duration of the impact (t)

Once floodborne debris impact loads have been quantified, decisions must be made on how to apply them to the foundation and how to design foundation elements to resist them. For open foundations, the *Coastal Construction Manual* (FEMA 55) advises applying impact loading to a corner or critical column or piling concurrently with other flood loads (see *Coastal Construction Manual*, Table 11-6). For closed foundations (which are not recommended in Coastal A Zones and are not allowed in V Zones), the *Coastal Construction Manual* advises that the designer assume that one corner of the foundation will be destroyed by debris and recommends the foundation and the structure above be designed to contain redundancy to allow load redistribution to prevent collapse or localized failure. The following should be considered in determining debris impact loads:

Size, shape, and weight of the debris. It is recommended that, in the absence of information about the nature of the potential debris, a weight of 1,000 pounds be used for the debris weight (W). Objects of this weight could include portions of damaged buildings, utility poles, portions of previously embedded piles, and empty storage tanks.

Debris velocity. Flood velocity can be approximated by one of the equations discussed in Section 3.2.4. For the calculation of debris loads, the velocity of the waterborne object is assumed to be the same as the flood velocity. Note that, although this assumption may be accurate for small objects, it will overstate debris velocities for large objects (e.g., trees, logs, pier pilings). The *Commentary* of ASCE 7-02 provides guidance on estimating debris velocities for large debris.

Portion of building to be struck. The object is assumed to be at or near the water surface level when it strikes the building. Therefore, the object is assumed to strike the building at the stillwater flood level.

Duration of impact. Uncertainty about the duration of impact (Δt) (the time from initial impact, through the maximum deflection caused by the impact, to the time the object leaves) is the most likely cause of error in the calculation of debris impact loads. ASCE 7-02 showed that measured impact duration (from initial impact to time of maximum force) from laboratory tests varied from 0.01 to 0.05 second. The ASCE 7-02 recommended value for Δt is 0.03 second.

NOTE: The method for determining debris impact loads in ASCE 7-02 was developed for riverine impact loads and has not been evaluated for coastal debris that may impact a building over several wave cycles. Although these impact loads are very large but of short duration, a structural engineer should be consulted to determine the structural response to the short load duration (0.03 second recommended).

3.7 Localized Scour

Waves and currents during coastal flood conditions are capable of creating turbulence around foundation elements and causing localized scour. Determining potential scour is critical in designing coastal foundations to ensure that failure during and after flooding does not occur as a result of the loss in either bearing capacity or anchoring resistance around the posts, piles, piers, columns, footings, or walls. Localized scour determinations will require knowledge of the flood depth, flow conditions, soil characteristics, and foundation type.

In some locations, soil at or below the ground surface can be resistant to localized scour, and scour depths calculated below will be excessive. In instances where the designer believes the soil at a site will be scour-resistant, a geotechnical engineer should be consulted before calculated scour depths are reduced.

3.7.1 Localized Scour Around Vertical Piles

The methods for calculating localized scour (S_{max}) in coastal areas have been largely based on empirical evidence gathered after storms. Much of the evidence gathered suggests that localized scour depths around piles and other thin vertical members are approximately equal to 1.0 to 1.5 times the pile diameter. Figure 3-5 illustrates localized scour at a pile, with and without a scour-resistant terminating stratum. Currently, there is no design guidance in ASCE 7-02 on how to calculate scour. Localized scour around a vertical pile or similar foundation element should be calculated with the following formula as given in FEMA 55:

$$S_{max} = 2.0a$$

Where

S_{max} = Maximum localized scour depth (ft)

a = Diameter of a round foundation element or the maximum diagonal cross-section dimension for a rectangular element (ft)

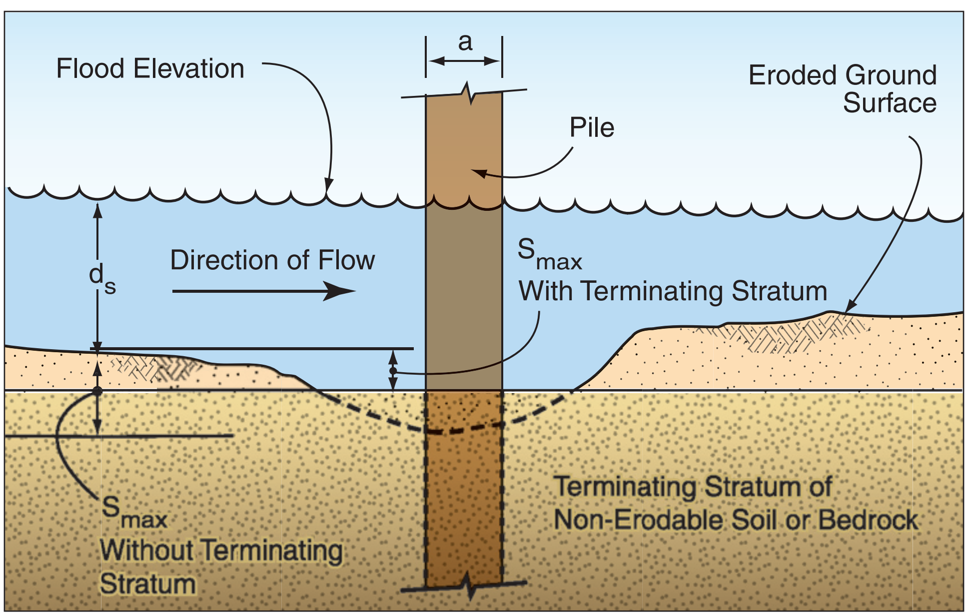


Figure 3-5. Scour at vertical foundation member stopped by underlying scour-resistant stratum

SOURCE: *COASTAL CONSTRUCTION MANUAL* (FEMA 55)

3.7.2 Localized Scour Around Vertical Walls and Enclosures

Localized scour around vertical walls and enclosed areas (e.g., typical A Zone construction) can be greater than that around vertical piles, and should be estimated using Table 3-3.

Table 3-3. Local Scour Depth as a Function of Soil Type

Soil Type	Expected Depth (% of d_s)
Loose sand	80
Dense sand	50
Soft silt	50
Stiff silt	25
Soft clay	25
Stiff clay	10

SOURCE: FEMA 55

3.8 Flood Load Combinations

Load combinations (including those for flood loads) are given in ASCE 7-02, Sections 2.3.2 and 2.3.3 for strength design and Sections 2.4.1 and 2.4.2 for allowable stress design.

The basic load combinations are:

Allowable Stress Design

(1) $D + F$

(2) $D + H + F + L + T$

(3) $D + H + F + (L_r \text{ or } S \text{ or } R)$

(4) $D + H + F + 0.75(L + T) + 0.75(L_r \text{ or } S \text{ or } R)$

(5) $D + H + F + (W \text{ or } 0.7E)$

(6) $D + H + F + 0.75(W \text{ or } 0.7E) + 0.75L + 1.5F_a + 0.75(L_r \text{ or } S \text{ or } R)$

(7) $0.6D + W + H$

(8) $0.6D + 0.7E + H$

Strength Design

(1) $1.4(D + F)$

(2) $1.2(D + F + T) + 1.6(L + H) + 0.5(L_r \text{ or } S \text{ or } R)$

(3) $1.2D + 1.6(L_r \text{ or } S \text{ or } R) + (L \text{ or } 0.8W)$

(4) $1.2D + 1.6W + L + 0.5(L_r \text{ or } S \text{ or } R)$

(5) $1.2D + 1.0E + L + 0.2S$

(6) $0.9D + 1.6W + 1.6H$

(7) $0.9D + 1.0E + 1.6H$

For structures located in V or Coastal A Zones:

Allowable Stress Design

Load combinations 5, 6, and 7 shall be replaced with the following:

(5) $D + H + F + 1.5F_a + W$

(6) $D + H + F + 0.75W + 0.75L + 1.5F_a + 0.75(L_r \text{ or } S \text{ or } R)$

(7) $0.6D + W + H + 1.5F_a$

Strength Design

Load combinations 4 and 6 given in ASCE 7-02 Section 2.3.1 shall be replaced with the following:

(4) $1.2D + 1.6W + 2.0F_a + L + 0.5(L_r \text{ or } S \text{ or } R)$

(6) $0.9D + 1.6W + 2.0\ F_a + 1.6H$

Where

D = Dead Load

W = Wind Load

E = Earthquake Load

F_a = Flood Load

F = Load due to fluids with well defined pressures and maximum heights

L = Live Load

L_r = Roof Live Load

S = Snow Load

R = Rain Load

H = Lateral Earth Pressure

Flood loads were included in the load combinations to account for the strong correlation between flood and winds in hurricane-prone regions that run along the Gulf of Mexico and the Atlantic Coast.

In non-Coastal A Zones, for Allowable Stress Design, replace the $1.5F_a$ with $0.75F_a$ in load combinations 5, 6, and 7 given above. For Strength Design, replace coefficients W and F_a in equations 4 and 6 above with 0.8 and 1.0, respectively.

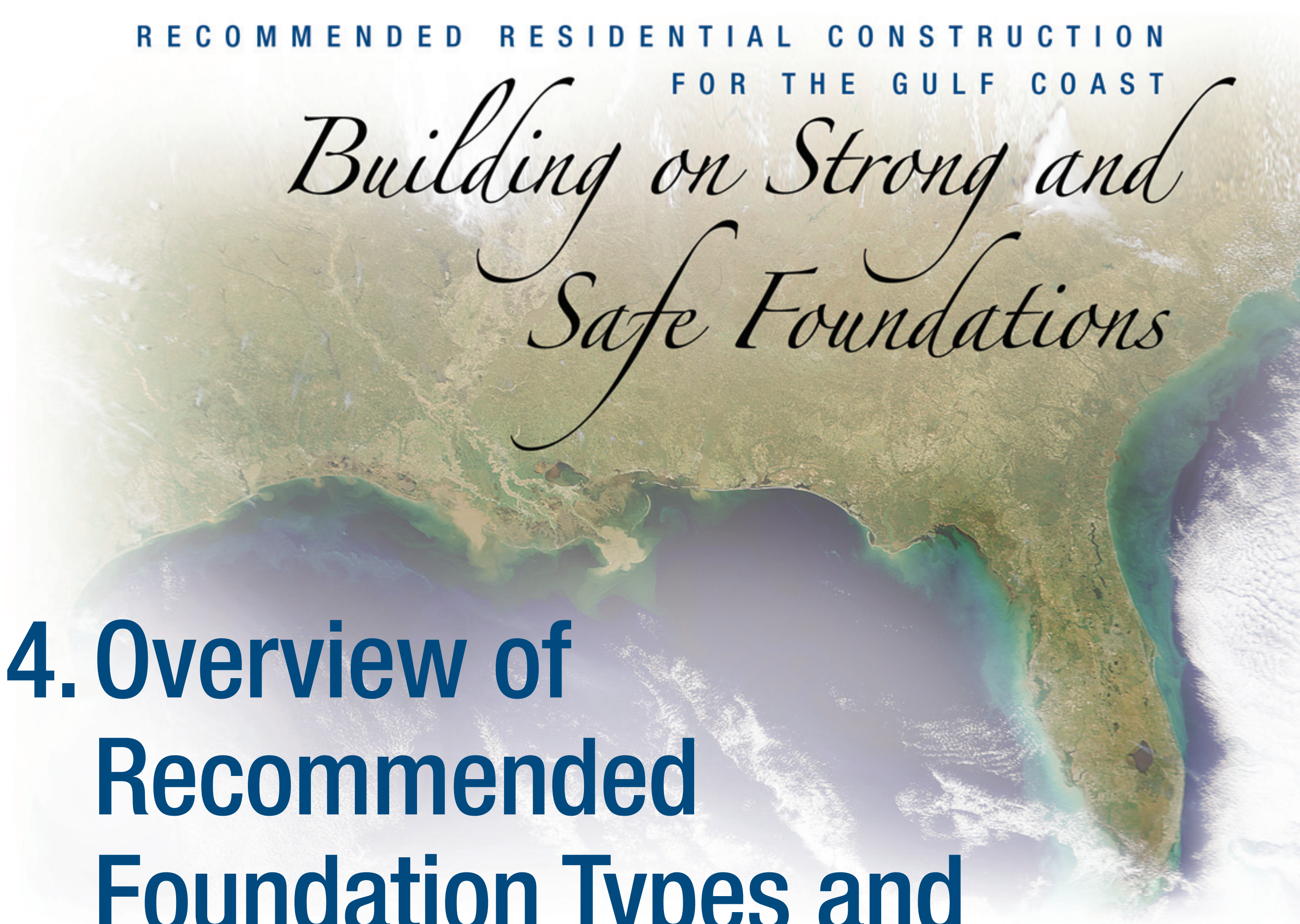
Designers should be aware that not all of the flood loads will act at certain locations or against certain building types. Table 3-4 provides guidance to designers for the calculation of appropriate flood loads in V Zones and Coastal A Zones (non-Coastal A Zone flood load combinations are shown for comparison).

The floodplain management regulations enacted by communities that participate in the NFIP prohibit the construction of solid perimeter wall foundations in V Zones, but allow such foundations in A Zones. Therefore, the designer should assume that breaking waves will impact piles in V Zones and walls in A Zones. It is generally unrealistic to assume that impact loads will occur on all piles at the same time as breaking wave loads; therefore, this manual recommends that impact loads be evaluated for strategic locations such as a building corner.

Table 3-4. Selection of Flood Load Combinations for Design

Case 1	**Pile or Open Foundation in V Zone (Required)**
	F_{brkp} (on all piles) + F_i (on one corner or critical pile only) or F_{brkp} (on front row of piles only) + F_{dyn} (on all piles but front row) +F_i (on one corner or critical pile only)
Case 2	**Pile or Open Foundation in Coastal Z Zone (Recommended)**
	F_{brkp} (on all piles) + F_i (on one corner or critical pile only) or F_{brkp} (on front row of piles only) + F_{dyn} (on all piles but front row) +F_i (on one corner or critical pile only)
Case 3	**Solid (Wall) Foundation in Coastal A Zone (NOT Recommended)**
	F_{brkp} (on walls facing shoreline, including hydrostatic component) + $F_{dyn;}$ assume one corner is destroyed by debris, and design in redundancy
Case 4	**Solid (Wall) Foundation in Non-Coastal A Zone (Shown for Comparison)**
	$F_{sta} + F_{dyn}$

SOURCE: *COASTAL CONSTRUCTION MANUAL* (FEMA 55)



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.

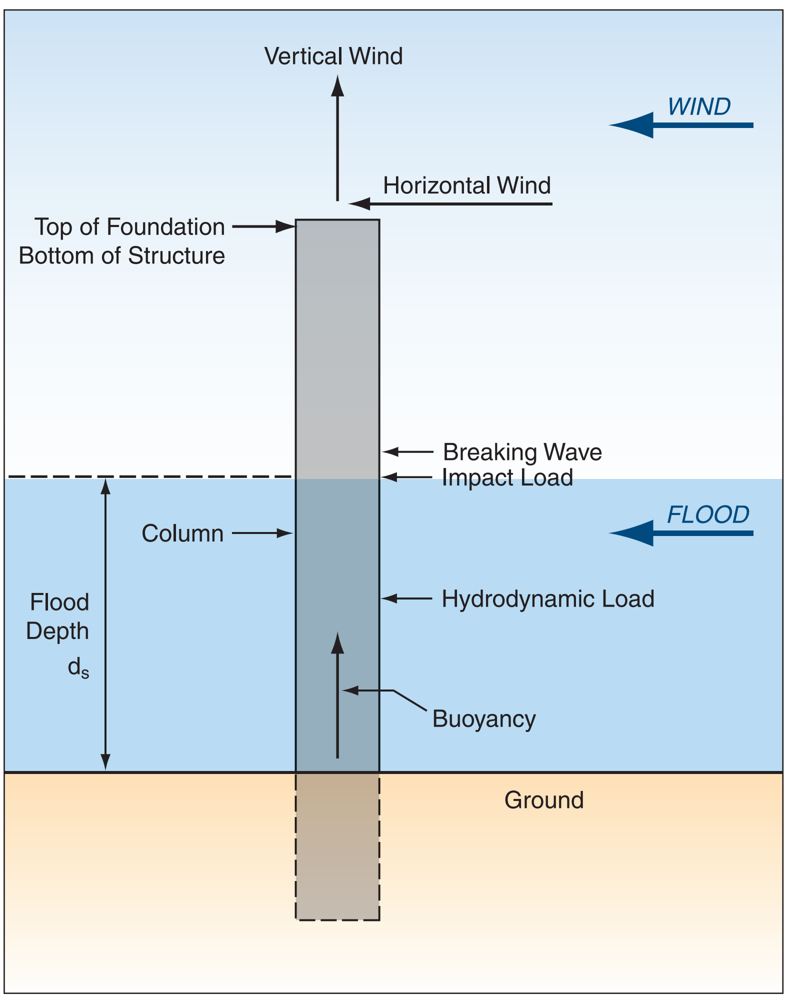


Figure 4-1.
Design loads acting on a column

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.

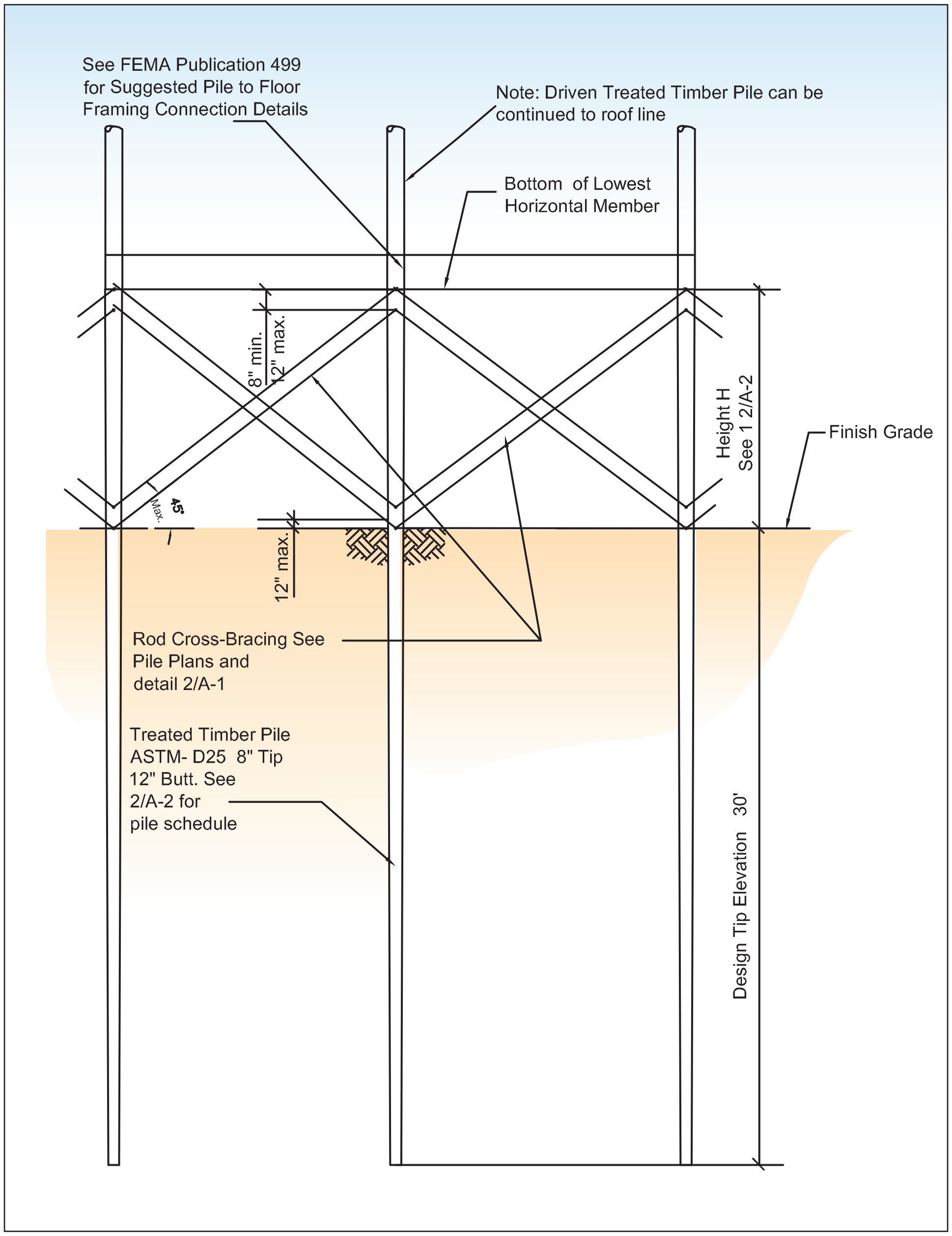


Figure 4-2.
Profile of Case A foundation type (see Appendix A for additional drawings)

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.

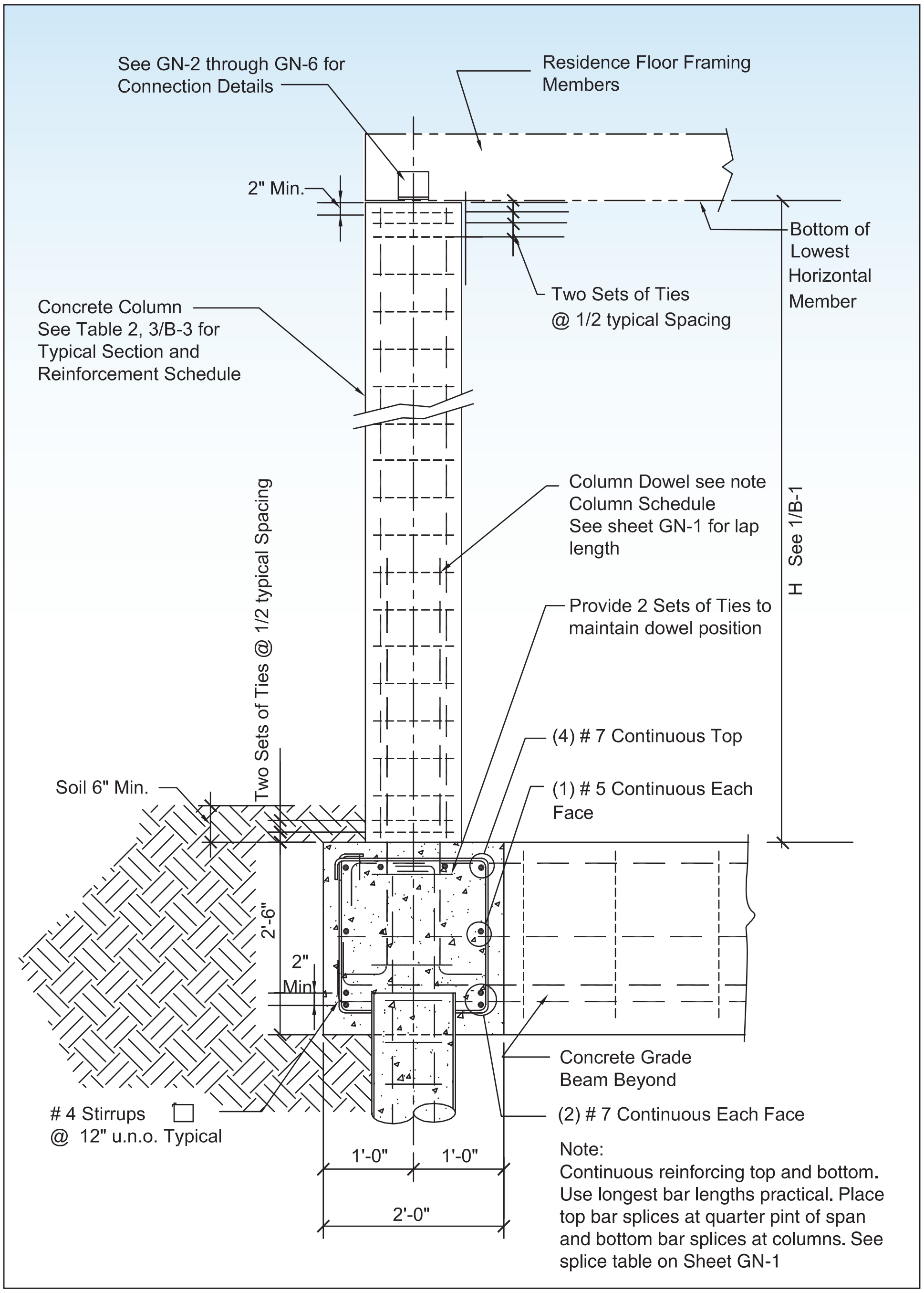


Figure 4-3. Profile of Case B foundation type (see Appendix A for additional drawings)

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.

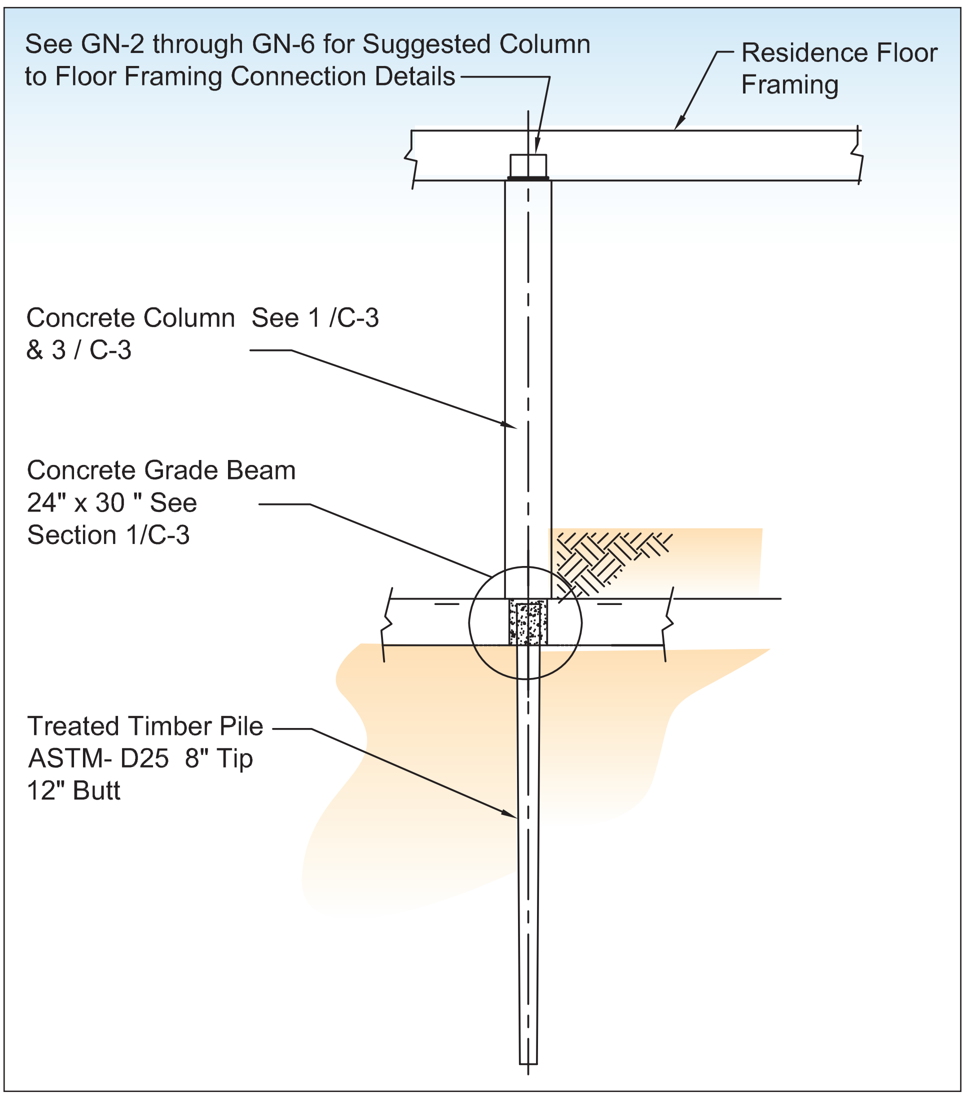


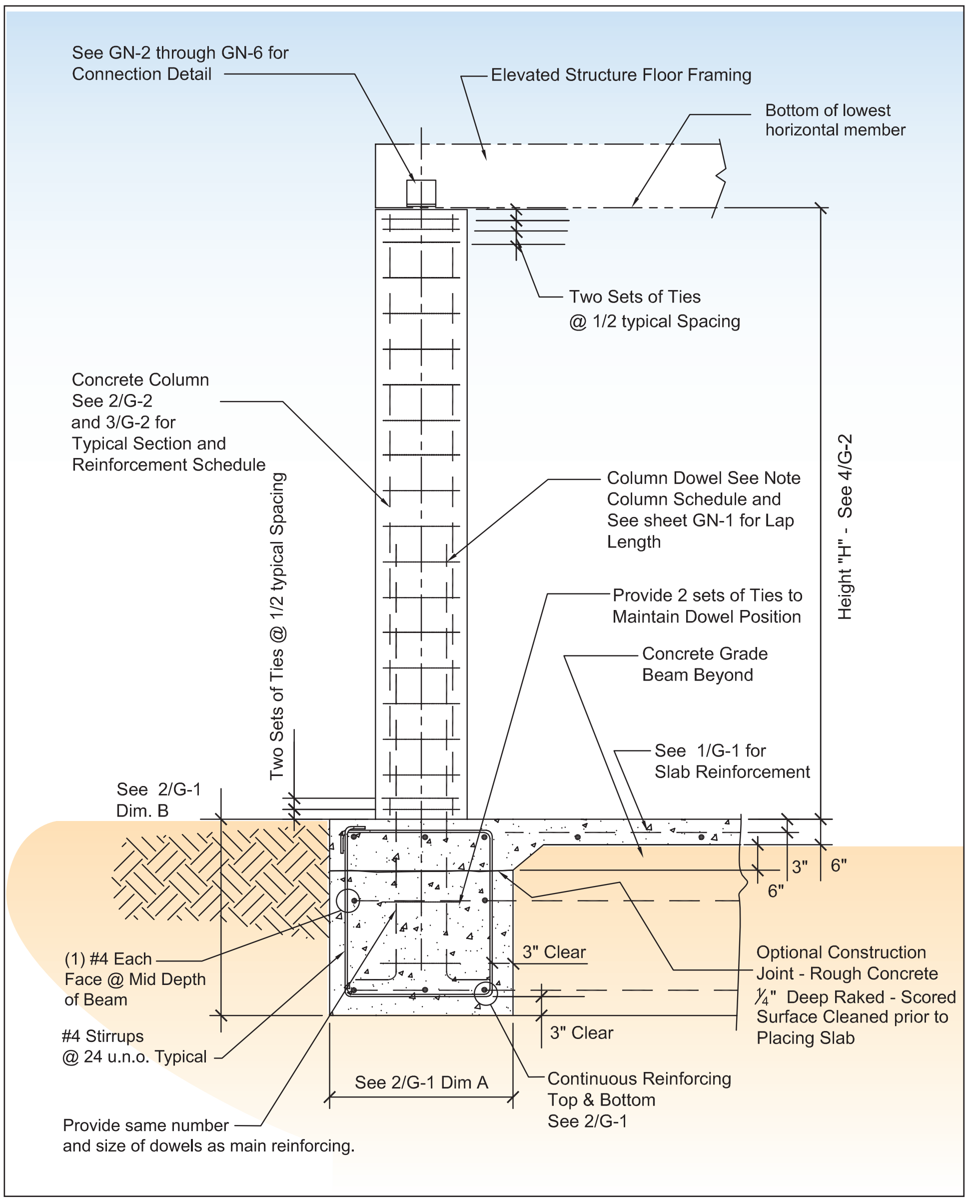
Figure 4-4. Profile of Case C foundation type (see Appendix A for additional drawings)

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)



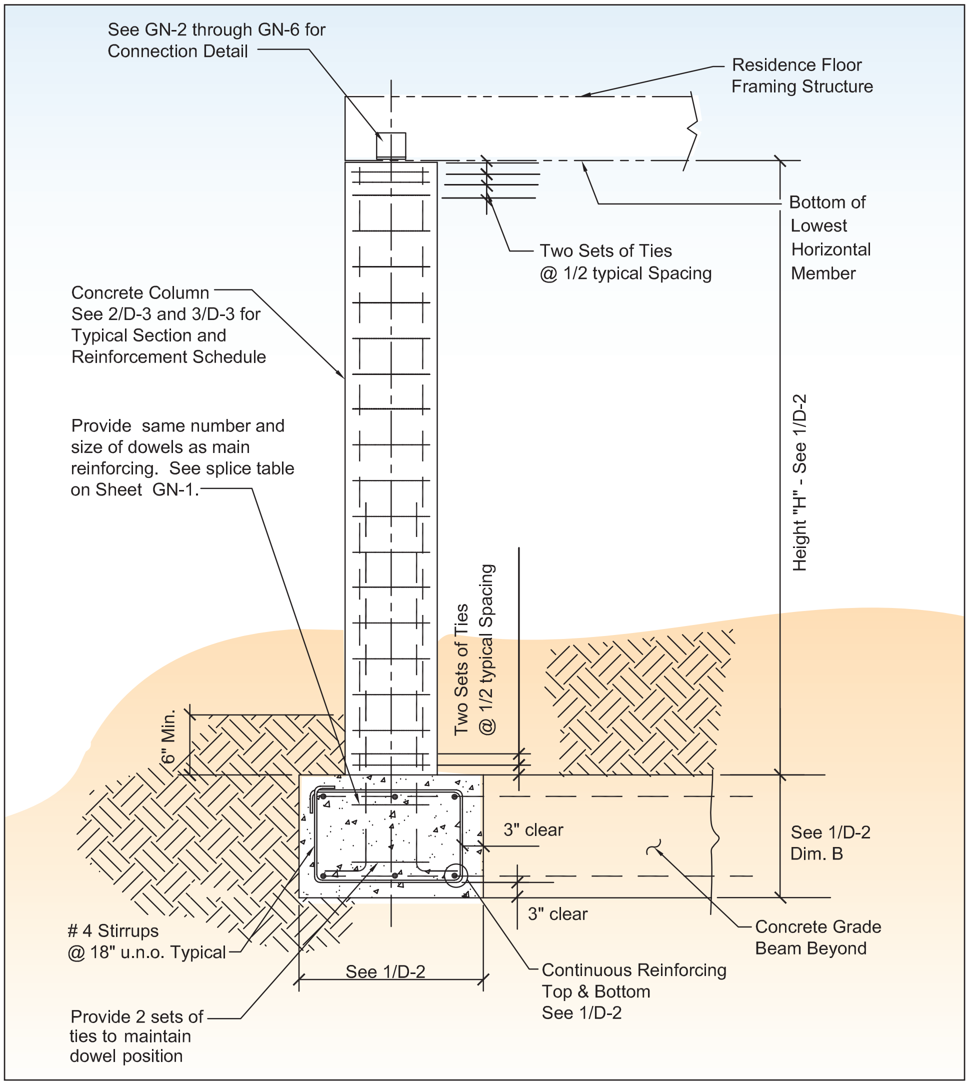


Figure 4-6. Profile of Case D foundation type (see Appendix A for additional drawings)

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.

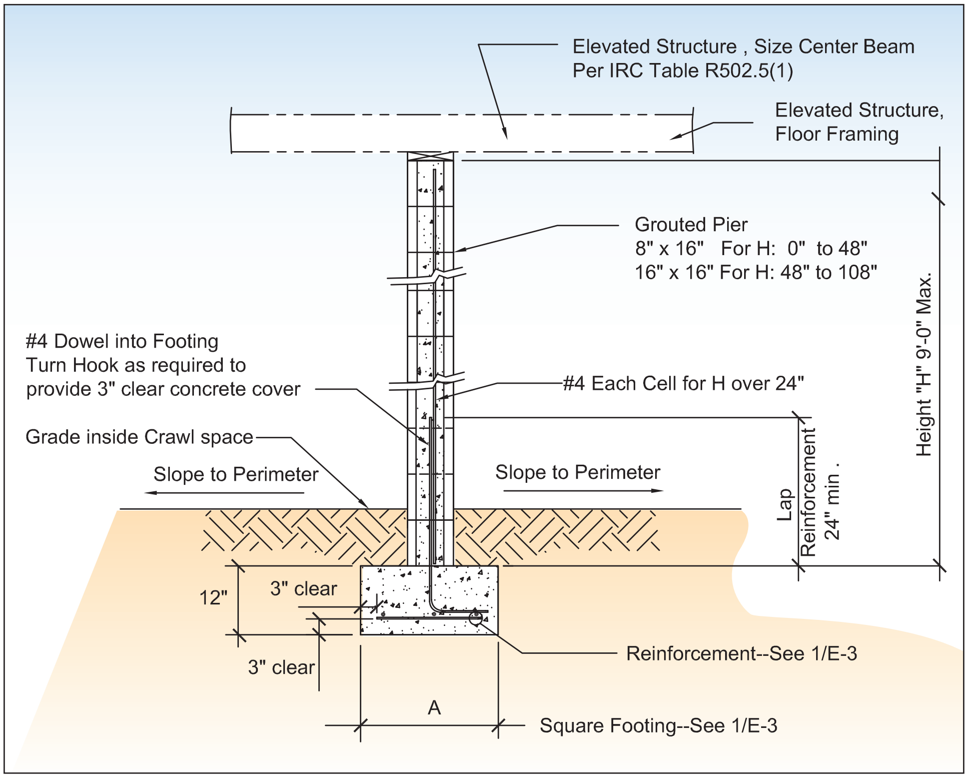


Figure 4-7.
Profile of Case E foundation type (see Appendix A for additional drawings)

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.

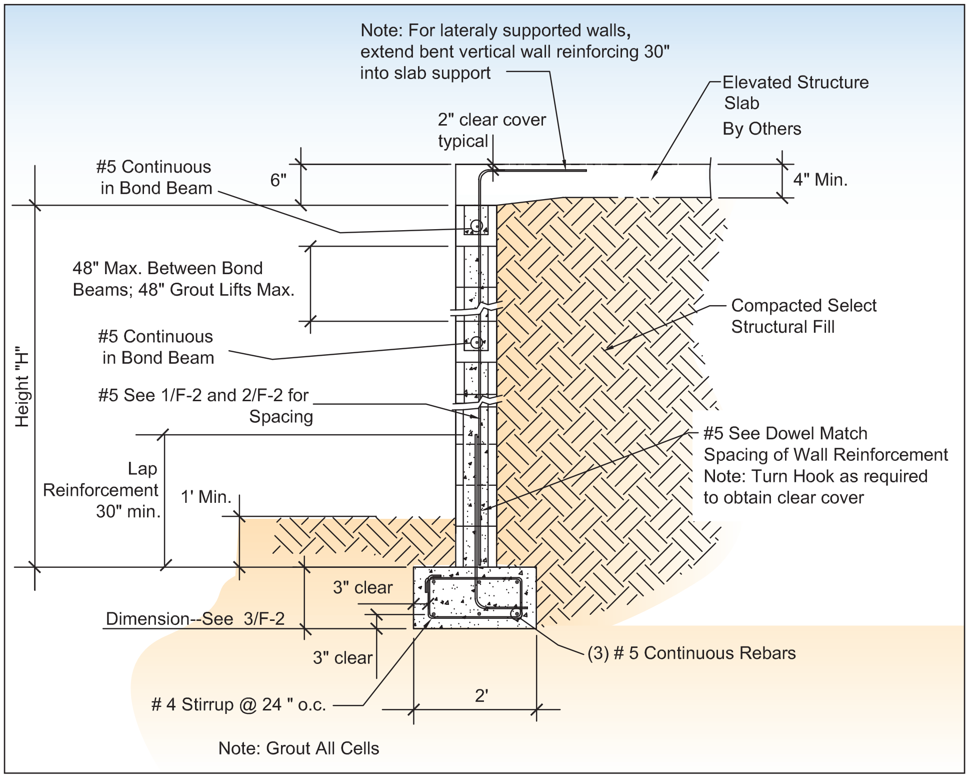


Figure 4-8. Profile of Case F foundation type (see Appendix A for additional drawings)

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.

RECOMMENDED RESIDENTIAL CONSTRUCTION FOR THE GULF COAST

5. Foundation Selection

This chapter presents foundation designs, along with the use of the drawings in Appendix A, to assist the homebuilder, contractor, and local engineering professional in developing a safe and strong foundation. Foundation design types, foundation design considerations, cost estimating, and how to use this manual are discussed.

5.1 Foundation Design Types

The homebuilder, contractor, and local engineering professional can utilize the designs in this chapter and Appendix A to construct residential foundations in the Gulf Coast. The selection of appropriate foundation designs for the construction of residences is dependent upon the coastal zone, wind speed, and elevation requirements, all of which have been discussed in the previous chapters. The following types of foundation designs are presented in this manual:

Open Foundations

- Timber pile
- Steel pipe pile with concrete column and grade beam
- Timber pile with concrete column and grade beam
- Concrete column and grade beam
- Concrete column and grade beam with slab

Closed Foundations

- Reinforced masonry – crawlspace
- Reinforced masonry – stem wall

Each of these foundation types designed for the Gulf Coast region have advantages and disadvantages that must be taken into account. Modifications to the details and drawings might be needed to incorporate specific house footprints, elevation heights, and wind speeds to a given foundation type. Consultation with a licensed professional engineer is encouraged prior to beginning construction.

The foundation designs and materials specified in this document are based on principles and practices used by structural engineering professionals with years of coastal construction experience. This manual has been prepared to make the information easy to understand.

Guidance on the use of the foundation designs recommended in this manual is provided in Appendix B. Examples of how the foundation designs in this manual can be used with some of the houses in the publication *A Pattern Book for Gulf Coast Neighborhoods* are presented in Appendix B. Design drawings for each of the foundation types are presented in Appendix A, and any assumptions used in these designs are in Appendix C.

5.2 Foundation Design Considerations

The foundation designs proposed are suitable for homes whose dimensions, weights, and roof pitches are within certain ranges of values. A licensed professional engineer should confirm the appropriateness of the foundation design of homes whose dimensions, weights, or roof pitches fall outside of those defined ranges.

Most of the foundation designs are based on a 14-foot wide (maximum) by 24-foot deep (minimum) "module" (see Figure 5-1). From this basic building block, foundations for specific homes can be developed. For example, if a 30-foot deep by 42-foot wide home is to be constructed, the foundation can be designed around three 14-foot wide by 30-foot deep sections. If a 24-foot deep by 50-foot wide home is desired, four 12.5-foot wide by 24-foot deep sections can be used. If a 22-foot deep home is desired, the foundation designs presented here should only be used after a licensed professional engineer determines that they are appropriate since the shallow depth of the building falls outside the range of assumptions used in the design.

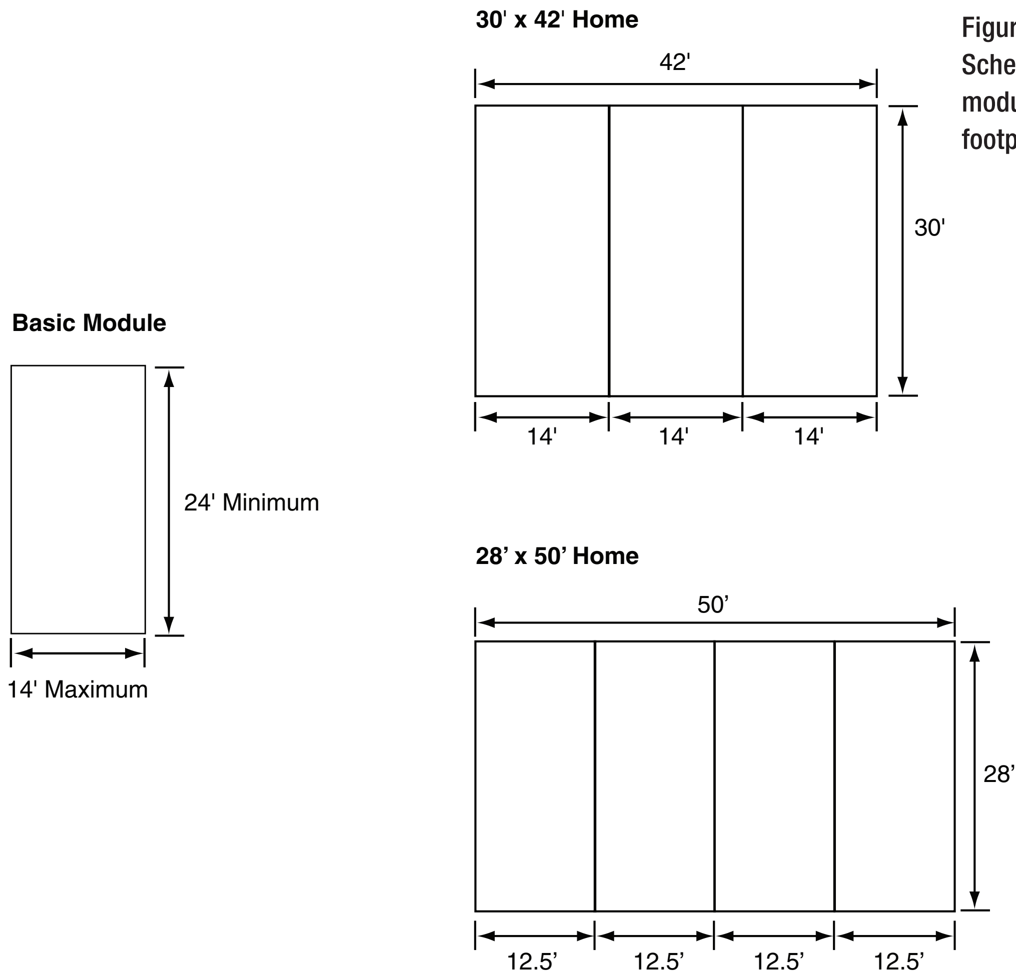


Figure 5-1.
Schematic of a basic module and two footprints

The licensed professional engineer should also consider the following:

- **Local soil conditions.** The piling foundations have been developed for relatively soft subsurface soils. Presumptive gravity loading values of 8 tons per pile, uplift loads of 4 tons per pile, and lateral loads of 1 ton per pile were used in these designs. Soil testing on the site may determine that fewer piles are needed to support the home, and the reduced cost of driving fewer piles could justify the cost of soils testing and redesign. Soils test should also be considered to validate the assumptions made.
- **Building weight.** The foundations have been designed to resist uplift forces resulting from a relatively light structure. If the actual home is heavier (e.g., from the use of concrete composite siding or steel framing), it may be cost-effective to reanalyze and redesign the footings. This is particularly true for a home that doesn't need to be elevated more than several feet or has short foundation walls that can help resist uplift.

- **Footprint complexity.** By necessity, the foundations have been designed for relatively simple rectangular footprints. If the actual footprint of the home is relatively complex, the engineer may need to consider torsional wind loading, differential movement among the "modules" that make up the house, concentrated loading in the home's floor and roof diaphragms, and shear wall placement.

5.3 Cost Estimating

Cost information that the homebuilders can use to estimate the cost of installing the foundation systems proposed in this manual are presented in Appendix E. These cost estimates are from information provided by local contractors and are based on May 2006 prices.

5.4 How to Use This Manual

The rest of this chapter is designed to provide the user with step by step procedures for the information provided in this document.

1. Determine location of the dwelling on a general map. Identify the location relative to key features such as highways and bodies of water. An accurate location is essential for using flood and wind speed maps in subsequent steps of the design process.

2. Determine location of dwelling on the appropriate FIRM

- Determine the flood insurance risk zone from the FIRM (Select V Zone, Coastal A Zone, non-Coastal A Zone, or other). Refer to FEMA 255, *Guide to Flood Maps, How to Use Flood Maps to Determine Flood Risk for a Property*, for instructions. For the Gulf Coast, the FEMA Hurricane Katrina Flood Recovery Advisories should be used until the Gulf Coast is restudied and remapped. New flood maps are scheduled to be completed in 2006.
- Determine the BFE or the interim Advisory Base Flood Elevations (ABFEs) for the location from the FIRM. If the dwelling is outside of floodprone areas, it only needs to be designed for gravity and appropriate wind loads. Seismic events are considered too rare for the Gulf Coast to control the design and analysis.

FIRM Panel No.	____________
Flood Insurance Risk Zone	____________
Base Flood Elevation (BFE) or Advisory Base Flood Elevation (ABFE)	____________

3. Identify the local building code. Several Gulf States are adopting new building codes to govern residential construction. Several parishes, counties, and towns in Louisiana and Mississippi have adopted the IBC and the IRC to govern construction. This document assumes that the IRC governs the design and construction requirements.

County/Parish/City	____________________
Building Code	____________________
Building Code Date	____________________

4. Identify the local freeboard requirements and DFE. Using either the local building codes, local floodplain ordinances, data obtained from local building officials, or personal preferences (only if greater than minimum requirements), determine the minimum freeboard above the BFE or ABFE. The DFE is the sum of the BFE or ABFE and freeboard values.

Base Flood Elevation (BFE) or Advisory Base Flood Elevation (ABFE)		______________
Freeboard	+	______________
Design Flood Elevation		______________

5. Determine the required Design Wind Velocity. The IRC references ASCE 7-02 as the source of the wind speed information. The IRC will be used as the source of all individual and combined loads.

Design Wind Velocity	______________________________
Wind Exposure Category	______________________________

6. Establish the topographic elevation of the building site and the dwelling. Elevations can be obtained from official topographic maps published by the National Geodetic Survey and/or as established or confirmed by a surveyor.

- If the dwelling and its surrounding site are above the DFE, no flood forces need to be considered.
- If the desired topographic elevation is below the DFE, the dwelling must be elevated above the BFE or ABFE.

Source of Topo Elevation	______________________________
Topo Elevation (Site)	______________________________

7. Determine the height of the base of the dwelling above grade. Subtract the lowest ground elevation at the building from the lowest elevation of the structure (i.e., bottom of lowest horizontal structural member).

Design Flood Elevation	______________________
Topo Elevation	______________________
Elevation Dimension	______________________

8. Determine the general soil classification for the site. To determine the load capacity of the soil, the soil must first be classified according to its strength groupings. For purposes of using this manual, the classification system has been greatly simplified into two groups commonly found in coastal areas along the Gulf of Mexico States: (1) loose granular, cohesionless (having little or no clay content) soils and (2) soft, cohesive (principally clayey content) soils.

Soil Classification	______________________

9. Determine the type of foundation to be used to support the structure. Depending on the location of the dwelling, design wind speed, and local soil conditions documented above, select the desired or required type of foundation. Note that more than one solution may be possible. Refer to Chapter 4 for the potential foundation designs that can be used within the flood zones determined from the FIRM maps. Drawings in Appendix A illustrate the construction details for each of the foundations. Refer to the drawings for further direction and information about the needs for each type of unit.

10. Evaluate alternate foundation type selections. The choice of foundation type may be on the basis of least cost or to provide a personal choice, functional, or aesthetic need at the site. Refer to Appendix E for guidance on preparing cost estimates. Functional needs such as provisions for parking, storage, or other non-habitable uses for the area beneath the living space should be considered in the selection of the foundation design. Aesthetic or architectural issues (i.e., appearance) also must be included in the evaluation process. Guidance for the architectural design considerations can be obtained from *A Pattern Book for Gulf Coast Neighborhoods* by the Mississippi Governor's Commission on Recovery, Rebuilding and Renewal (see Appendix B) and from many other sources.

As part of the final analysis, it is strongly recommended that the selection and evaluation process be coordinated with or reviewed by knowledgeable contractors or design professionals to arrive at the best solution to fulfill all of the regulatory and functional needs for the construction.

11. Select the foundation design. If the home's dimensions, height, roof pitch, and weight are within the ranges used to develop these designs, the foundation designs can be used "as is." However, if the proposed structure has dimensions, height, roof pitch, or weights that fall outside of the range of values used, a licensed professional engineer should be consulted. The materials presented in the appendices should help reduce the engineering effort needed to develop a custom design. Figure 5-2 is a foundation selection decision tree for determining which foundation design to use based on the requirements of the home. Table 5-1 shows which foundation design cases can be used for the home based on height of elevation and wind velocity.

Because the designs are good for a range of buildings, they will be conservative for some applications. A licensed professional engineer will be able to provide value engineering and may produce a more efficient design that reduces construction costs.

5.5 Design Examples

The foundation designs were developed to allow a "modular approach" for developing foundation plans. In this approach, individual rectangular foundation components can be assembled into non-rectangular building footprints (see Figures 5-3 through 5-5). Appendix D provides detailed calculations and analysis for open and closed foundation designs. There are, however, a few rules that must be followed when assembling the modules:

1. **The eave-to-ridge dimension of the roof is limited to 23 feet.** The upper limit on roof height is to limit the lateral forces to those used in developing the designs.

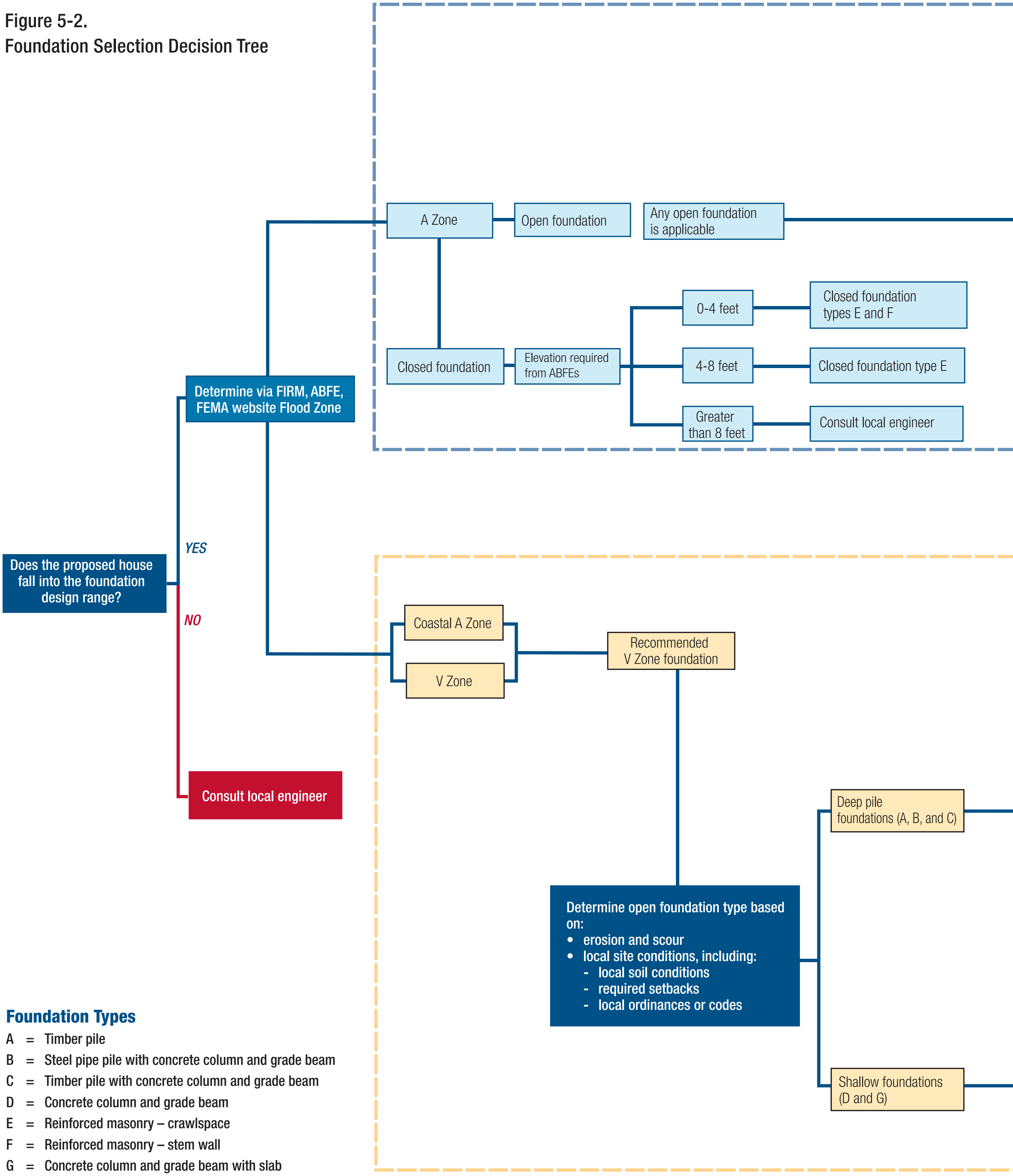
2. **Roof slopes shall not be shallower than 3:12 or steeper than 12:12.** For a 12:12 roof pitch, this corresponds to a 42-foot deep home with a 2-foot eave overhang.

3. **The "tributary load depth" of the roof framing shall not exceed 23 feet, including the 2-foot maximum roof overhang.** This limit is placed to restrict uplift forces on the windward foundation elements to those forces used in developing the design. As a practical matter, clear span roof trusses are rarely used on roofs over 42 feet deep; therefore, this limit should not be unduly restrictive. The roof framing that consists of multiple spans will require vertical load path continuity down through the interior bearing walls to resist uplift forces on the roof. Load path continuity can be achieved in interior bearing walls using many of the same techniques used on exterior bearing walls.

4. **On the perimeter foundation wall designs (Cases E and F), foundation shear walls must run the full depth of the building module, and shear walls can not be spaced more than 42 feet apart.**

5. **All foundation modules shall be at least 24 feet deep and at least 24 feet long.** Although the basic module is limited to 42 feet long, longer home dimensions can be developed, provided that the roof does not extend beyond the building envelope as depicted in Figure 2 of the Introduction.

Figure 5-2.
Foundation Selection Decision Tree



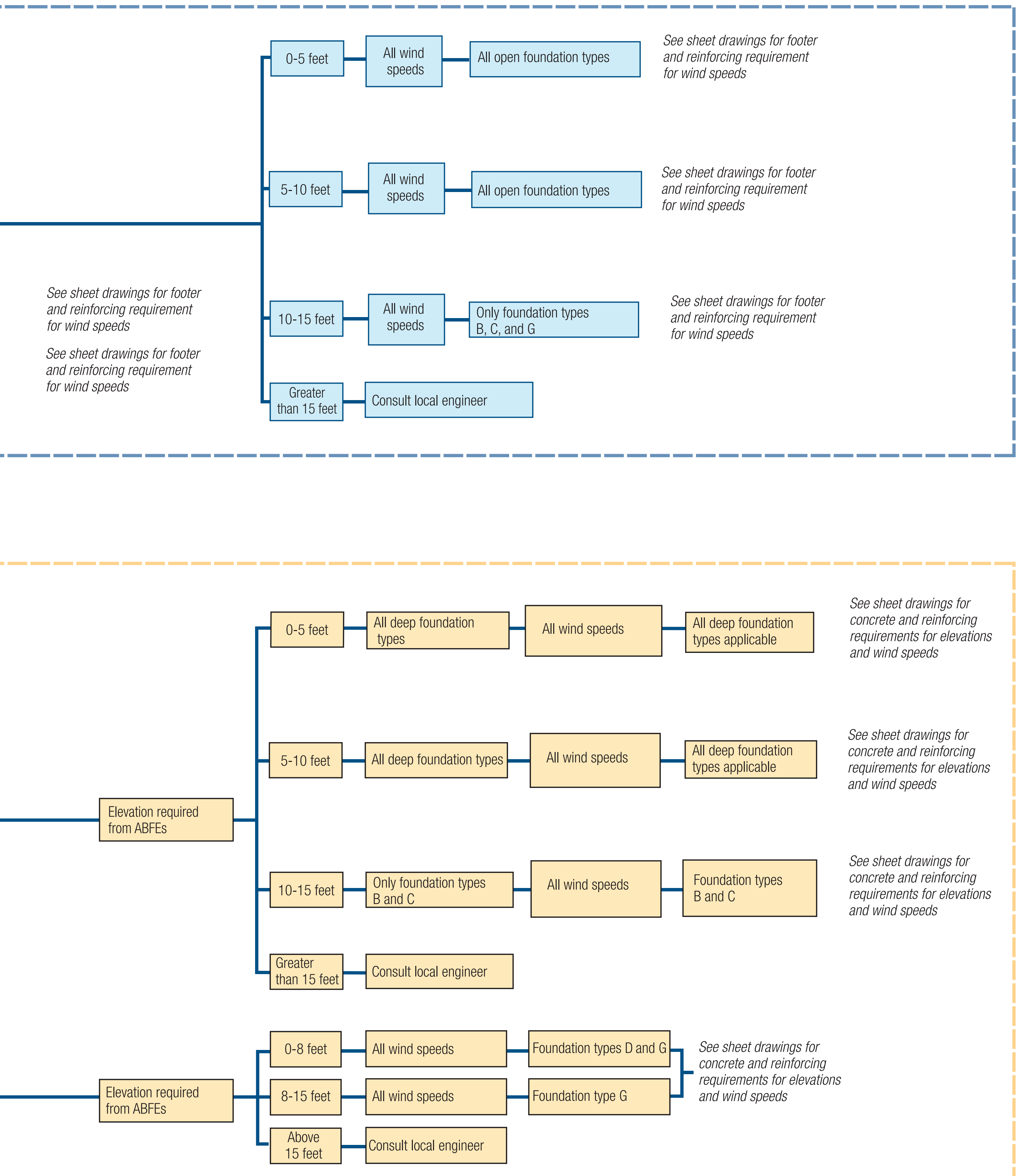

0-5 feet
All wind speeds
All open foundation types
See sheet drawings for footer and reinforcing requirement for wind speeds
5-10 feet
All wind speeds
All open foundation types
See sheet drawings for footer and reinforcing requirement for wind speeds
See sheet drawings for footer and reinforcing requirement for wind speeds
See sheet drawings for footer and reinforcing requirement for wind speeds
10-15 feet
All wind speeds
Only foundation types B, C, and G
See sheet drawings for footer and reinforcing requirement for wind speeds
Greater than 15 feet
Consult local engineer
0-5 feet
All deep foundation types
All wind speeds
All deep foundation types applicable
See sheet drawings for concrete and reinforcing requirements for elevations and wind speeds
5-10 feet
All deep foundation types
All wind speeds
All deep foundation types applicable
See sheet drawings for concrete and reinforcing requirements for elevations and wind speeds
Elevation required from ABFEs
10-15 feet
Only foundation types B and C
All wind speeds
Foundation types B and C
See sheet drawings for concrete and reinforcing requirements for elevations and wind speeds
Greater than 15 feet
Consult local engineer
0-8 feet
All wind speeds
Foundation types D and G
See sheet drawings for concrete and reinforcing requirements for elevations and wind speeds
Elevation required from ABFEs
8-15 feet
All wind speeds
Foundation type G
Above 15 feet
Consult local engineer

Table 5-1. Foundation Design Cases Based on Height of Elevation and Wind Velocity

	Height (H) (ft)	Wind Velocity of 120 to 150 (mph) V Zone	Coastal A Zone*	Non-Coastal A Zone
One-Story Dwelling	< 4	A,B,C	A,B,C,D,G	A,B,C,D,E,F,G
	5	A,B,C	A,B,C,D,G	A,B,C,D,E,G
	6	A,B,C	A,B,C,D,G	A,B,C,D,E,G
	7	A,B,C	A,B,C,D,G	A,B,C,D,E,G
	8	A,B,C	A,B,C,D,G	A,B,C,D,E,G
	9	A,B,C	A,B,C,G	A,B,C,G
	10	A,B,C	A,B,C,G	A,B,C,G
	11	B,C	B,C,G	B,C,G
	12	B,C	B,C,G	B,C,G
	13	B,C	B,C,G	B,C,G
	14	B,C	B,C,G	B,C,G
	15	B,C	B,C,G	B,C,G
Two-Story Dwelling	< 4	A,B,C	A,B,C,D,G	A,B,C,D,E,F,G
	5	A,B,C	A,B,C,D,G	A,B,C,D,E,G
	6	A,B,C	A,B,C,D,G	A,B,C,D,E,G
	7	A,B,C	A,B,C,D,G	A,B,C,D,E,G
	8	A,B,C	A,B,C,D,G	A,B,C,D,E,G
	9	A,B,C	A,B,C,G	A,B,C,G
	10	A,B,C	A,B,C,G	A,B,C,G
	11	B,C	B,C,G	B,C,G
	12	B,C	B,C,G	B,C,G
	13**	B,C	B,C	B,C
	14**	B,C	B,C	B,C
	15**	B,C	B,C	B,C

* In the Coastal A Zone, the tops of all footings and grade beams in Cases D and G foundations must be placed below the maximum estimated erosion and scour depth.

** Some foundation designs are not appropriate for two-story dwelling for a design wind speed of 150 mph. See individual design drawings for more details.

Foundation Types

A = Timber pile

B = Steel pipe pile with concrete column and grade beam

C = Timber pile with concrete column and grade beam

D = Concrete column and grade beam

E = Reinforced masonry – crawlspace

F = Reinforced masonry – stem wall

G = Concrete column and grade beam with slab

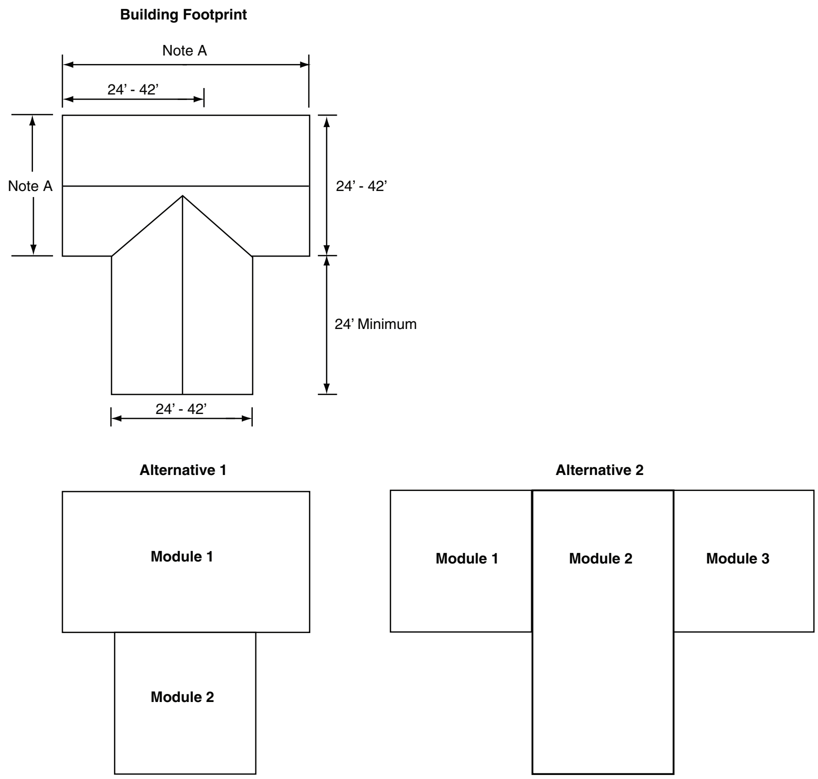


Figure 5-3.
"T" shaped modular design
Note A: Overall building dimensions can exceed 42 feet. The vertical dimensions from the eave to the ridge roof shall not exceed 23 feet.

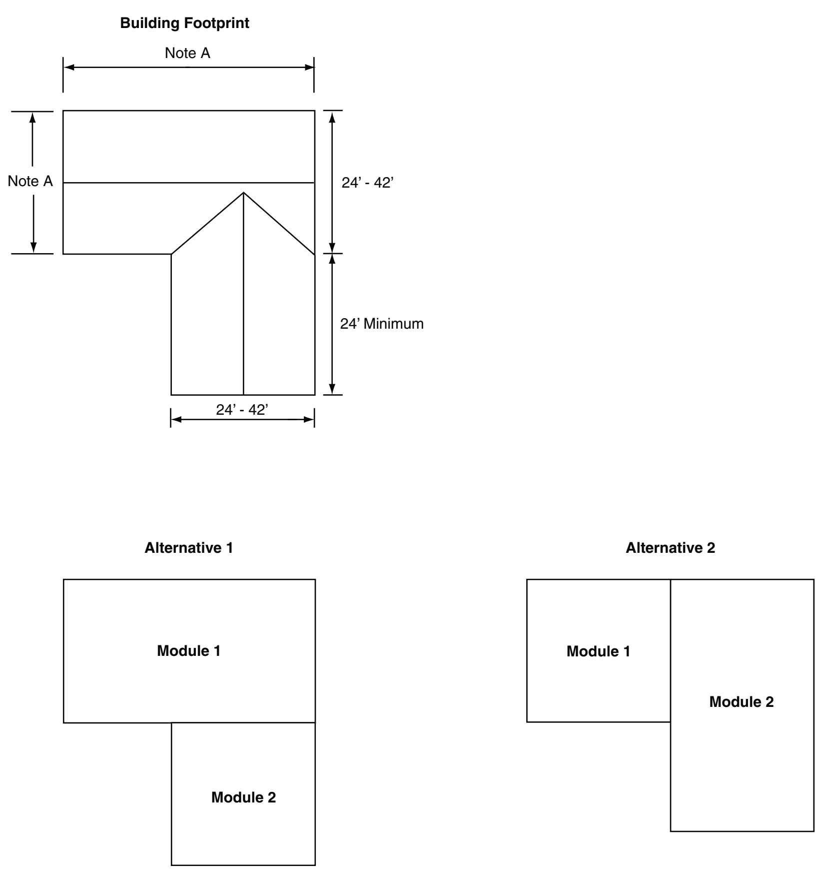
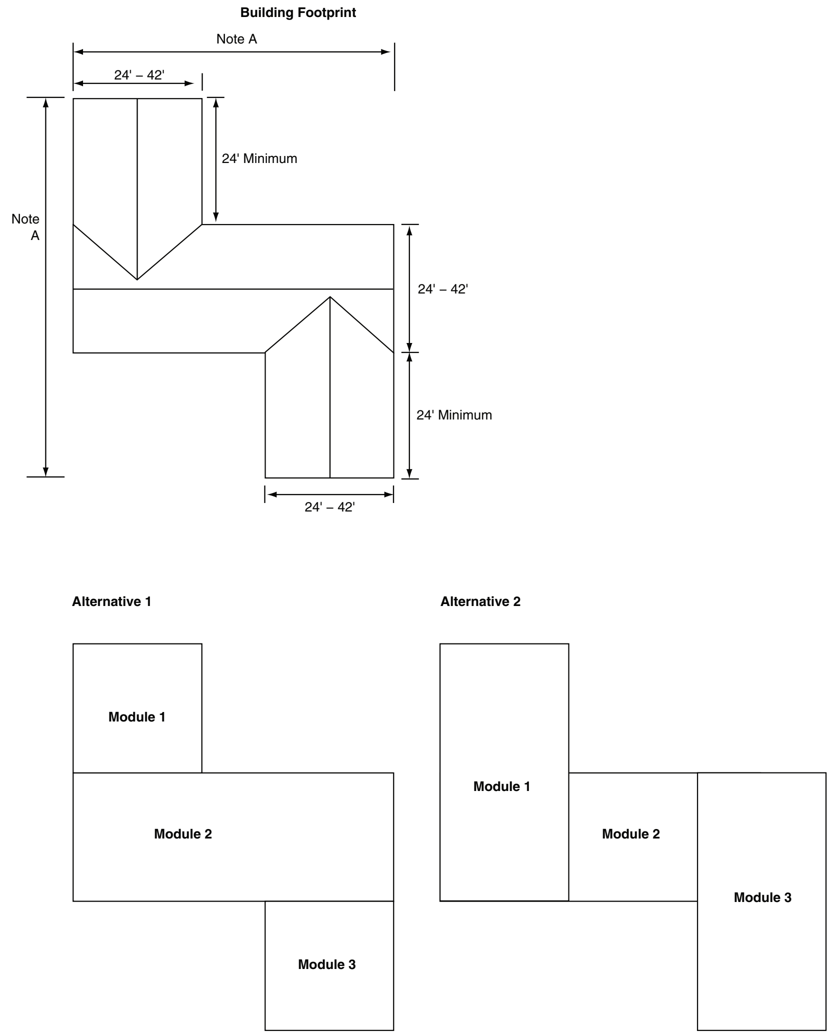


Figure 5-4.
"L" shaped modular design
Note A: Overall building dimensions can exceed 42 feet. The vertical dimensions from the eave to the ridge roof shall not exceed 23 feet.

Figure 5-5.
"Z" shaped modular design
Note A: Overall building dimensions can exceed 42 feet. The vertical dimensions from the eave to the ridge roof shall not exceed 23 feet.



Building on Strong and Safe Foundations

A. Foundation Designs

Drawing	Drawing Number	Sheet Number	Revision Number
Title Sheet & Drawing Index	T-1	1 of 31	1
General Notes	GN-1	2 of 31	1
Wood Beam Connections to Concrete Columns	GN-2 to GN-6	3 to 7 of 31	1
Case A - Open Foundation Driven Treated Timber Pile	A-1 to A-3	8 to 10 of 31	1
Case B - Open Foundation Open Ended Steel Pile	B-1 to B-5	11 to 15 of 31	1
Case C - Open Foundation Driven Timber Pile & Concrete Pile	C-1 to C-6	16 to 21 of 31	1
Case D - Open Foundation Continuous Footing & Concrete Column	D-1 to D-3	22 to 24 of 31	1
Case G - Open Foundation Coastal Grade Beam/ Waffle	G-1, G-2	25 to 26 of 31	1
Case E - Closed Foundation Crawl Space Foundation	E-1 to E-3	27 to 29 of 31	1
Case F - Closed Foundation Backfilled Stemwall Foundation	F-1, F-2	30 to 31 of 31	1

1
T-1
Drawing Index

Foundation Designs
Title Sheet & Drawing Index

DRAWING NO.: T-1 SHEET 1 of 31
DATE: August 8, 2006
REVISED: REV. 9

FEMA

1 General

The use of the foundation designs of this manual are not intended to convey any particular sequence or procedure. The respective builder and/or contractor shall be responsible for taking adequate means and measures to insure the stability of the building and it's components during construction. These shall include, but are not limited to;necessary shoring, sheeting, temporary bracing, dewatering, etc. This manual has been provided to assist in the reconstruction efforts after Hurricane Katrina. Builders, architects, or engineers using this manual assume responsibility for the resulting designs.

2 Foundation

Foundation designs are based on minimum values believed to exist in most areas of the Gulf Coast Region. Actual site soil characteristics shall be verified as being in compliance with the assumed values stated and in compliance with local building codes. Parties using the foundation designs may wish to retain the services of a Geotechnical Engineer to verify local conditions and to provide site specific values.

Soil supported foundations are based on a presumptive allowable soil pressure of 1500 pounds per square foot. In non V zones, compacted structural fill may be used. It is recommended that structural fill be placed in maximum 6" layers and compacted to 95% density as measured by the Modified Proctor method. It is also recommended, and may be required by local code, that field compaction tests be performed by a testing agent. Pile supported foundations are based on presumptive values indicated on the detail drawings.

It is advised that the location of all underground utilities be verified prior to commencing any foundation work. Proper care should be taken during any excavation work as uncharted underground utilities may exist in the area.

3 Concrete

All structural concrete, for foundations, slabs on grade, columns and beams, etc., shall be a plant batched ready-mix. The concrete mix shall be of standard weight aggregates able to achieve a 28 day compressive strength of 4000 psi. The use of Calcium Chlorides shall not be permitted. Use of water reducing agents / superplasticizer are recommended. Use of plastic fiber additives for exposed concrete slabs at grade is also recommended.

All concrete work shall comply with the requirements of ASTM Standard C94 for the measuring, mixing, transporting, placing, etc. Concrete tickets should be time stamped when the concrete is batched. The maximum time allowed, from when the mixing water is added to the time the concrete is deposited should not exceed one and one half hours. Use of concrete that is not in compliance with the above can result in significant reduction in concrete strength and performance. Concrete shall be placed with due regard to extreme temperature conditions. Refer to ACI 305 " Hot Weather Concreting" and ACI 306 "Cold Weather Concreting" for guidance in placing concrete during weather extremes.

Refer to ACI 117 and ACI 347R for guidance in planning Form work design and for finish standards and requirements.

A standard hook shall be provided at the termination of all beam top reinforcing bars. Corner bars with full tension laps, matching the size and spacing of the continuous bar shall be provided.

Reinforcing steel shall be of ASTM A615 Grade 60 deformed bars, free from oil, scale and excessive rust. Reinforcing shall be detailed, fabricated and placed in accordance with the typical bending diagrams, placing requirements and details of the latest editions of the American Concrete Institute (ACI) standards and specifications. These publications include ACI 318, ACI 301, ACI 304, ACI 315 and ACI SP-68. Minimum Cover for reinforcing is; 3" for concrete cast against soil and 2" for concrete that is exposed to weather. It is recommended that the owner utilize a concrete testing agent to verify concrete strength. Reinforcing shall be secured in place by the use of metal ties and supported by metal bolsters, chairs, spacers and other devices.
Welded wire fabric shall conform to ASTM A185 and be furnished in flat sheets only.

Standard Lap lengths are as follows:

Bar size	Lap length	Bar size	Lap length
#3	18"	#7	42"
#4	24"	#8	48"
#5	30"	#9	54"
#6	36"	#10	60"

Reinforcement
Lap Splice Table

4 Reinforced Masonry Construction

All concrete masonry unit (CMU) construction shall conform to the recommendations of the "BUILDING CODE REQUIREMENTS FOR MASONRY STRUCTURES", ACI 530-02/ASCE 5-02/TMS 402-02 and ACI 530.1-02 Specifications for Masonry Structures.
All steel reinforcement shall conform to ASTM A615 Grade 60 material.
All steel reinforcement lap lengths shall conform to table shown in SECTION 3.
The compressive strength of masonry, f'm, shall be a minimum of 1500 psi.
All reinforced cells shall be solidly filled with grout. All cells that have anchors, embedded plates, etc., shall be filled with grout. All cells within 8" above grade and all cells below grade shall be filled with grout. Grout shall have a 28-day compressive strength of 3000 psi. and be of pea gravel aggregates.
All CMU shall be laid in a running bond with a full mortar bed.

5 Structural Steel

Structural shapes, anchor bolts, etc. that are indicated to be galvanized, shall be hot dip galvanized after fabrication per ASTM A 368, A123 to G90 standard.

6 Connections

Connections to wood framing are based on lumber having a minimum specific gravity of 0.55. See sheet GN-2 to GN-6 for these details.

7 Driven Piles

Treated Timber Piles shall conform to latest revision of ASTM Specification D-25. Piles shall be of Southern Pine or Douglas Fir clean or rough peeled. Piles also shall have a minimum tip diameter of 8 inches and a minimum butt diameter of 12 inches as measured 3 feet from the end of the pile.

All treated timber piles shall be preservative treated. Preservative retention shall be 0.61 pounds per cubic foot. Pile preservative treatment shall comply with AWPA C3 standards.

Treat cut ends and drilled holes of treated timber piles with the same penetrating preservative as base treatment chemical. All piles shall be uniformly spaced along width and depth of building. Variations of +/- 1' are allowed to address site conditions, provided piles are spaces a minimum of 4 pile diameters unless otherwise noted.

1
GN -1
General Notes

General Notes

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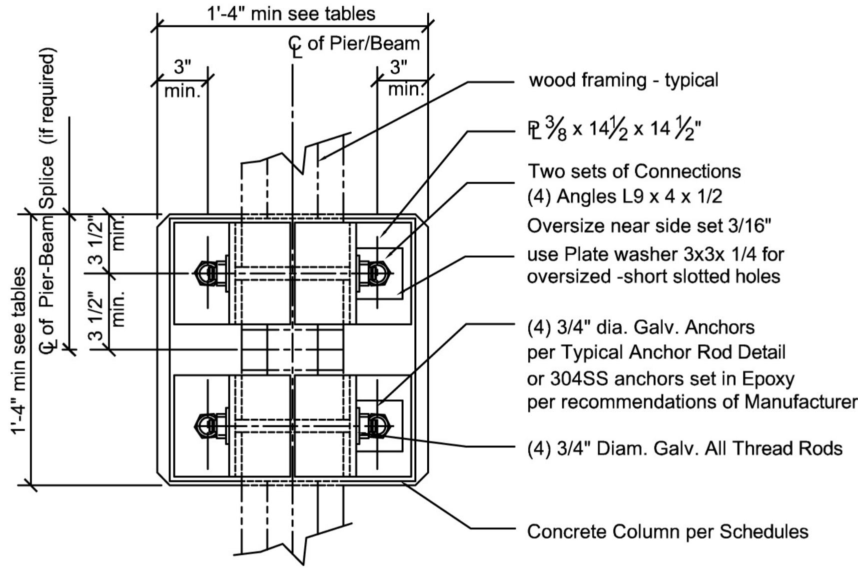
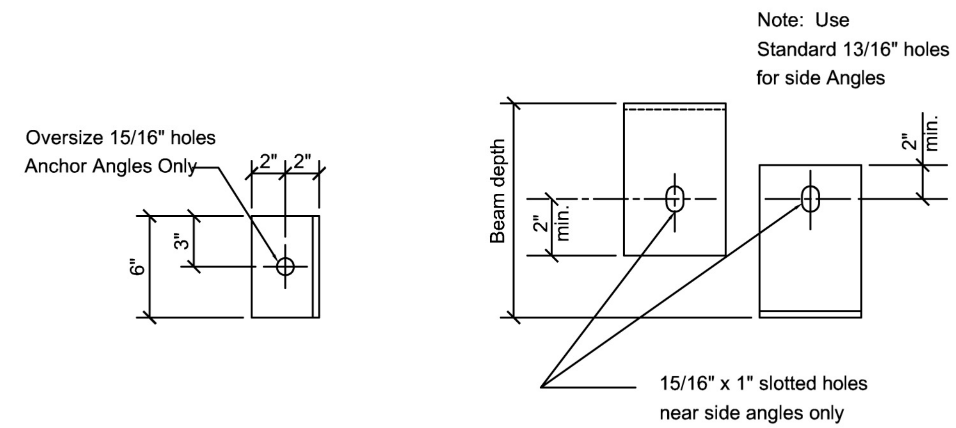


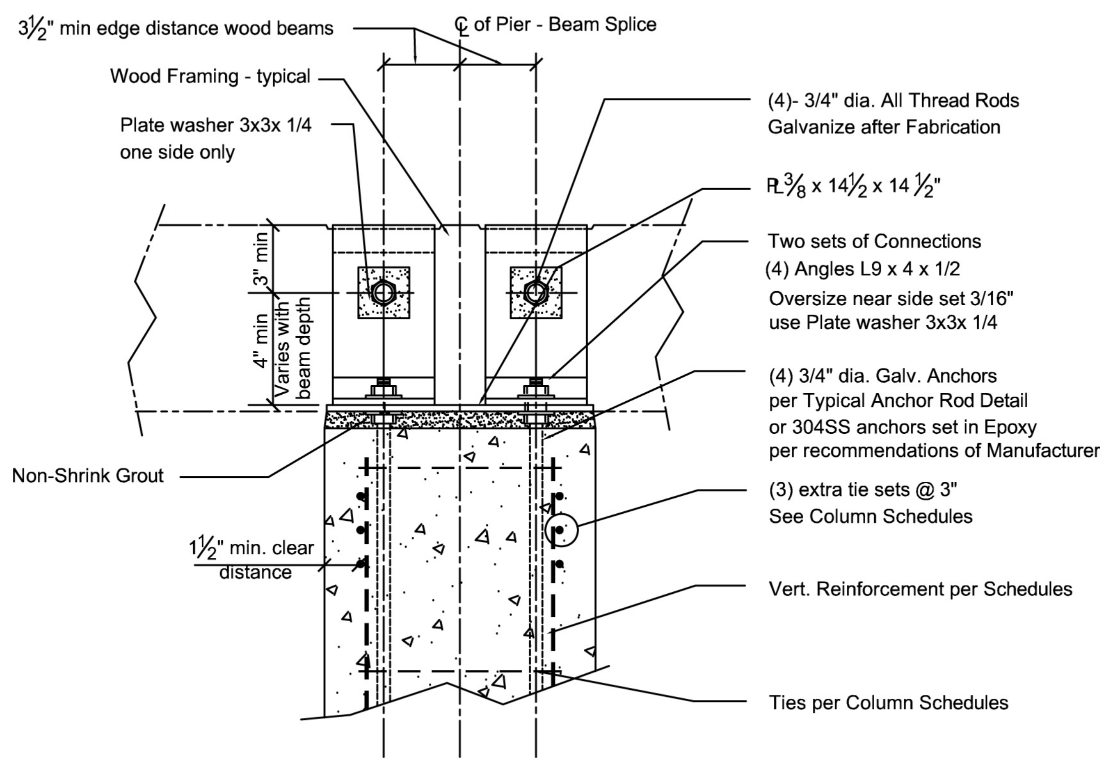
Captive-Clamped Beam (CCB) - Typical Connection Plan Detail

1 GN-2 SCALE: NTS



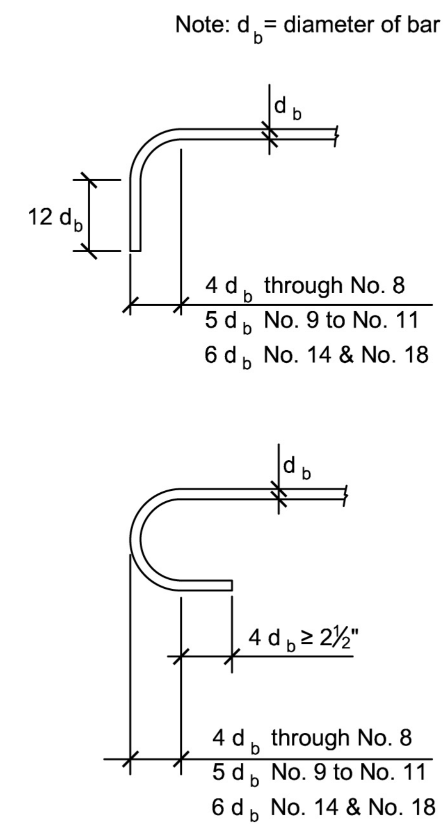
Captive-Clamped Beam (CCB) - Typical Connection Angle Detail

2 GN-2 SCALE: NTS



Captive-Clamped Beam (CCB) - Typical Connection Elevation

3 GN-2 SCALE: NTS



Standard Hooks

4 GN-2 SCALE: NTS

Note: All steel material min. ASTM grade A36 and Galvanized after fabrication u.n.o.
Connection design is based on wood species having a specific gravity of at least 55%
such as southern yellow pine.

Connection Details	
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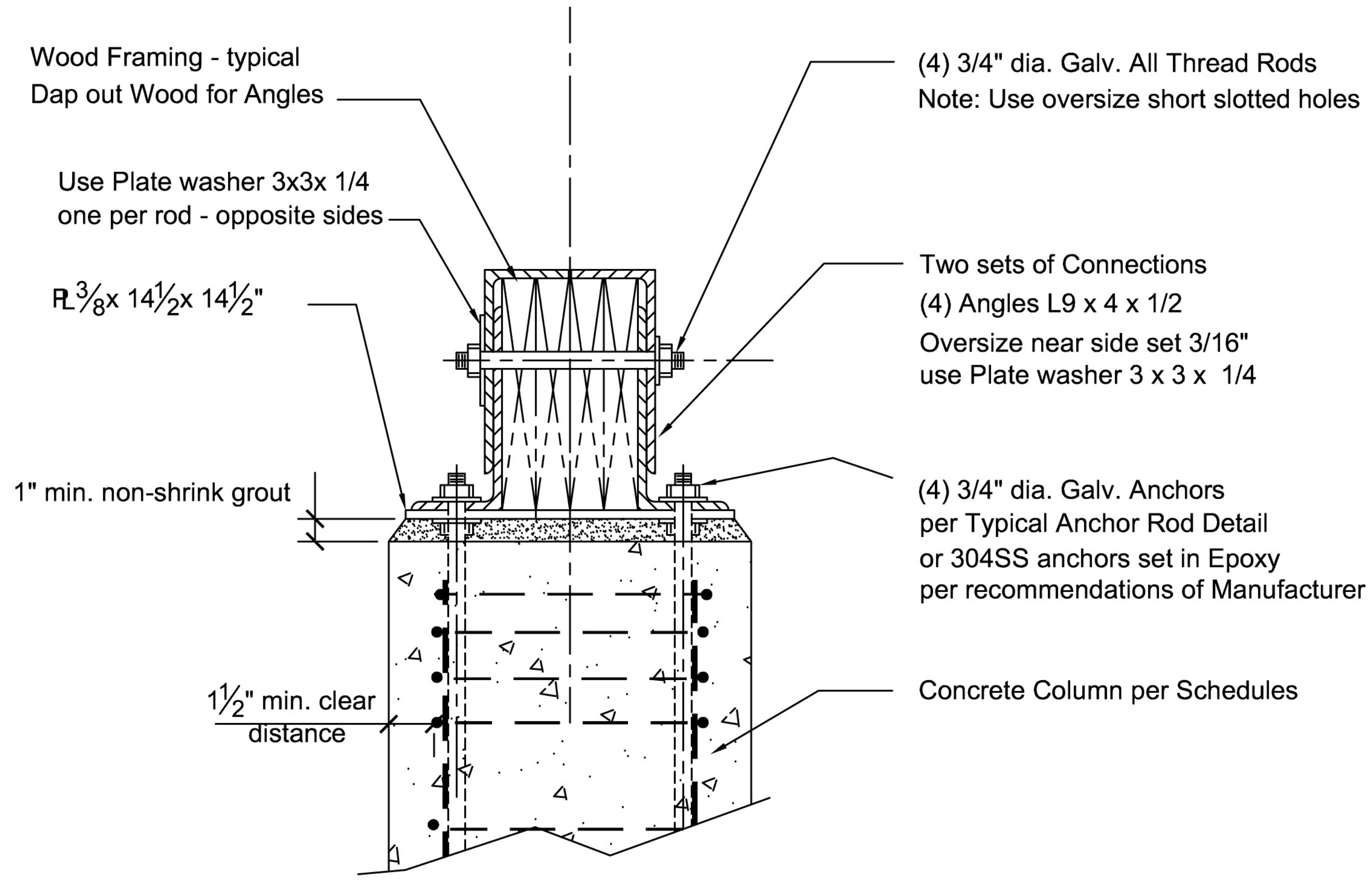
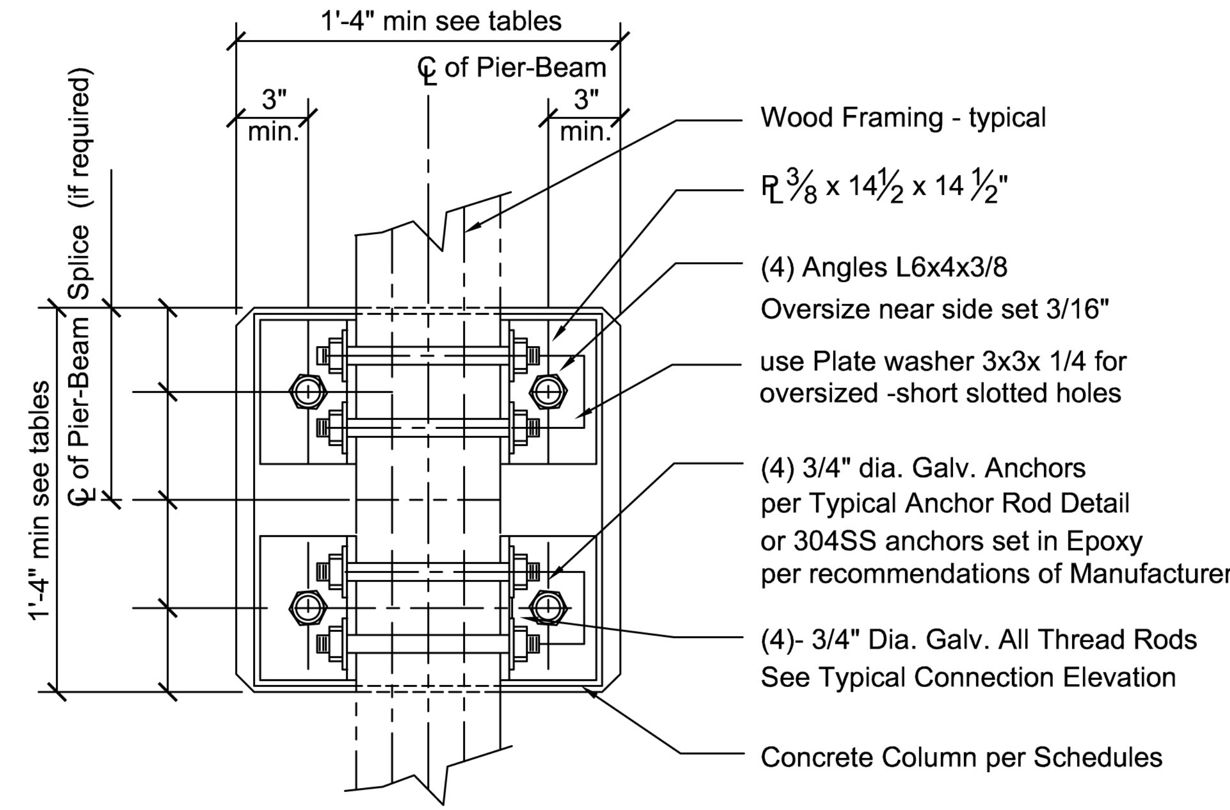


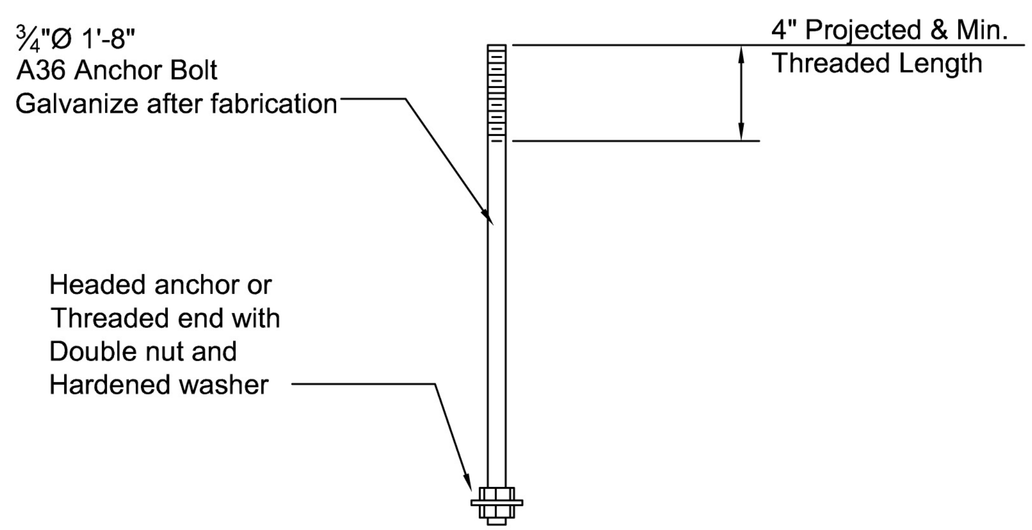
1 / GN-3 Captive-Clamped Beam (CCB) - Typical Connection Section

SCALE: NTS



2 / GN-3 Double Angle Beam (DAB) - Typical Connection Plan Detail

SCALE: NTS



3 / GN-3 Typical Anchor Rod Detail - Cast-In Place

SCALE: NTS

Connection Details	
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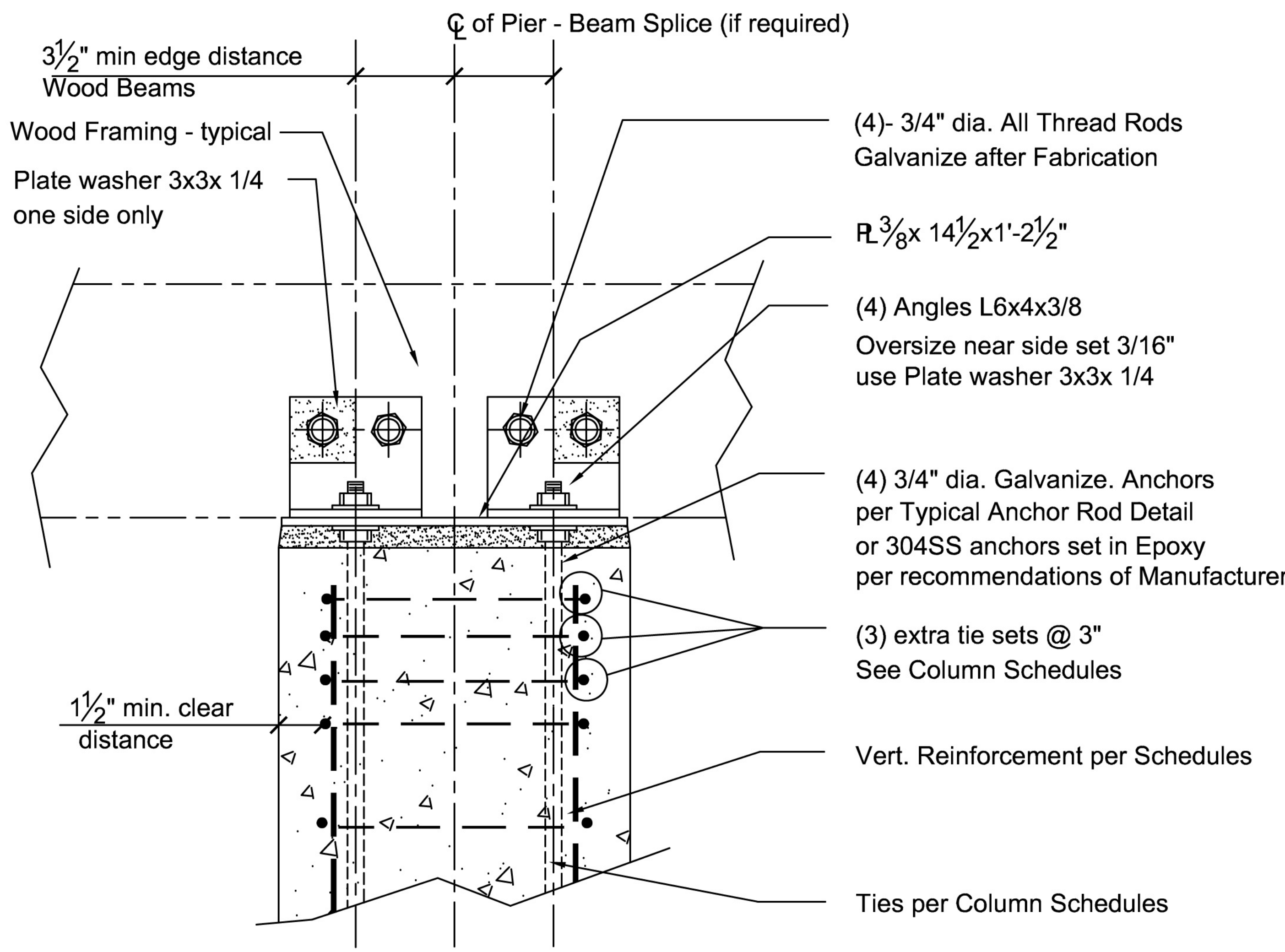
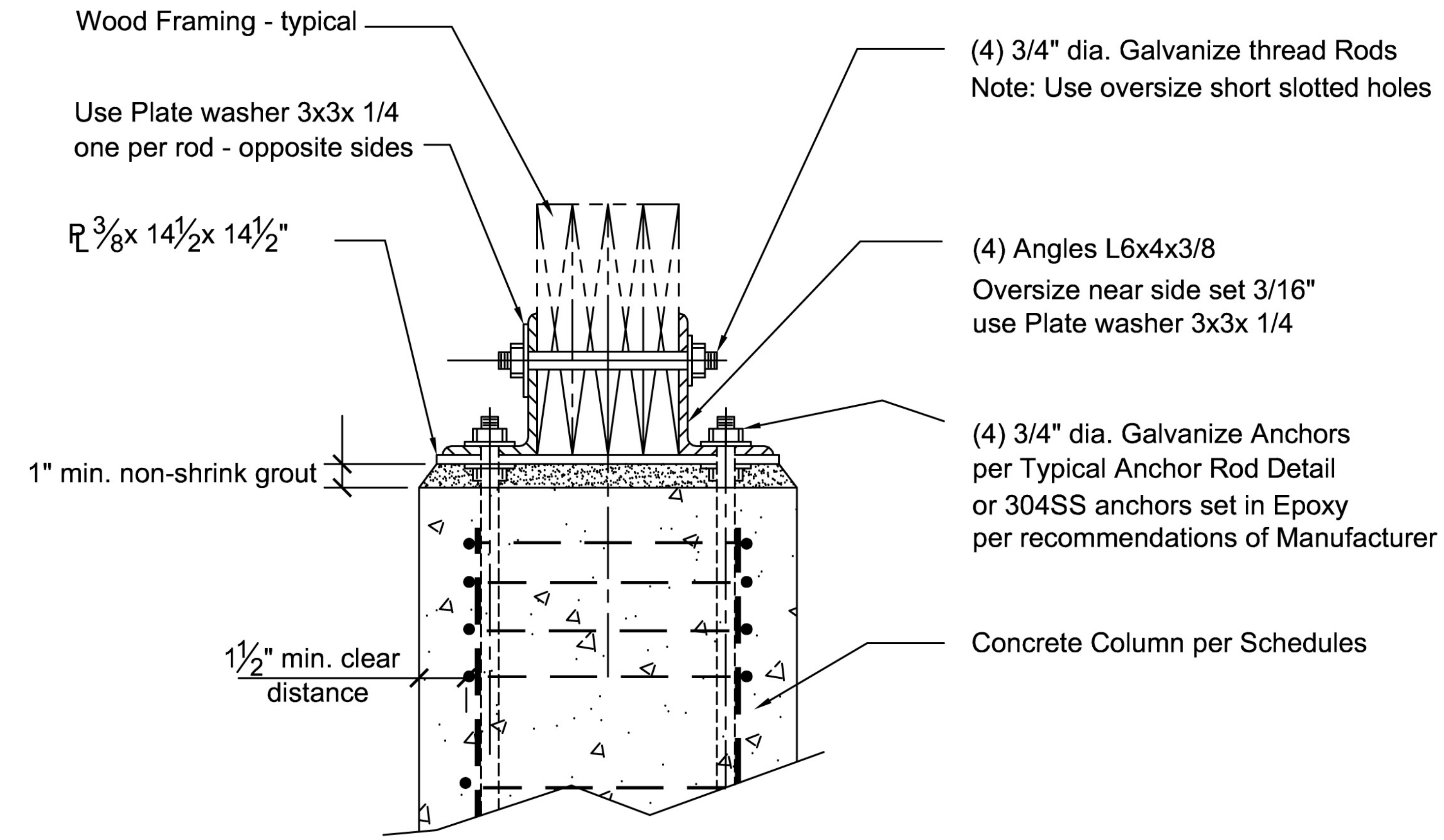


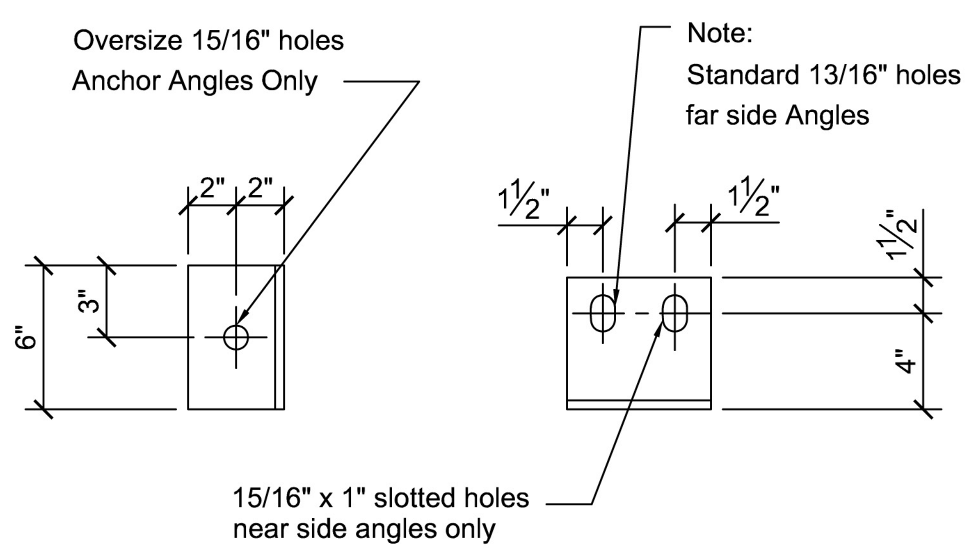
1/GN-4 Double Angle Beam (DAB) - Typical Connection Section

SCALE: NTS



2/GN-4 Double Angle Beam (DAB) - Typical Connection Section

SCALE: NTS



3/GN-4 Double Angle Beam (DAB) - Typical Connection Section

SCALE: NTS

Connection Details	
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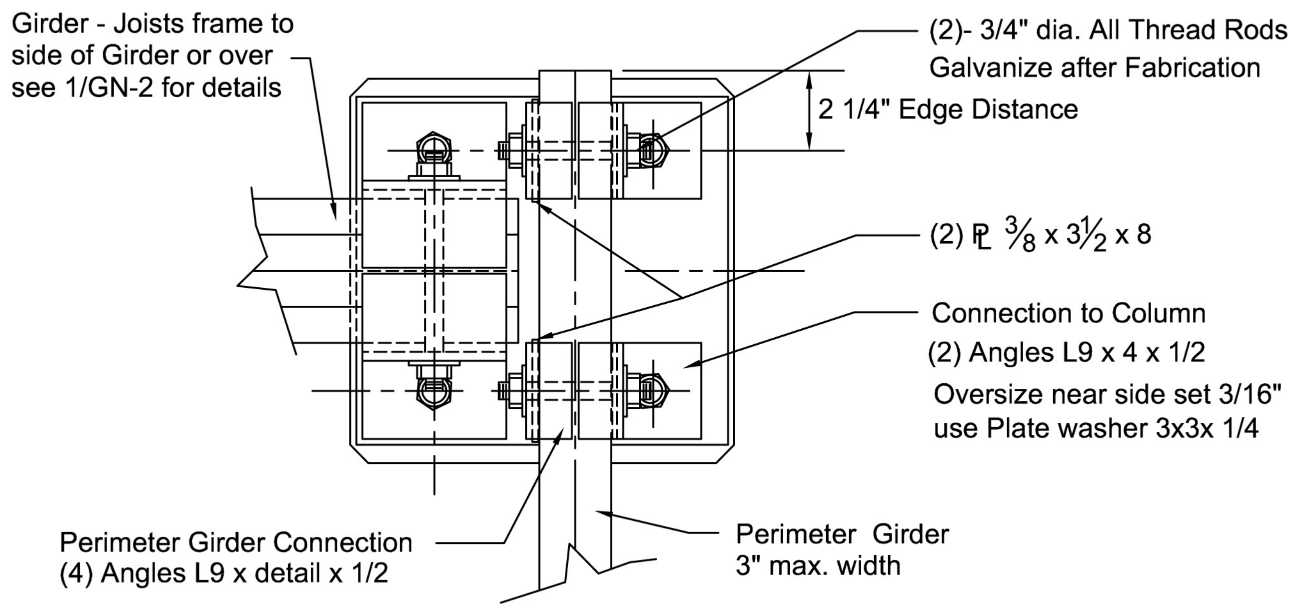
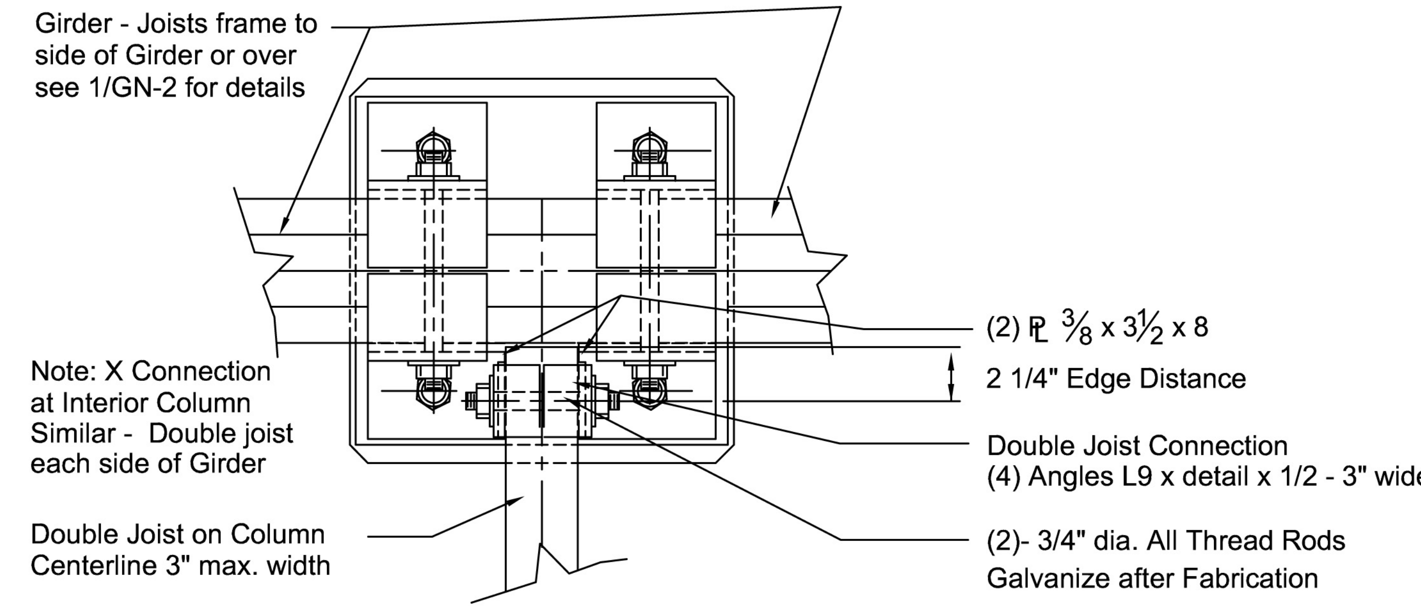


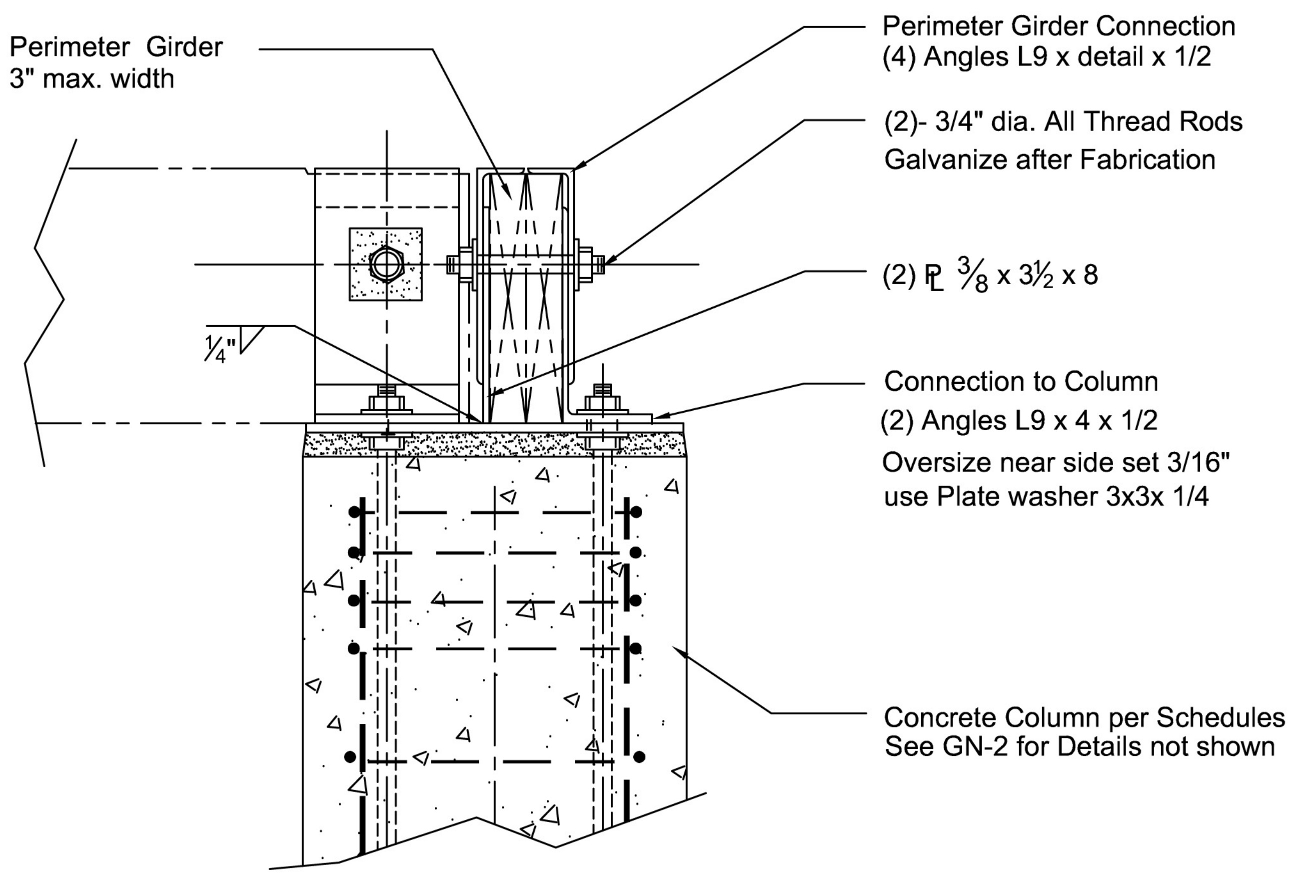
Captive-Clamped Beam (CCB) - Typical
Corner Connection Plan Detail

1
GN-5
SCALE: NTS



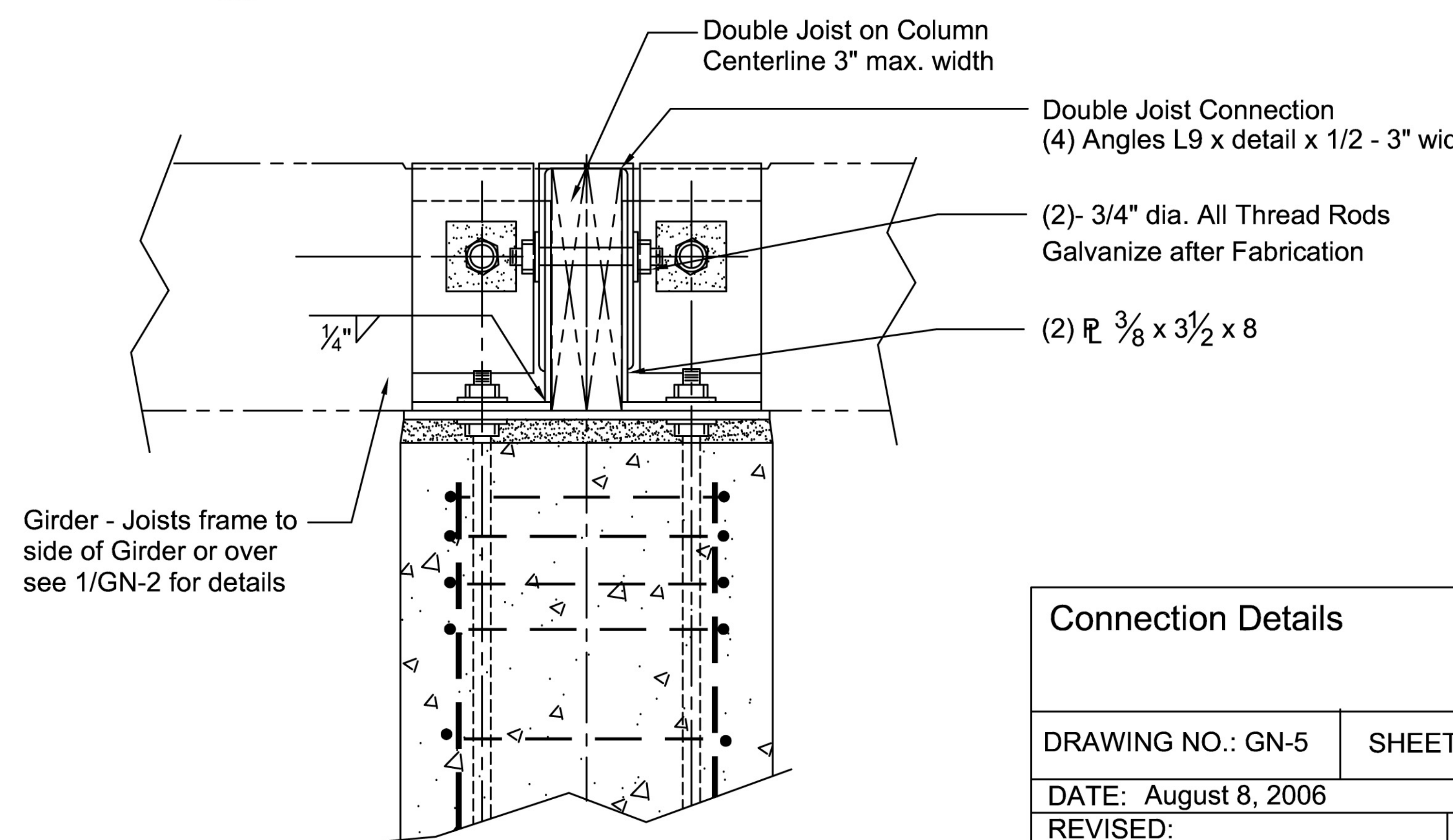
Captive-Clamped Beam (CCB) - Typical
T Connection Plan Detail

3
GN-5
SCALE: NTS



Captive-Clamped Beam (CCB) - Typical
Corner Connection Section

2
GN-5
SCALE: NTS



Captive-Clamped Beam (CCB) - Typical
"T" Connection Section

4
GN-5
SCALE: NTS

Connection Details	
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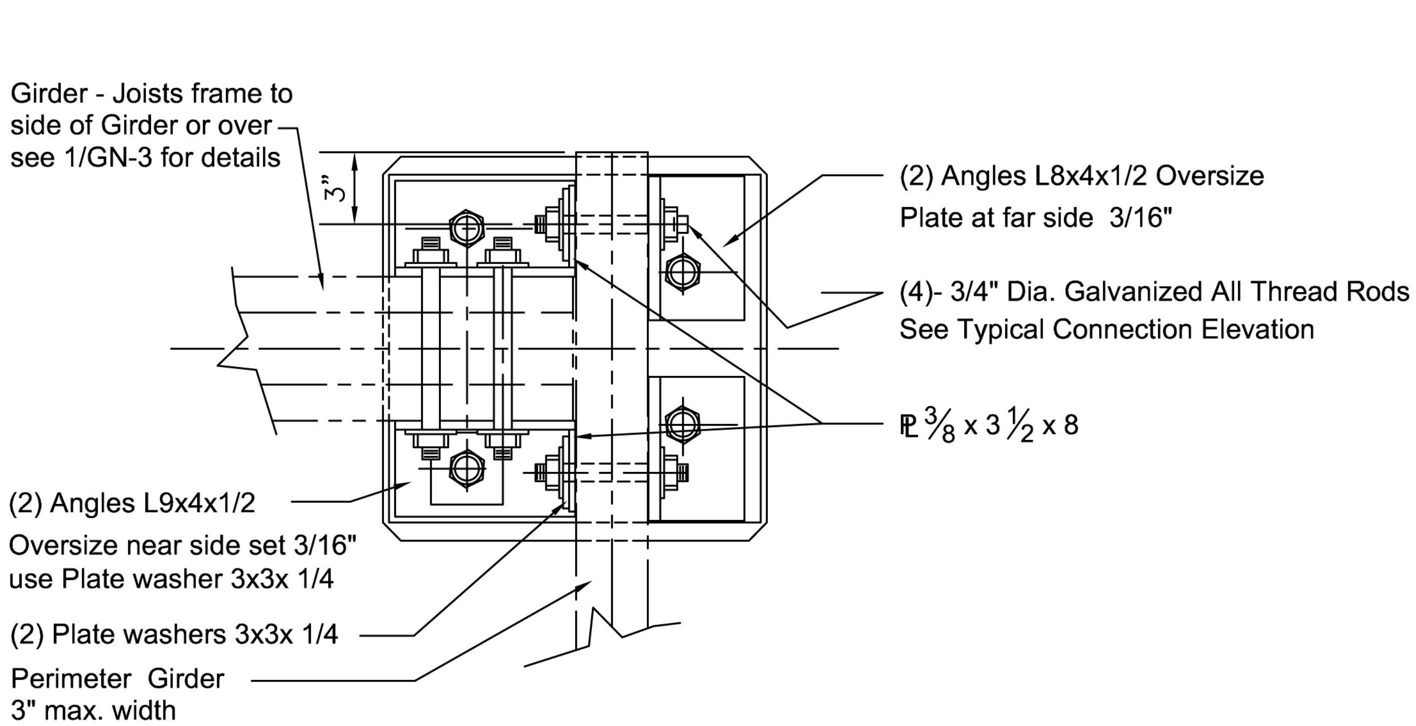
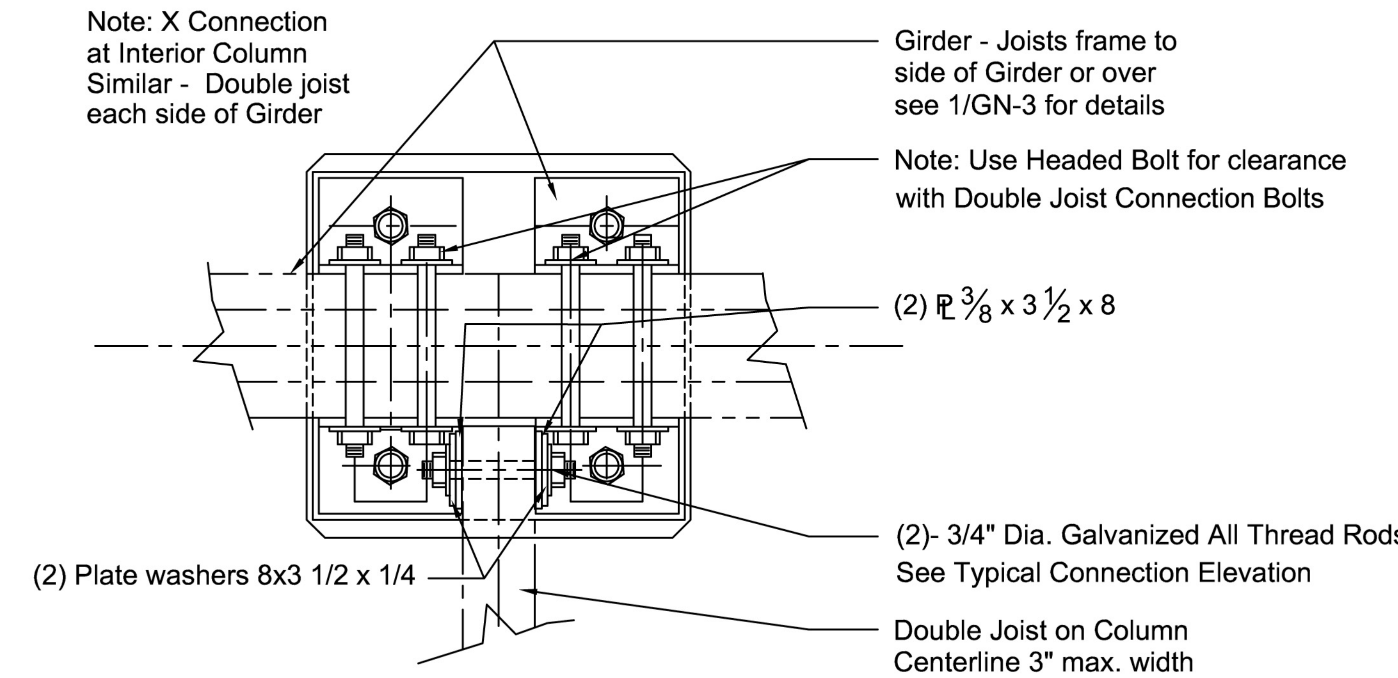


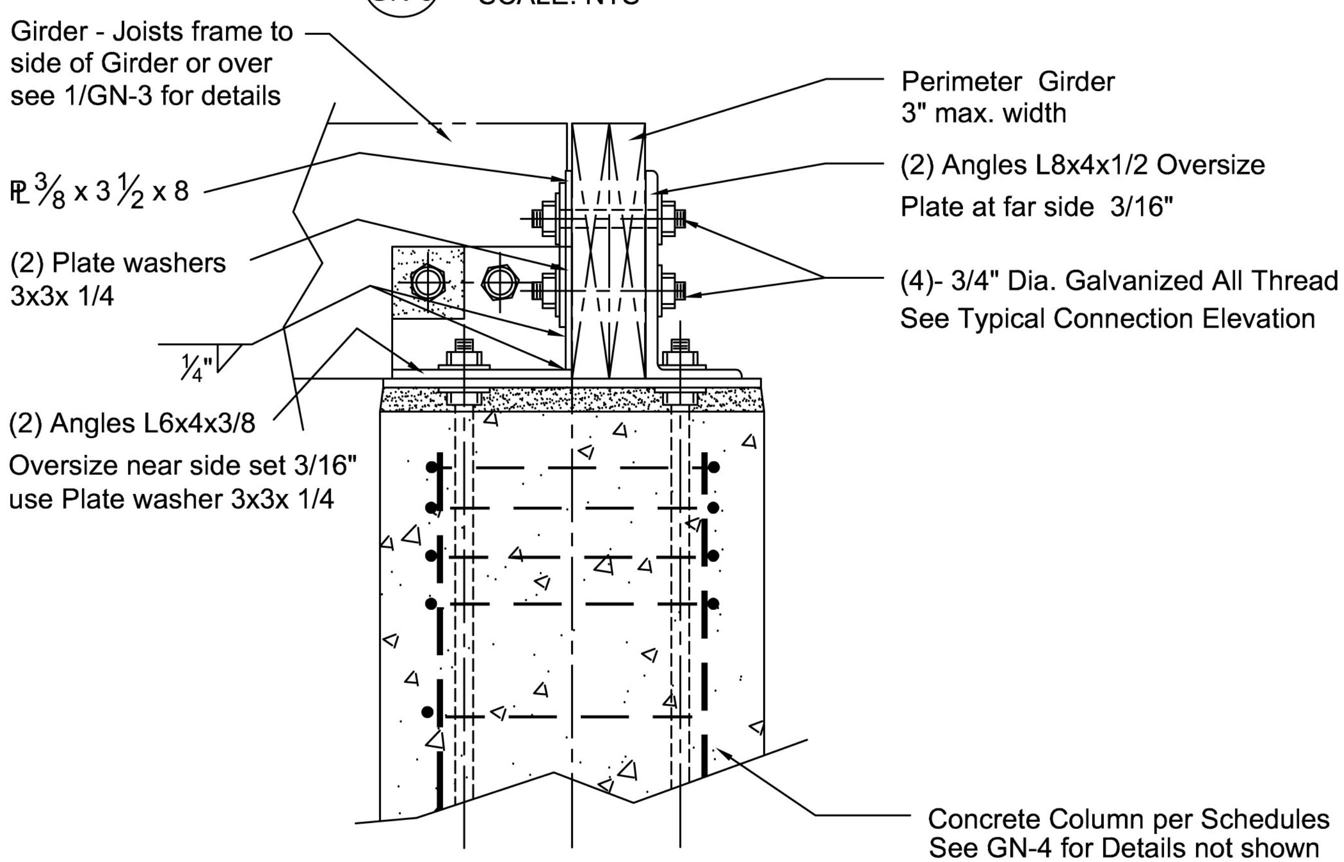
1/GN-6 Double Angle Beam (DAB) Corner Connection Plan

SCALE: NTS



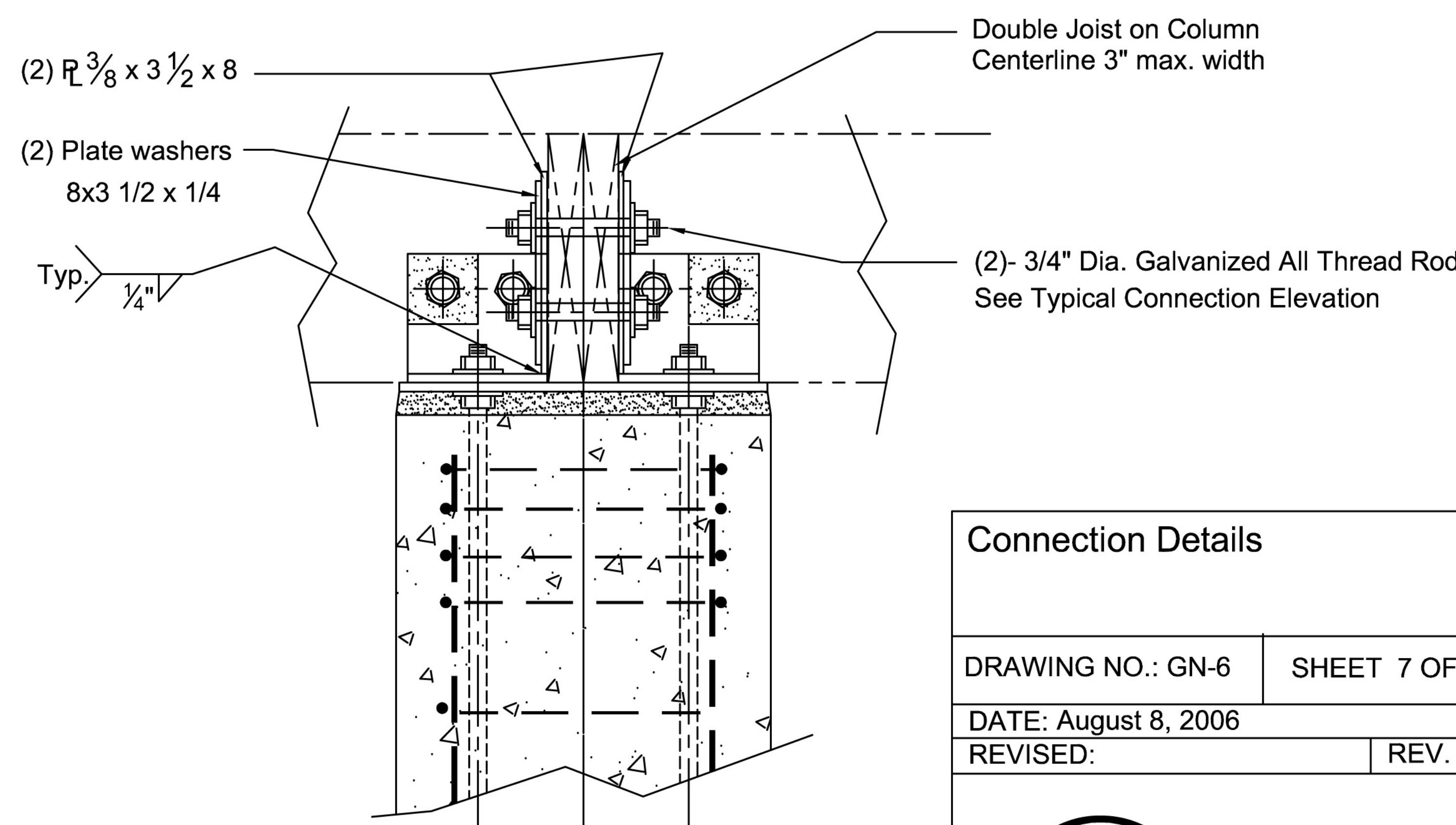
3/GN-6 Double Angle Beam (DAB) T Connection Plan

SCALE: NTS



2/GN-6 Double Angle Beam (DAB) Corner Connection Section

SCALE: NTS



2/GN-6 Double Angle Beam (DAB) T Connection Section

SCALE: NTS

Connection Details	
DRAWING NO.: GN-6	SHEET 7 OF 31
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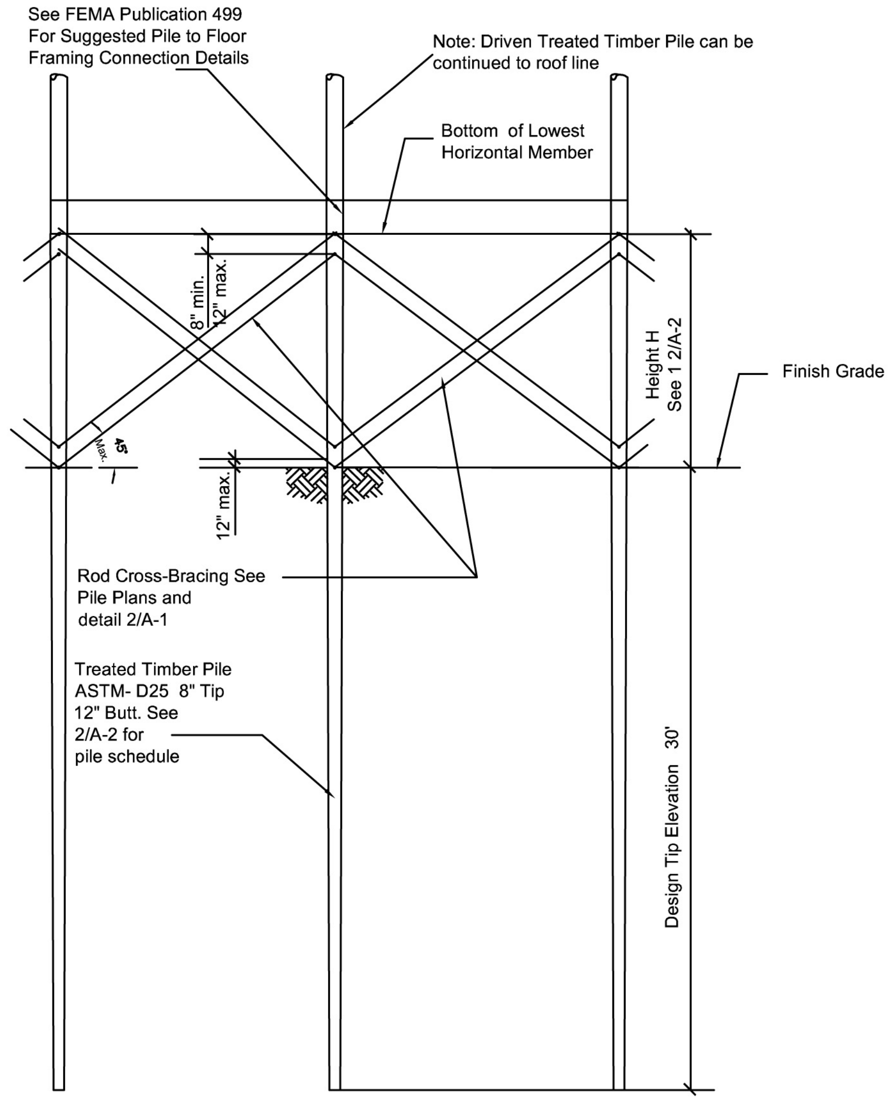
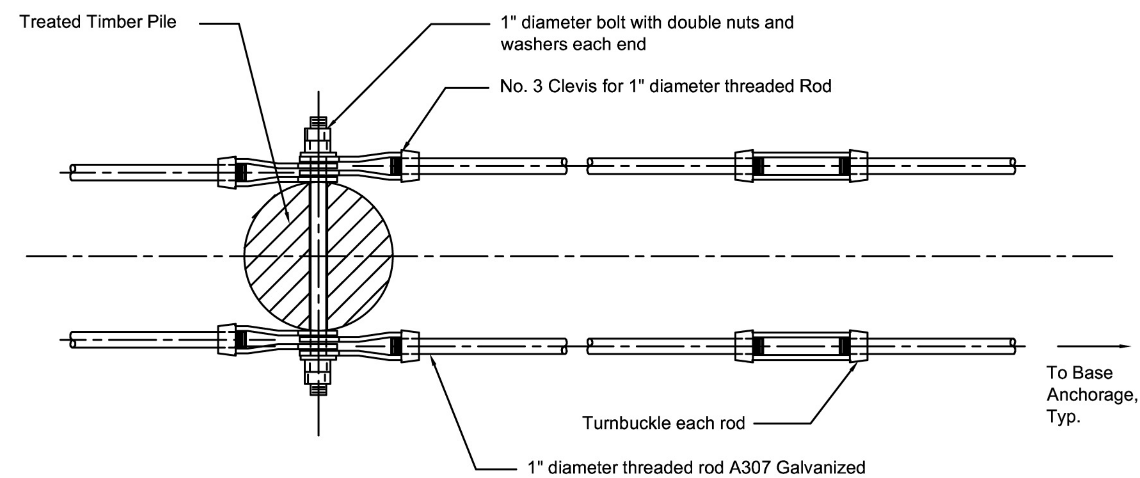


1
A-1

Case A Open Foundation - Driven Treated Timber Pile

Pile Profile - Double Rod Cross Bracing Shown

SCALE: NTS

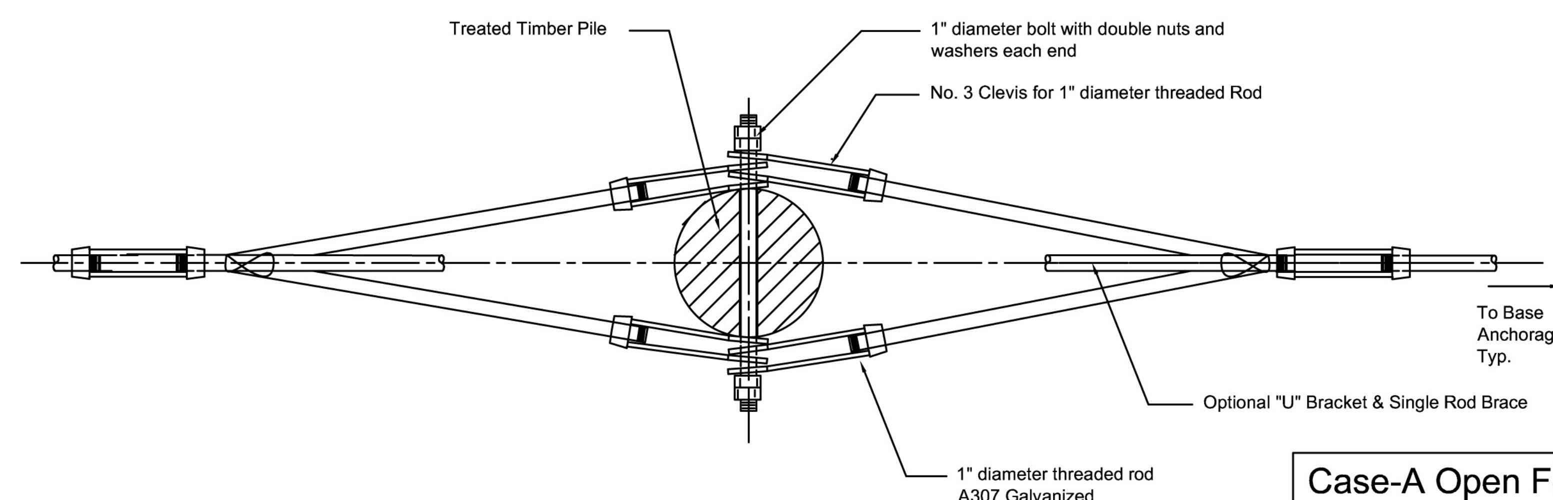


2
A-1

Case A Open Foundation - Driven Treated Timber Pile

Rod Bracing Detail

SCALE: NTS



Note: All steel shall be Galvanized

3
A-1

Case A Open Foundation - Driven Treated Timber Pile

Rod Bracing Detail (Alternate)

SCALE: NTS

Piles are assumed to have the following capacities:

Compression	14000 pounds
Tension	9300 pounds
Lateral	4000 pounds

Case-A Open Foundation Driven Treated Timber Pile	
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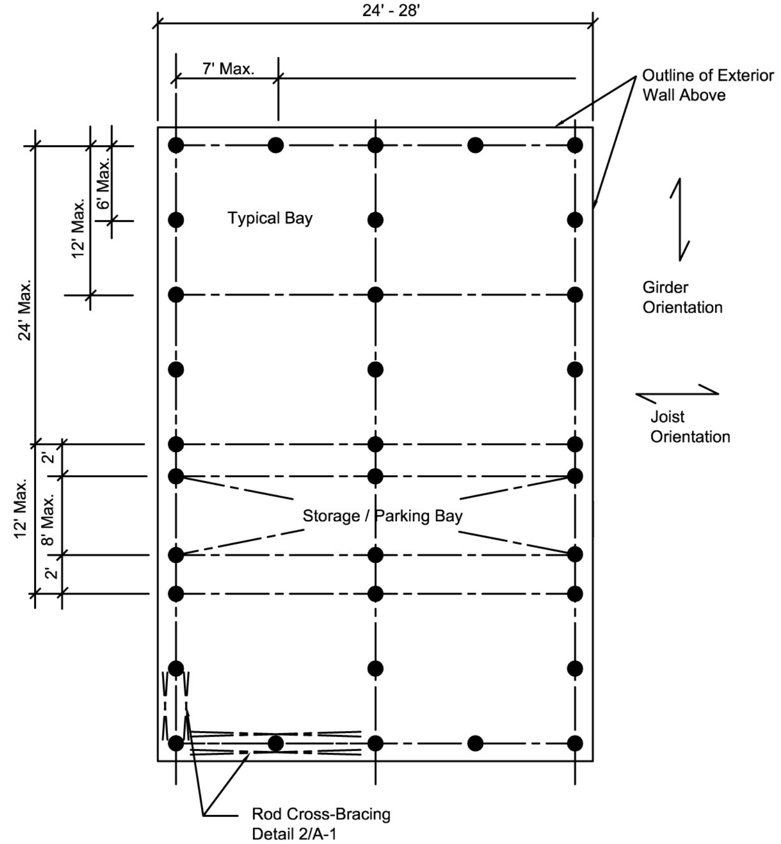
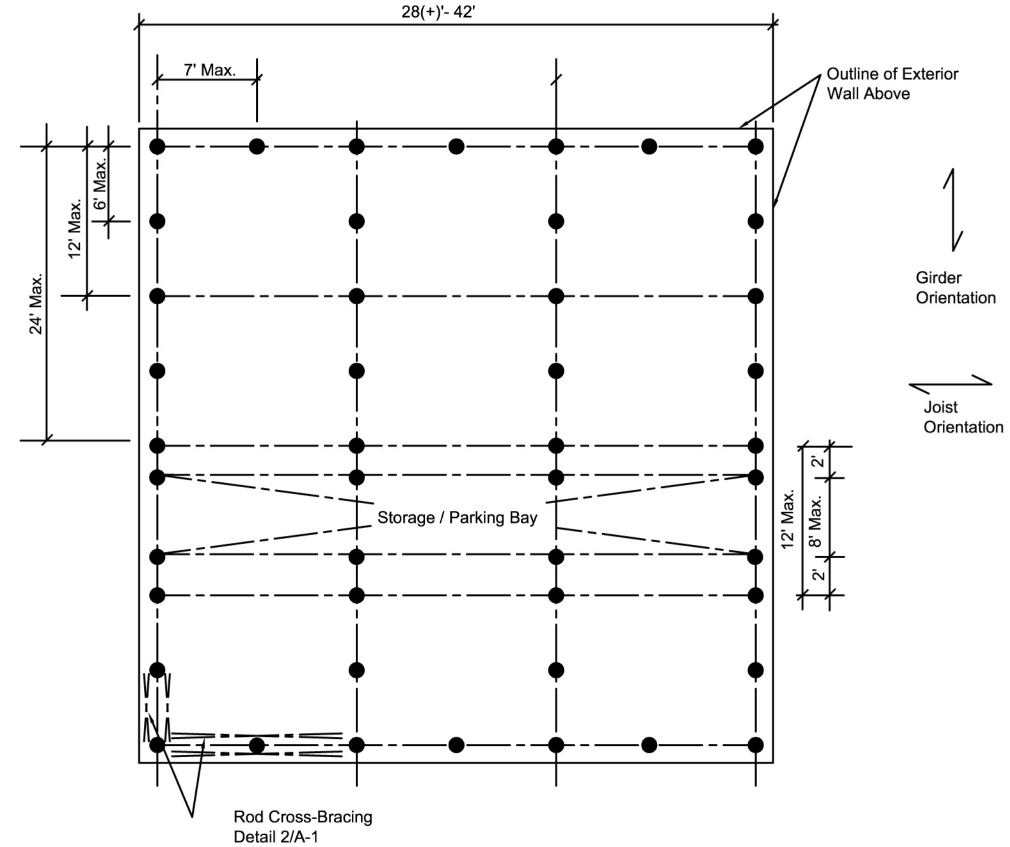


8-Bay Pile Plan



12-Bay Pile Plan

1/A-2 Case A Open Foundation - Driven Treated Timber Pile Pile Plan - 1

SCALE: NTS

Braced Timber Pile Foundation				
Pile Schedule - One Story Structures				
"H"	Wind Speed			
	150 mph	140 mph	130 mph	120 mph
< 6 ft	Pile Plan 1	Pile Plan 1	Pile Plan 1	Pile Plan 1
8 ft	Pile Plan 1	Pile Plan 1	Pile Plan 1	Pile Plan 1
10 ft	Pile Plan 1	Pile Plan 1	Pile Plan 1	Pile Plan 1

Braced Timber Pile Foundation				
Pile Schedule - Two Story Structures				
"H"	Wind Speed			
	150 mph	140 mph	130 mph	120 mph
< 6 ft	Pile Plan 1	Pile Plan 1	Pile Plan 1	Pile Plan 1
8 ft	Pile Plan 1	Pile Plan 1	Pile Plan 1	Pile Plan 1
10 ft	Pile Plan 2	Pile Plan 2	Pile Plan 2	Pile Plan 2

Note:
1) Pile Bracing shall not be installed in areas where pile diameter is less than 8 inches
2) See Drawing A-3 for bracing schedule.

2/A-2 Case A - Table 1 Treated Timber Pile Pile Plan Schedule

Case-A Open Foundation Driven Treated Timber Pile	
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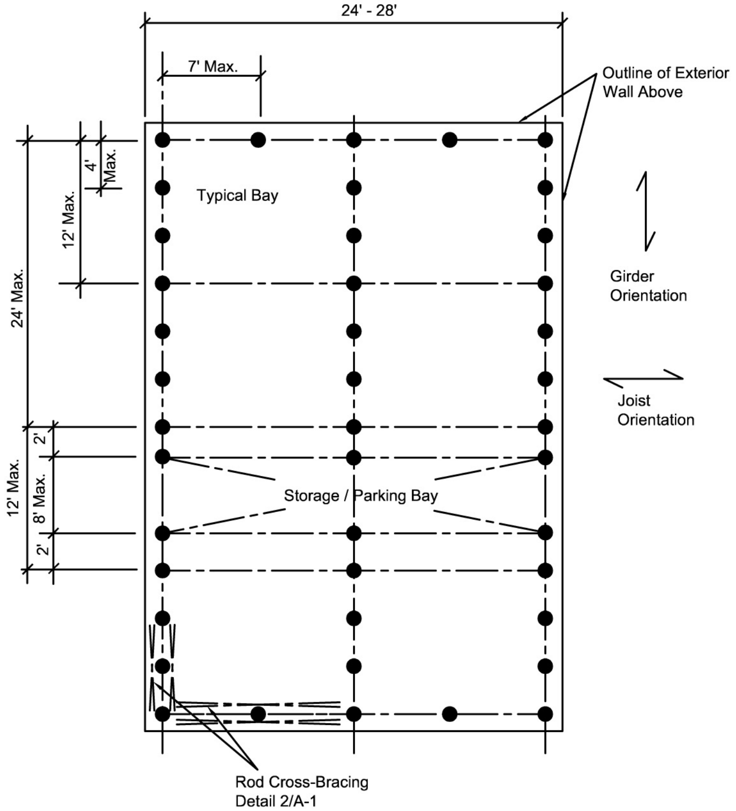
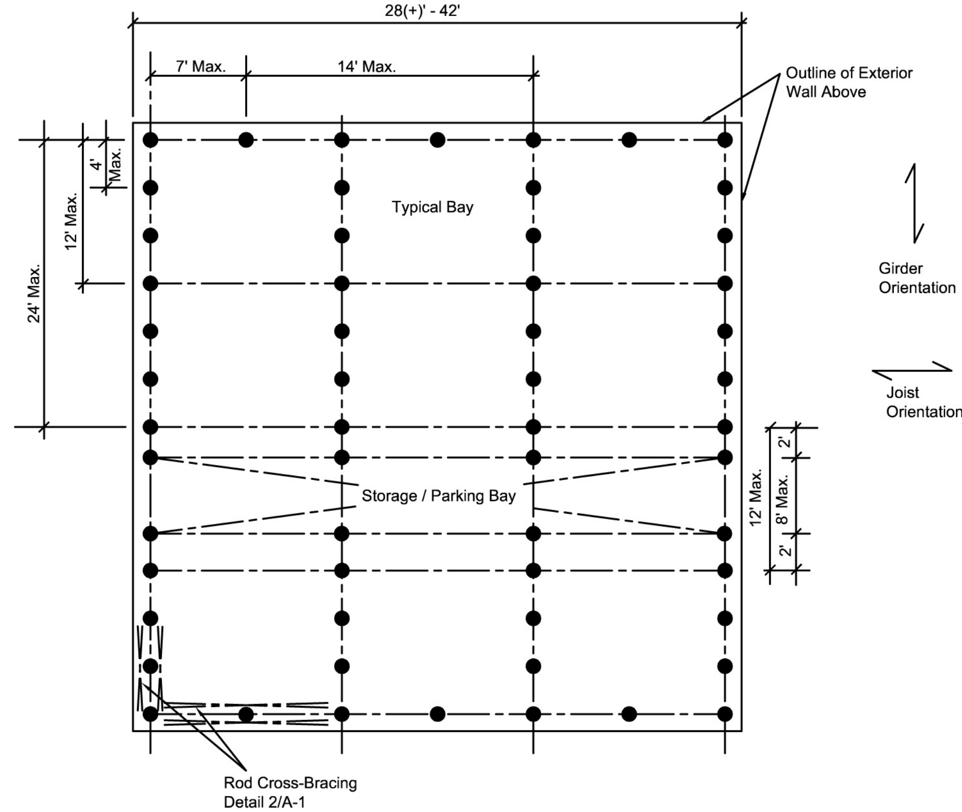


8-Bay Pile Plan



12-Bay Pile Plan

Braced Timber Pile Foundation				
Bracing Schedule - One Story Structures				
"H"	Wind Speed			
	150 mph	140 mph	130 mph	120 mph
< 6 ft *	12	11	10	10
8 ft	14	12	12	11
10 ft	16	14	14	13

Braced Timber Pile Foundation				
Bracing Schedule - Two Story Structures				
"H"	Wind Speed			
	150 mph	140 mph	130 mph	120 mph
< 6 ft *	18	17	16	15
8 ft	20	19	18	17
10 ft	25	24	23	22

1 A-3 Case A Open Foundation - Driven Treated Timber Pile Pile Plan - 2

SCALE: NTS

2 A-3 Case A - Table 1 Driven Treated Timber Pile Pile Bracing Schedule

Bracing Notes:

1) Bracing quantities shown in Table 1 are for "pairs" of 1 inch diameter braces required for each 24 feet of home. Each brace pair shall be installed to form an "X" as shown on Detail 1/A-1 and connected to the pilings with 1 inch through bolts.
2) Bracing quantities shown in Table 1 shall be installed in both directions (across width and length of home). All corner piles and piles adjacent to framed openings in the first floor shall be braced. Bracing in other areas shall be uniformly distributed. Bracing in only one direction can be placed in other areas of the home to create storage/parking areas provided the total number of braces specified is installed.
3) Bracing shall be scaled for homes with other dimensions by the factor (N/24)xL where N is the number of braces shwon in Table 1 and L is the dimension of the home perpendicular to the braces. For example: a 32' by 24' wide one story home located in a 130 mph wind speed zone and elevated 8' requires 20 braces perpendicular to the 32' dimension ((32'/24')x12 braces) and 12 braces perpendicular to the 24' dimension.
4) Rod shall be installed at a maximum angle of 45 degrees to the horizontal and shall be connected to the top of the pile within 12" of the bottom girder and within 12" of exterior grade.
5) Each rod in the brace pairs shall be connected to a single bolt in the piling to create a double shear connection.
6) Up to two braces can be connected to a single pile (in both directions). Brace connection points shall be offset vertically 8" (min) to 12" (max).
7) Provide a tensioning turnbuckle for each rod brace.
8) Two rods and turnbuckles in a brace pair may be substituted with a single rod, turnbuckle and two "U" brackets. U brackets must have an inside diameter of no more than 1 inch greater than pile diameter at the brace point, must be capable of resisting a 7,500# working load without yielding and must transfer loads to the piling without creating torsion forces.
9) Pile Bracing shall not be installed in areas where pile diameter is less than 8 inches
10) * No bracing is required for H < 4 ft.

Case-A Open Foundation
Driven Treated Timber Pile

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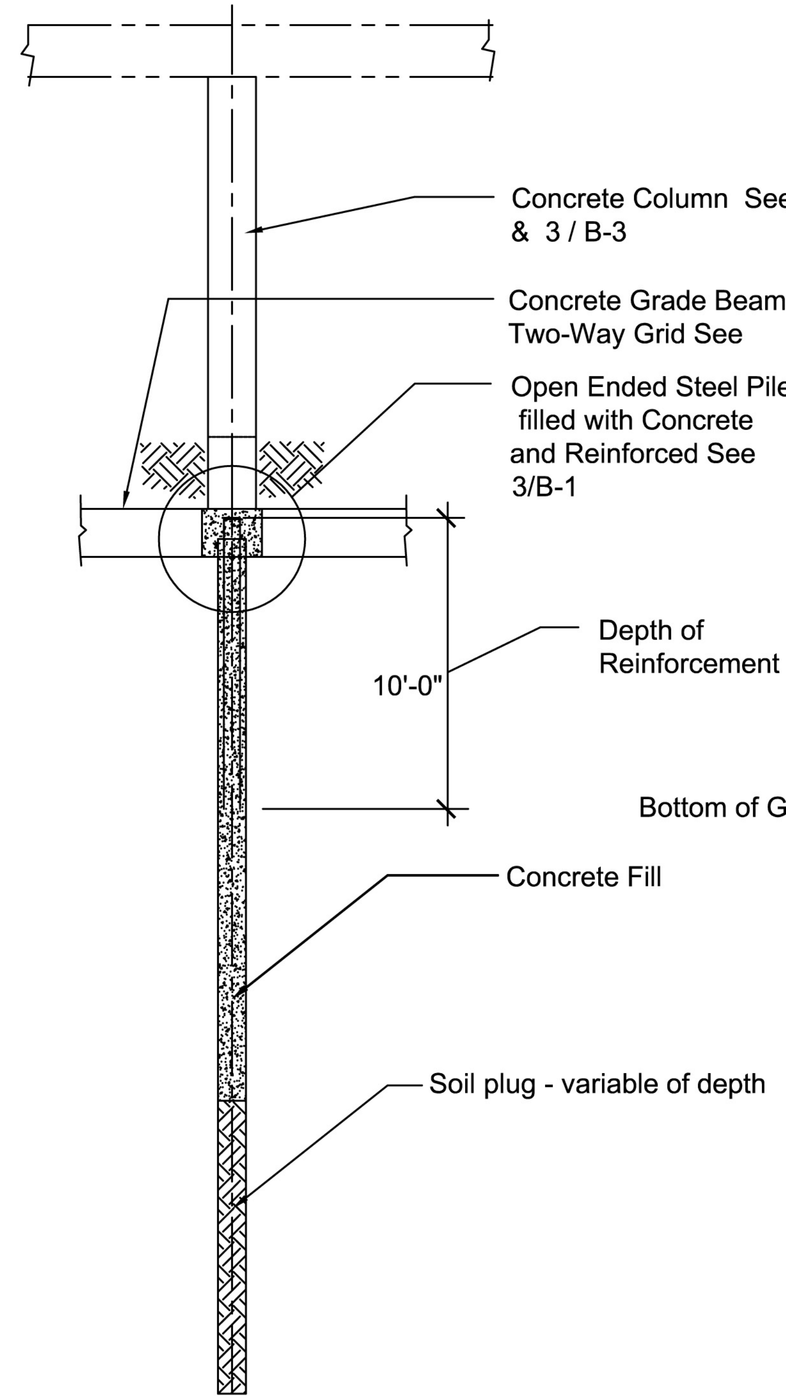
Square Column Size & Reinforcement Schedule								
One Story								
"H"	150 mph		140 mph		130 mph		120 mph	
	Size (sq)	Reinforcing	Size (sq)	Reinforcing	Size (sq)	Reinforcing	Size (sq)	Reinforcing
8 ft	16"	A	16"	A	16"	A	16"	A
10 ft	16"	C	16"	C	16"	B	16"	B
12 ft	18"	D	18"	D	16"	D	16"	D
15 ft	20"	A	20"	A	18"	D	18"	C

Square Column Size & Reinforcement Schedule								
Two Story								
"H"	150 mph		140 mph		130 mph		120 mph	
	Size (sq)	Reinforcing	Size (sq)	Reinforcing	Size (sq)	Reinforcing	Size (sq)	Reinforcing
8 ft	16"	B	16"	B	16"	B	16"	A
10 ft	16"	D	16"	C	16"	C	16"	B
12 ft	18"	D	18"	C	18"	C	18"	B
15 ft	20"	A	20"	A	18"	D	18"	D

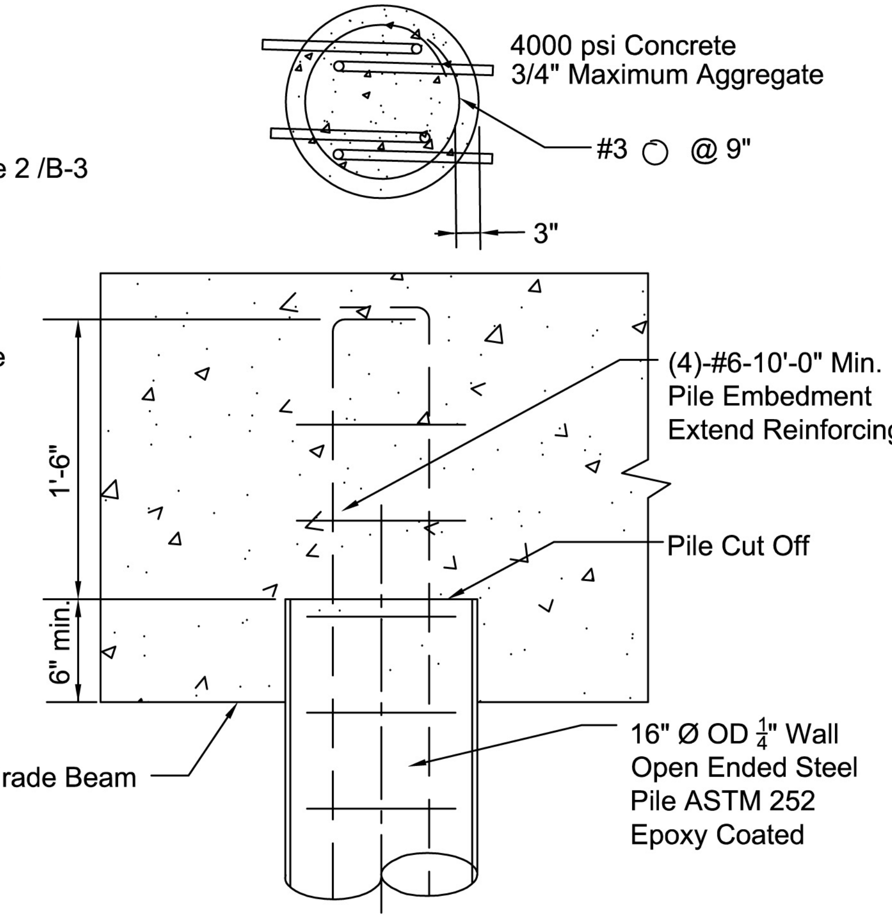
Notes:
1) See Table 2, 3/B3 sheet for Column size and reinforcement details

1 / B-1 Case B Open Foundation - Steel Pile/Concrete Column/Grade Beam
Table 1 Column Schedule



2 / B-1 Case B Open Foundation - Steel Pile/Concrete Column/Grade Beam
Pile Detail
SCALE: NTS

Piles are assumed to have the following capacities:
Compression 20,000 lbs.
Tension 13,400 lbs.
Lateral 8,000 lbs.



3 / B-1 Case B Open Foundation - Steel Pile/Concrete Column/Grade Beam
Pile Detail
SCALE: NTS

Case-B Open Foundation Steel Pipe Pile with Concrete Column and Grade Beam	
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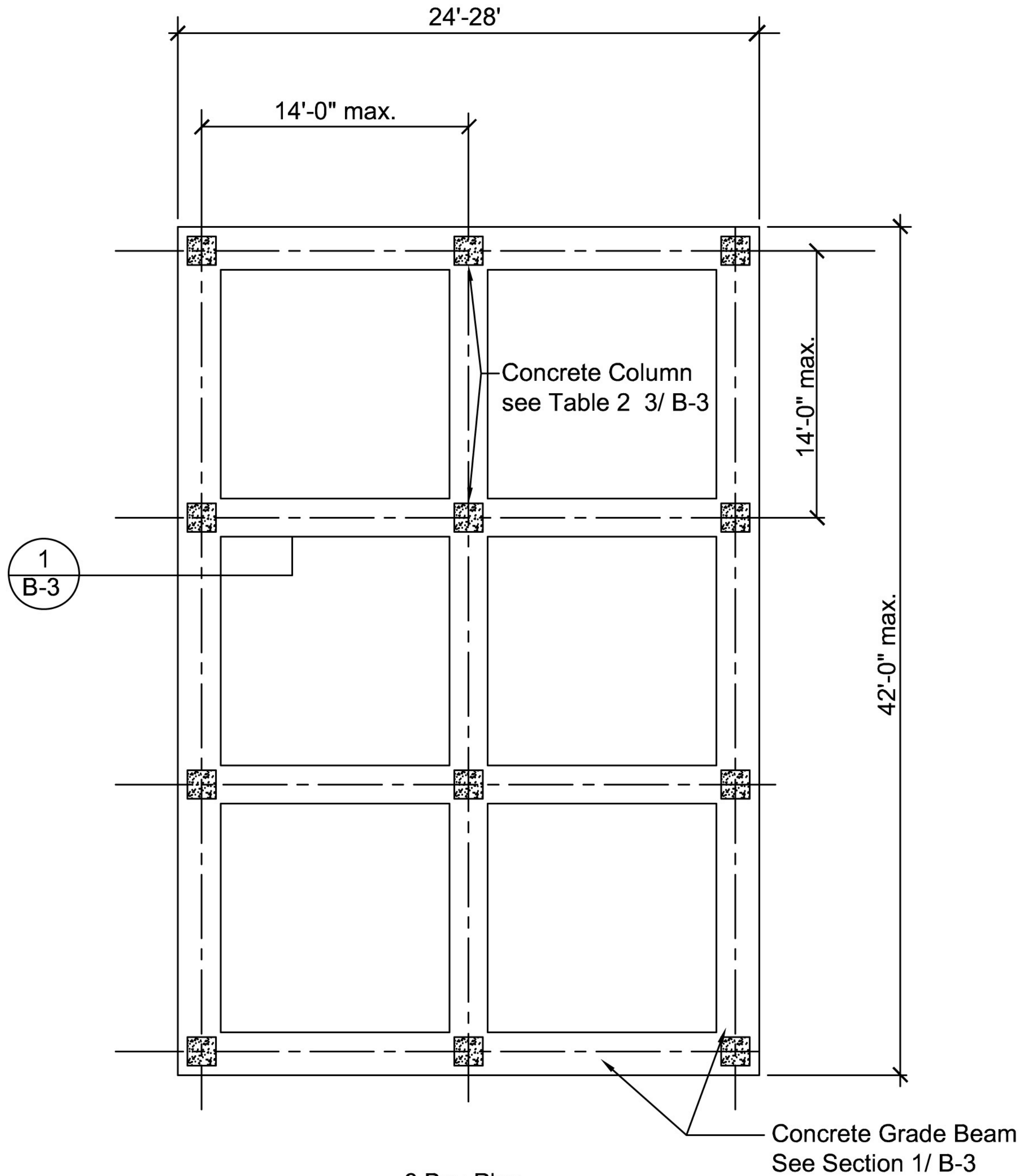
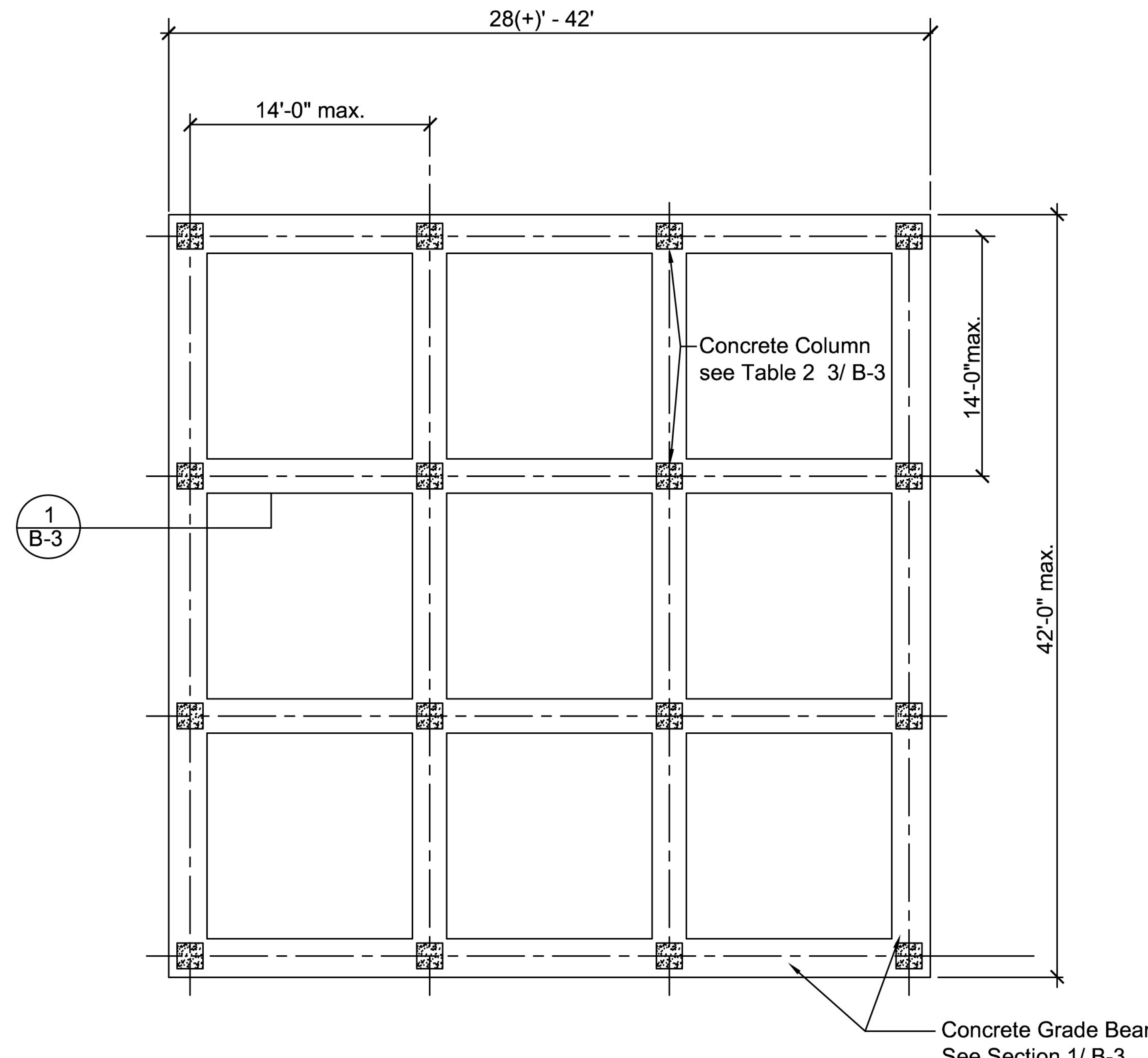


6 Bay Plan



9 Bay Plan

1
B-2
Open Foundation - Column & Grade Beam

SCALE: NTS

Case-B Open Foundation Steel Pipe Pile with Concrete Column and Grade Beam	
DRAWING NO.: B-2	SHEET 12 OF 31
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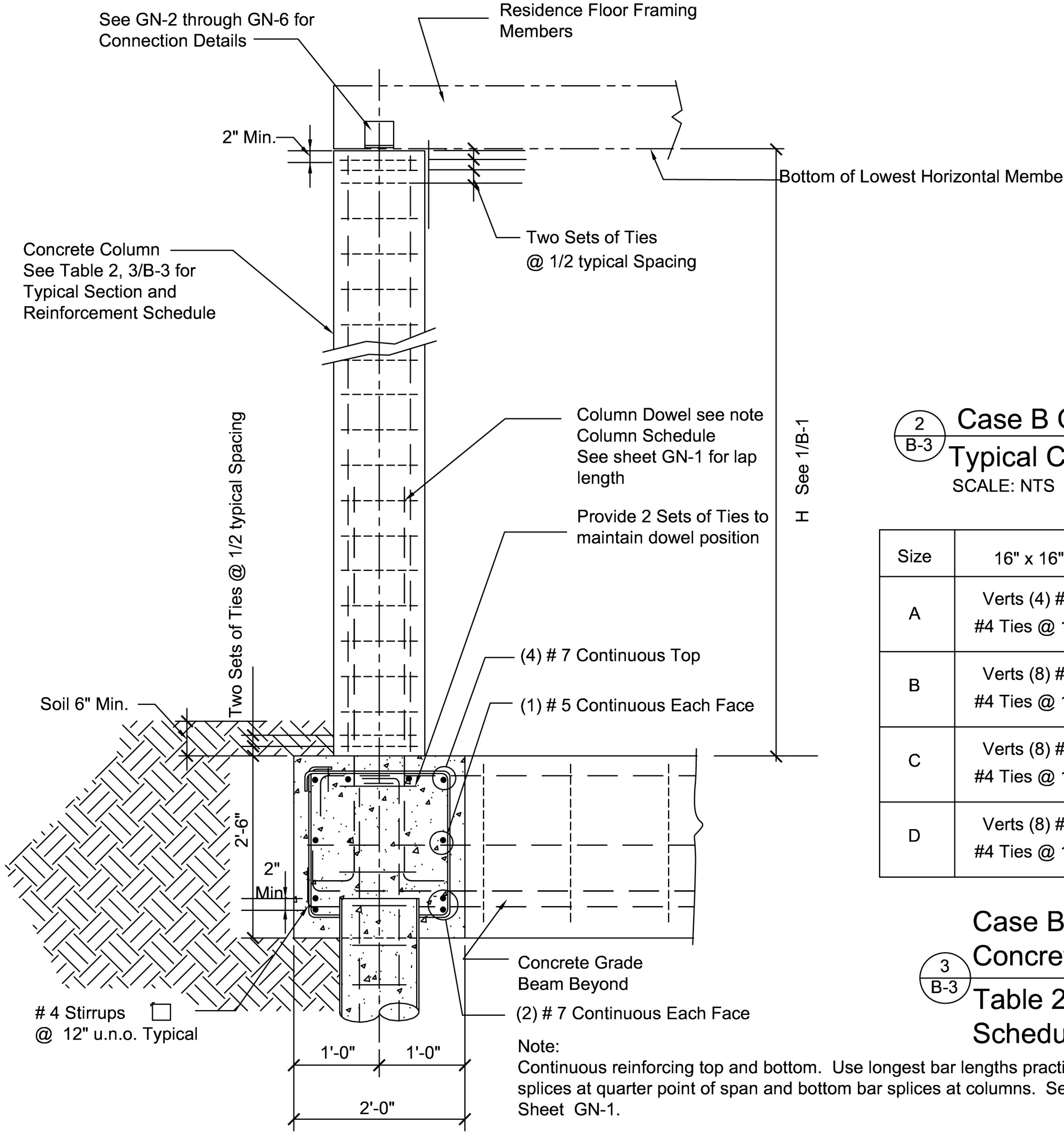
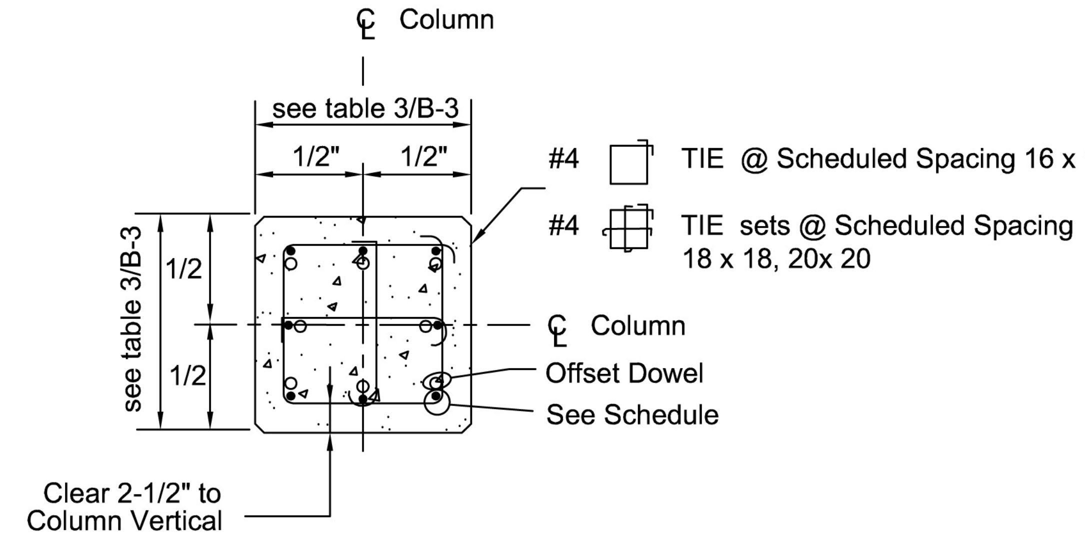


Note:
Continuous reinforcing top and bottom. Use longest bar lengths practical. Place top bar splices at quarter point of span and bottom bar splices at columns. See splice table on Sheet GN-1.

1/B-3 Case B Open Foundation - Steel Pile/Concrete Column/Grade Beam
Column & Grade Beam Section
SCALE: NTS



2/B-3 Case B Open Foundation - Steel Pile/Concrete Column/Grade Beam
Typical Column Section
SCALE: NTS

Size	16" x 16"	18" x 18"	20" x 20"
A	Verts (4) # 9 #4 Ties @ 16"		Verts (8) # 10 #4 Ties @ 18"
B	Verts (8) # 7 #4 Ties @ 14"	Verts (8) # 8 #4 Ties @ 16"	
C	Verts (8) # 8 #4 Ties @ 16"	Verts (8) # 9 #4 Ties @ 18"	
D	Verts (8) # 9 #4 Ties @ 16"	Verts (8) # 10 #4 Ties @ 18"	

Notes:
1) Provide same number and size of dowels as main reinforcing. See splice table on Sheet GN-1.

3/B-3 Case B Open Foundation - Steel Pile/ Concrete Column/Grade Beam
Table 2 - Column Reinforcement Schedule

Case-B Open Foundation
Steel Pipe Pile with Concrete Column and Grade Beam

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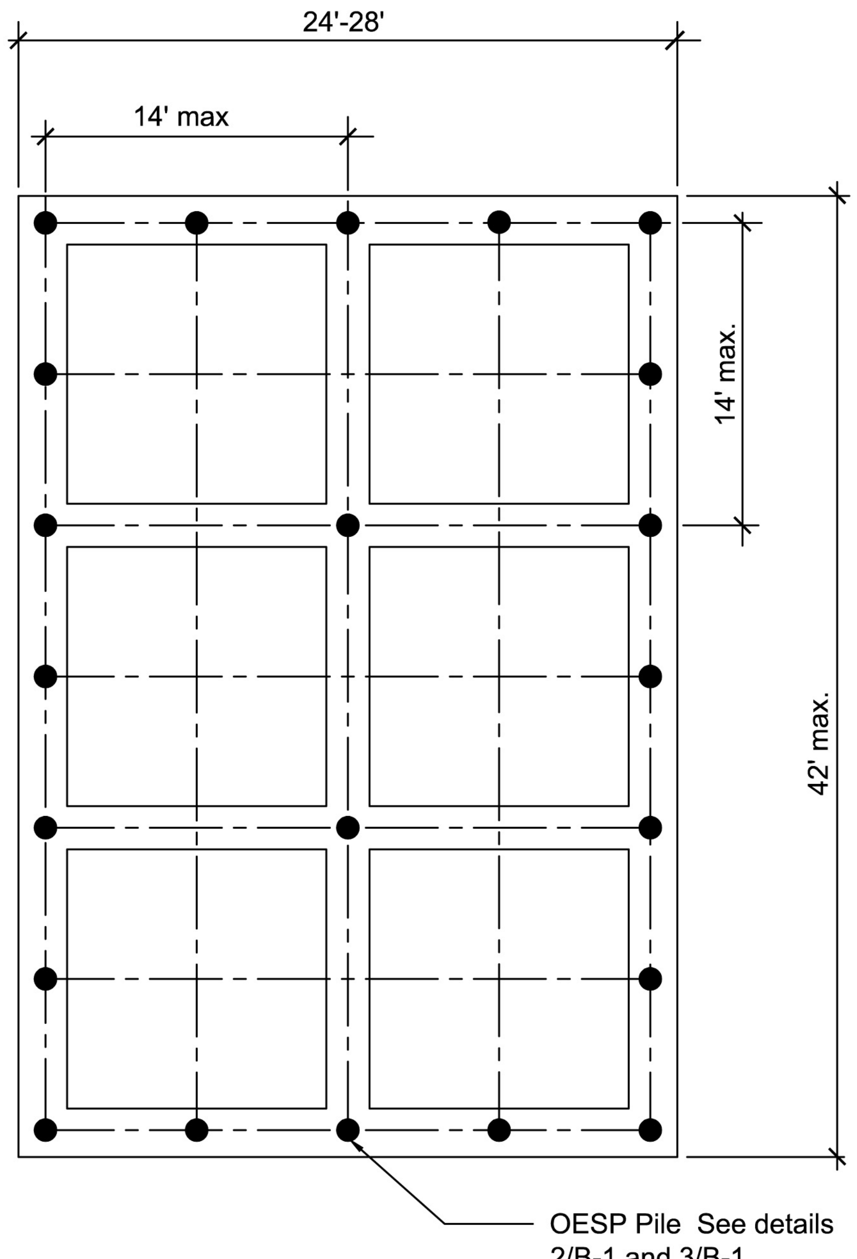
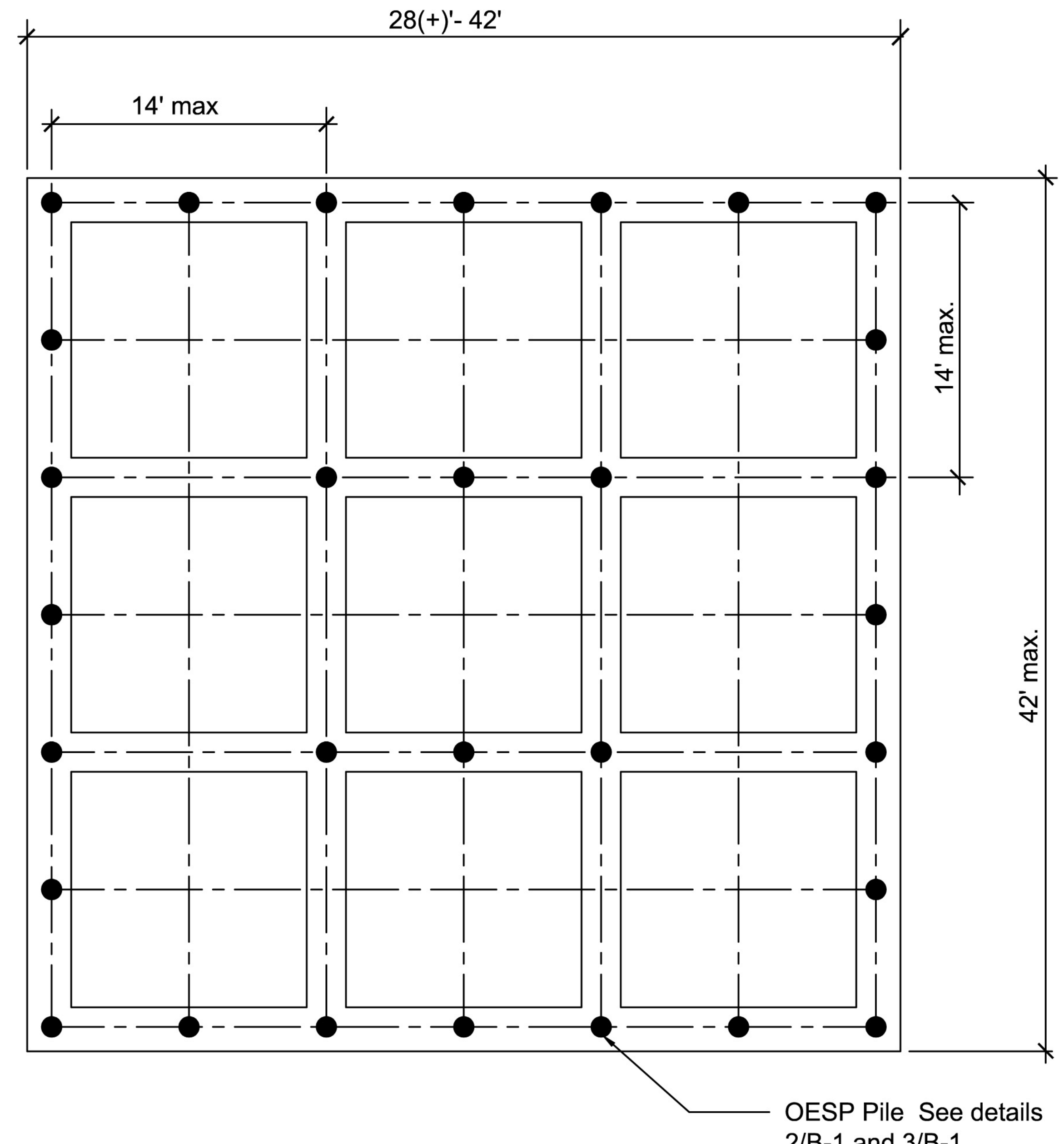
FEMA



6 Bay Pile Plan

One Story and Two Story Residences Height H up to 12' - for winds up to 150 mph



9 Bay Pile Plan

One Story and Two Story Residences Height H up to 15' - for winds up to 150 mph

Case B Open Foundation - Steel Pile/ Concrete Column/Grade Beam

1
B-4

22 Piles
SCALE: NTS

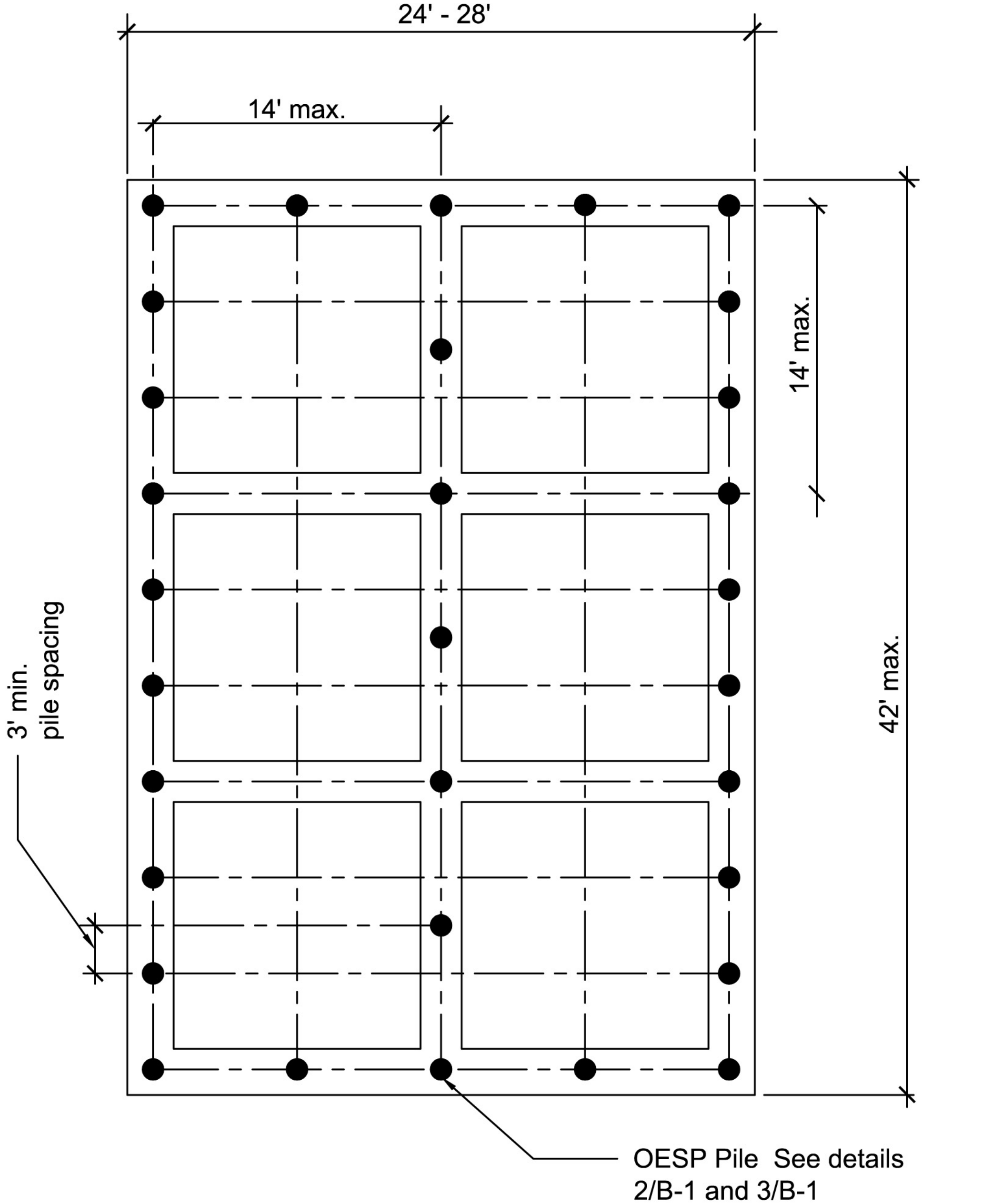
Case B Open Foundation - Steel Pile/ Concrete Column/Grade Beam

2
B-4

30 Piles
SCALE: NTS

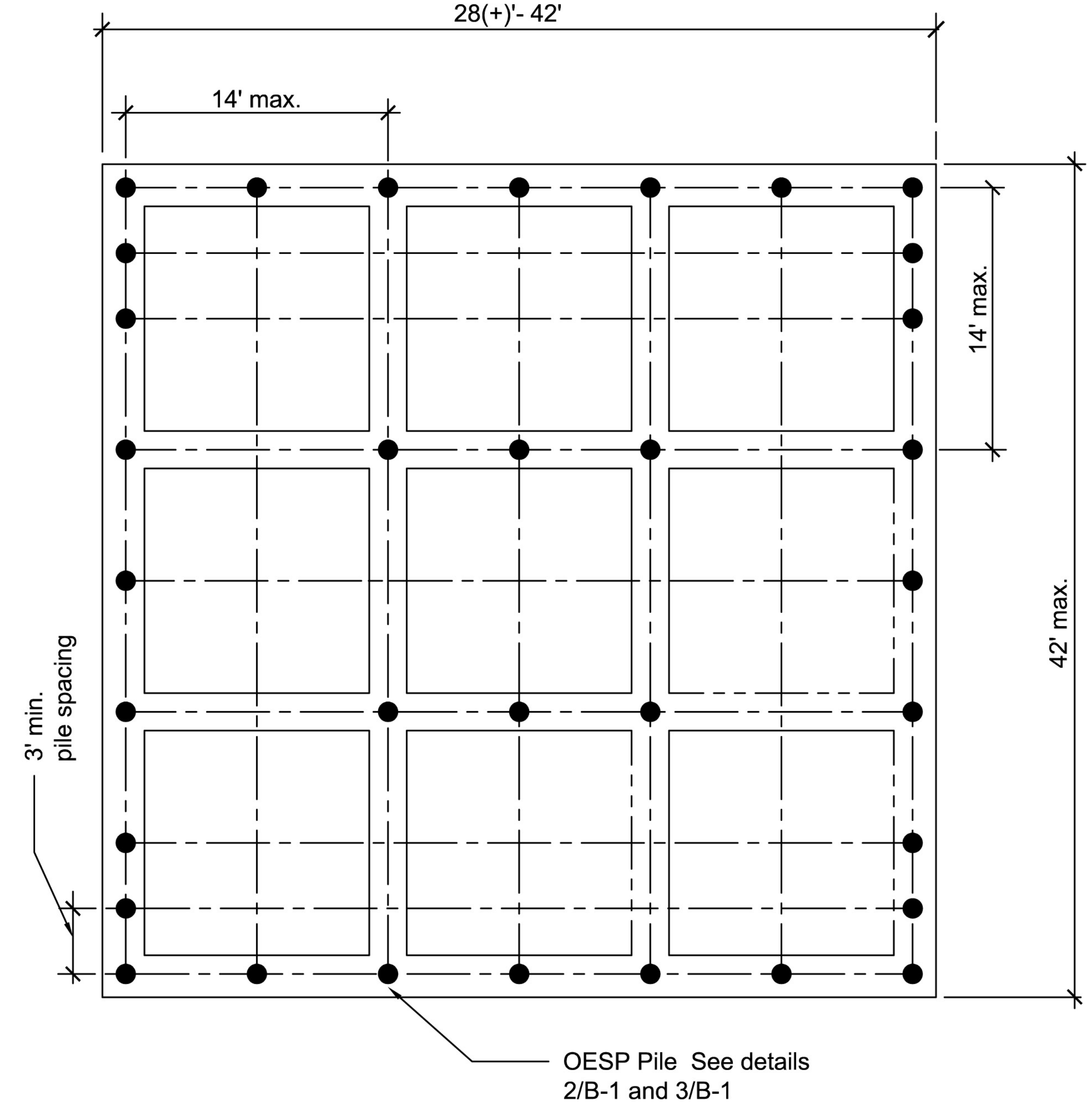
Case-B Open Foundation Steel Pipe Pile with Concrete Column and Grade Beam	
DRAWING NO.: B-4	SHEET 14 OF 31
DATE: August 8, 2006	
REVISED:	REV. 9

FEMA



6 Bay Pile Plan

One Story and Two Story Residences Height H up to 12' - for winds up to 150 mph



9 Bay Pile Plan

One Story and Two Story Residences Height H up to 15' - for winds up to 150 mph

1
B-5

Case B Open Foundation - Steel Pile/
Concrete Column/Grade Beam

31 PILES
SCALE: NTS

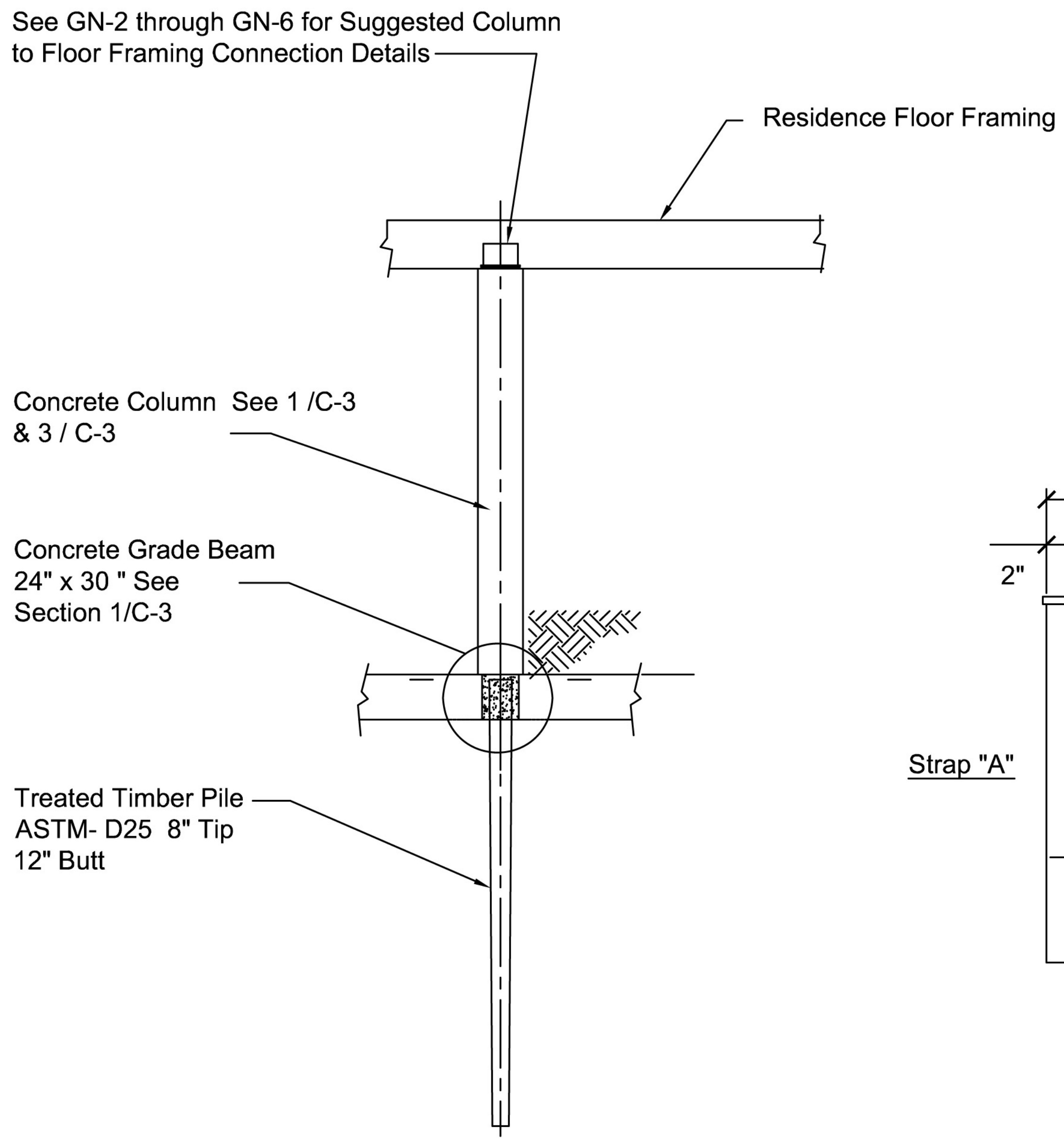
2
B-5

Case B Open Foundation - Steel Pile/
Concrete Column/Grade Beam

36 PILES
SCALE: NTS

Case-B Open Foundation Steel Pipe Pile with Concrete Column and Grade Beam	
DRAWING NO.: B-5	SHEET 15 OF 31
DATE: August 8, 2006	
REVISED:	REV. 9

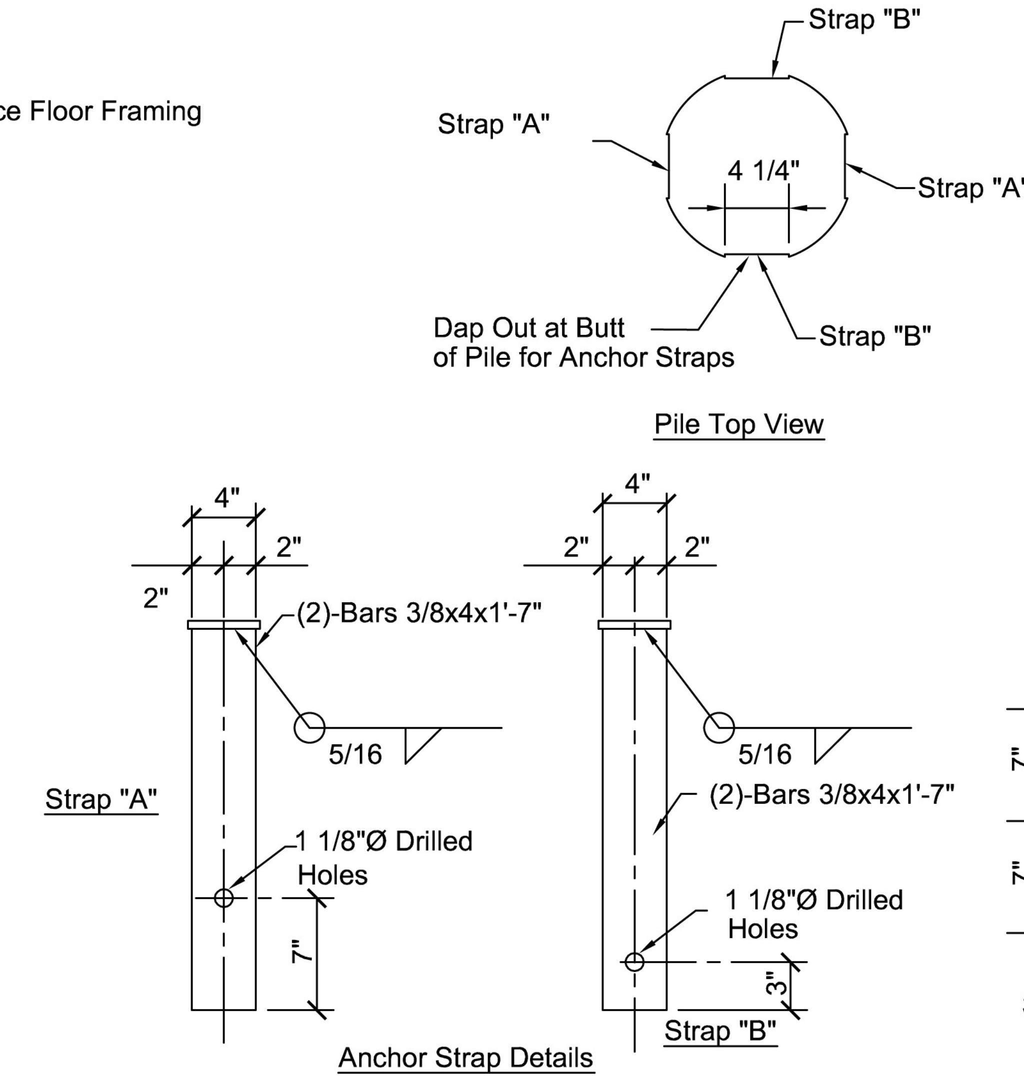
FEMA

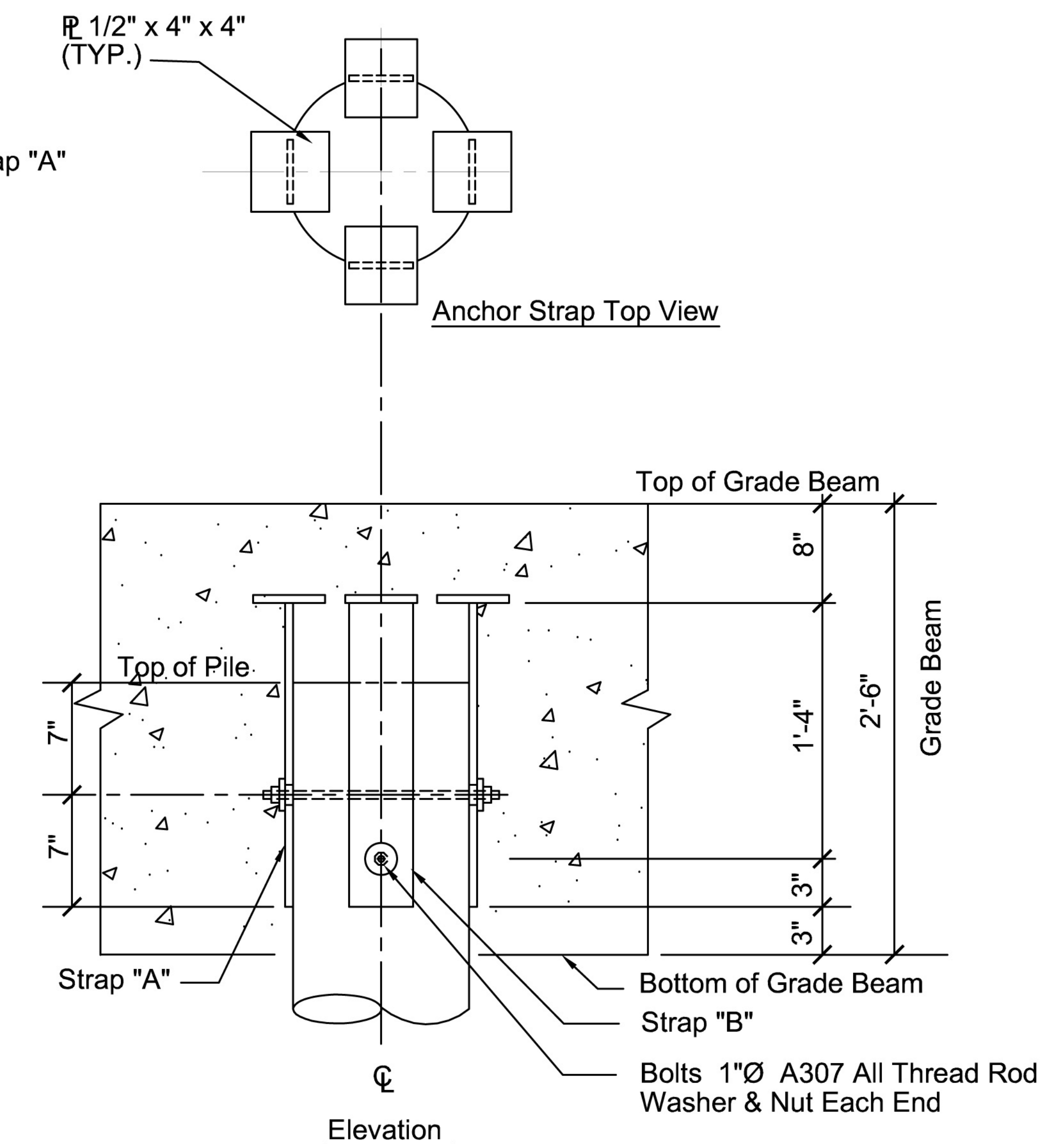


Case C Open Foundation - Concrete Column / Driven Treated Timber Pile Profile

1 / C-1

SCALE: NTS

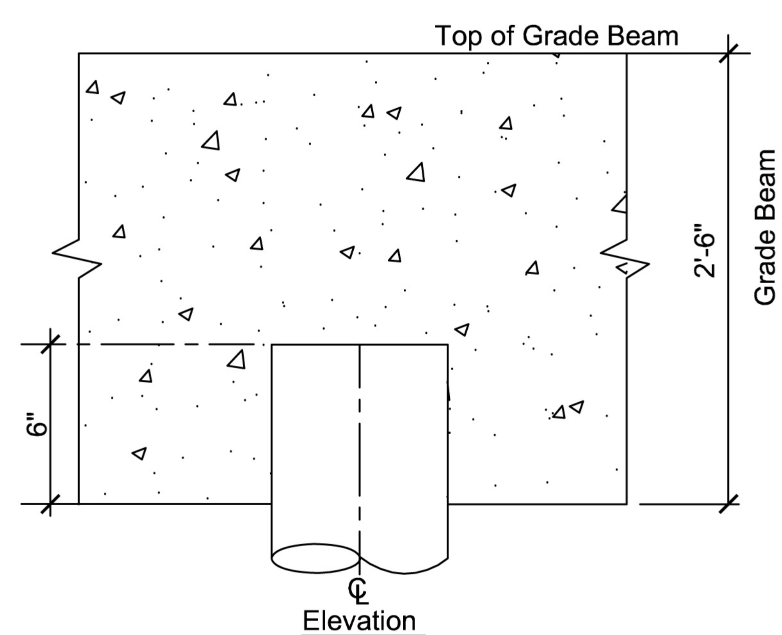




Case C Open Foundation - Timber Pile with Concrete Column & Grade Beam Tension Connection Details

2 / C-1

SCALE: NTS



Case C Open Foundation - Timber Pile with Concrete Column & Grade Beam Non-Tension Pile Detail

3 / C-1

SCALE: NTS

Piles are assumed to have the following capacities:

Compression	14000 pounds
Tension	9300 pounds
Lateral	4000 pounds

Case - C Open Foundation Timber Pile with Concrete Column and Grade Beam	
DRAWING NO.: C-1	SHEET 16 OF 31
DATE: August 8, 2006	
REVISED:	REV. 9

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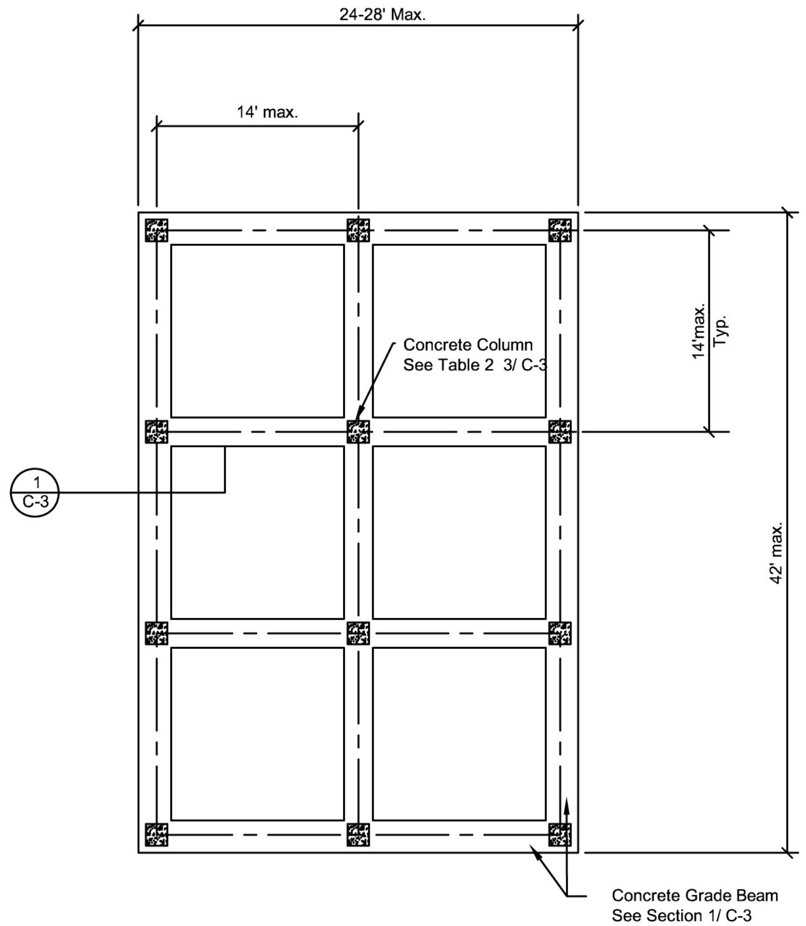


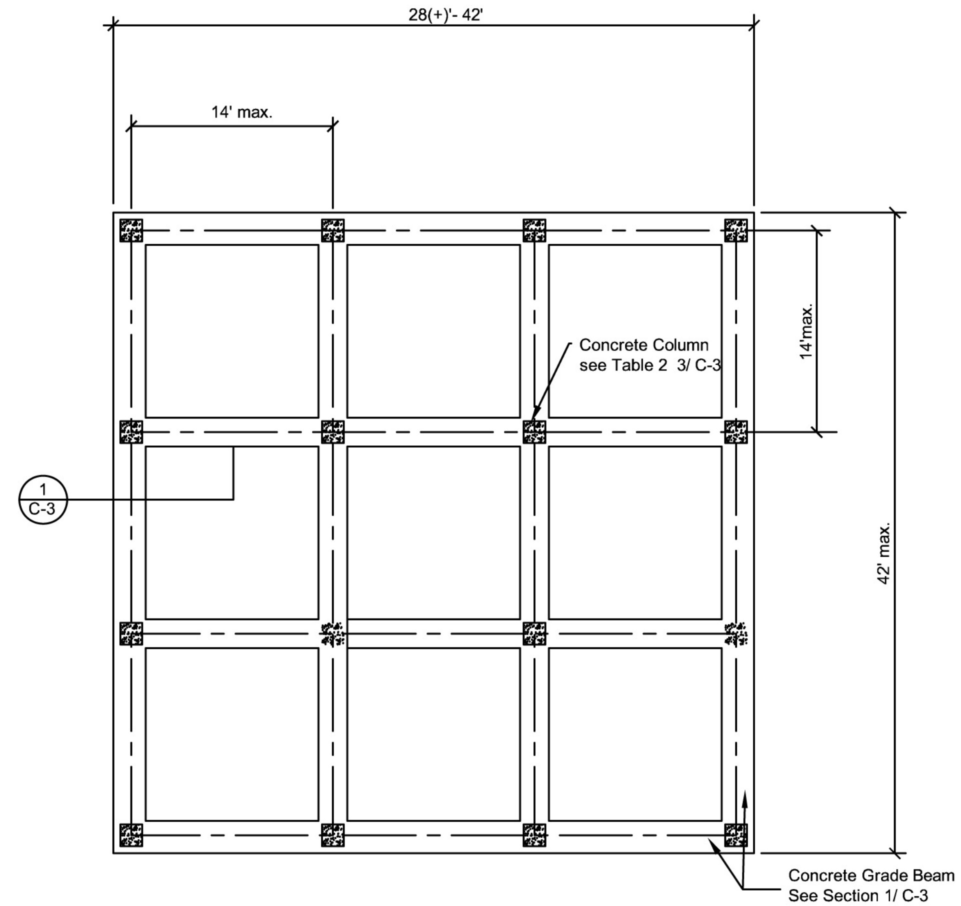
6 Bay Column Plan

Case C Open Foundation - Timber Pile with Concrete Column & Grade Beam

1
C-2

Plan

SCALE: NTS



9 Bay Column Plan

Case C Open Foundation - Timber Pile with Concrete Column & Grade Beam

2
C-2

Plan

SCALE: NTS

Column Size & Reinforcement Schedule - One Story

"H"	150 mph		140 mph		130 mph		120 mph	
	Size (sq)	Reinforcing	Size (sq)	Reinforcing	Size (sq)	Reinforcing	Size (sq)	Reinforcing
8 ft	16"	A	16"	A	16"	A	16"	A
10 ft	16"	C	16"	C	16"	B	16"	B
12 ft	18"	D	18"	D	16"	D	16"	D
15 ft	20"	A	20"	A	18"	D	18"	C

Column Size & Reinforcement Schedule - Two Story

"H"	150 mph		140 mph		130 mph		120 mph	
	Size (sq)	Reinforcing	Size (sq)	Reinforcing	Size (sq)	Reinforcing	Size (sq)	Reinforcing
8 ft	16"	B	16"	B	16"	B	16"	A
10 ft	16"	D	16"	C	16"	C	16"	B
12 ft	18"	D	18"	C	18"	C	18"	B
15 ft	20"	A	20"	A	18"	D	18"	D

Case C Open Foundation - Timber Pile with Concrete Column & Grade Beam

3
C-2

Schedule

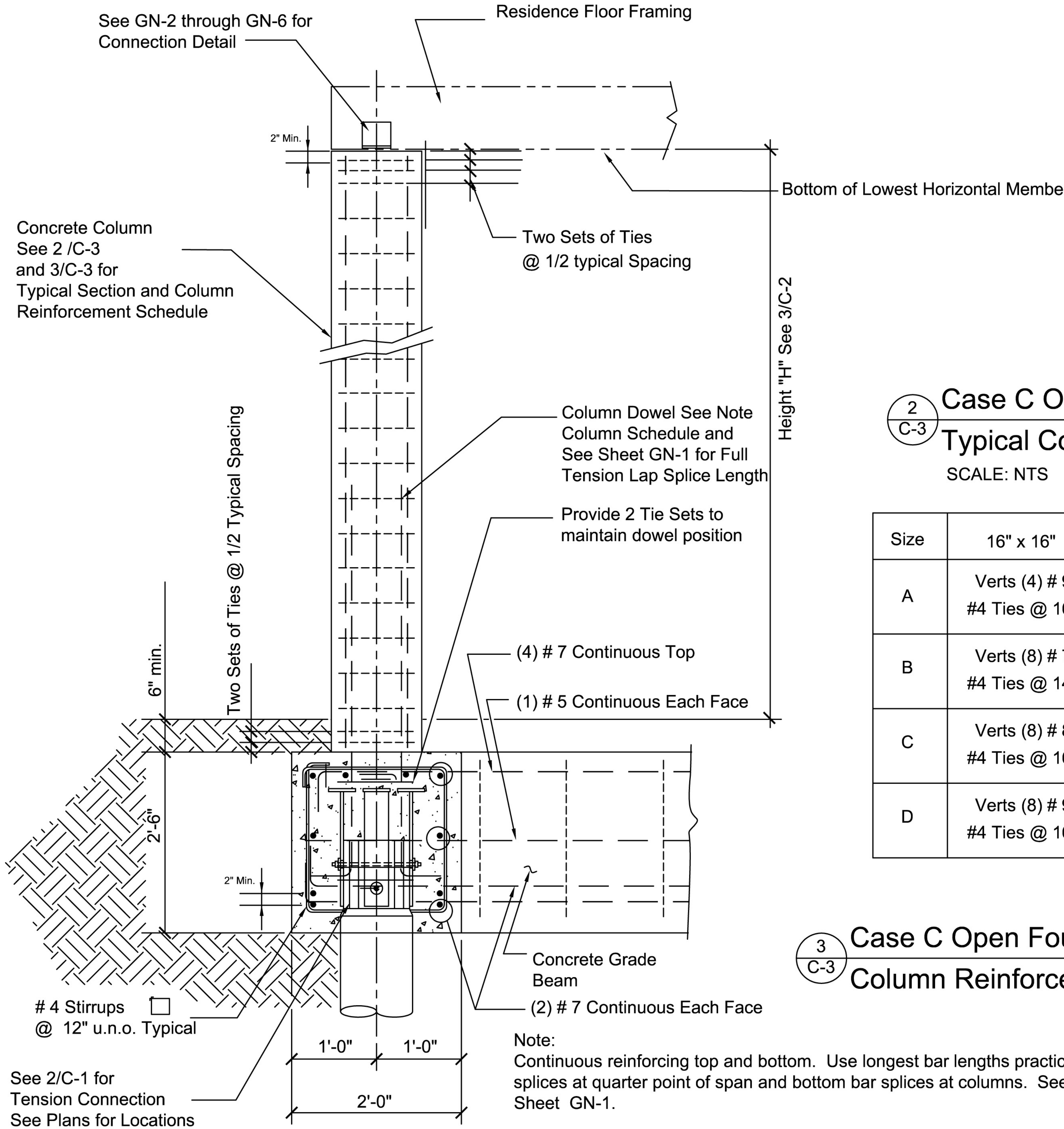
Notes:

1) See Table 2, 3/C3 sheet for Column size and reinforcement details

Case- C Open Foundation Timber Pile with Concrete Column and Grade Beam	
DRAWING NO.: C-2	SHEET 17 OF 31
DATE: August 8, 2006	
REVISED:	REV. 9

U.S. DEPARTMENT OF HOMELAND SECURITY

FEMA

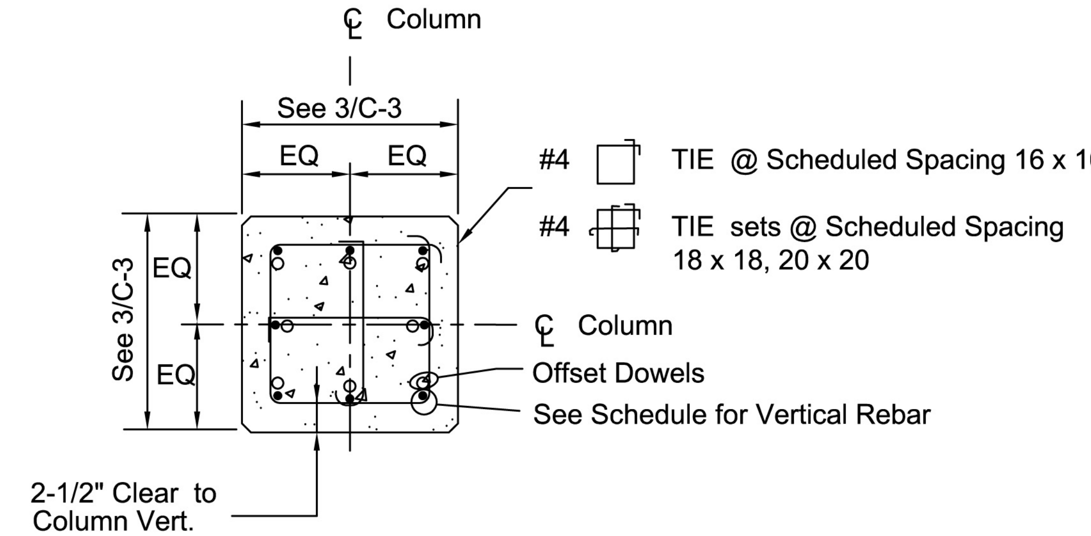


Note:
Continuous reinforcing top and bottom. Use longest bar lengths practical. Place top bar splices at quarter point of span and bottom bar splices at columns. See splice table on Sheet GN-1.

1
C-3

Case C Open Foundation - Concrete Column/ Timber Pile Foundation
Column & Grade Beam Section

SCALE: NTS



2
C-3

Case C Open Foundation - Concrete Column/ Timber Pile Foundation
Typical Column Section

SCALE: NTS

Size	16" x 16"	18" x 18"	20" x 20"
A	Verts (4) # 9 #4 Ties @ 16"		Verts (8) # 10 #4 Ties @ 18"
B	Verts (8) # 7 #4 Ties @ 14"	Verts (8) # 8 #4 Ties @ 16"	
C	Verts (8) # 8 #4 Ties @ 16"	Verts (8) # 9 #4 Ties @ 18"	
D	Verts (8) # 9 #4 Ties @ 16"	Verts (8) # 10 #4 Ties @ 18"	

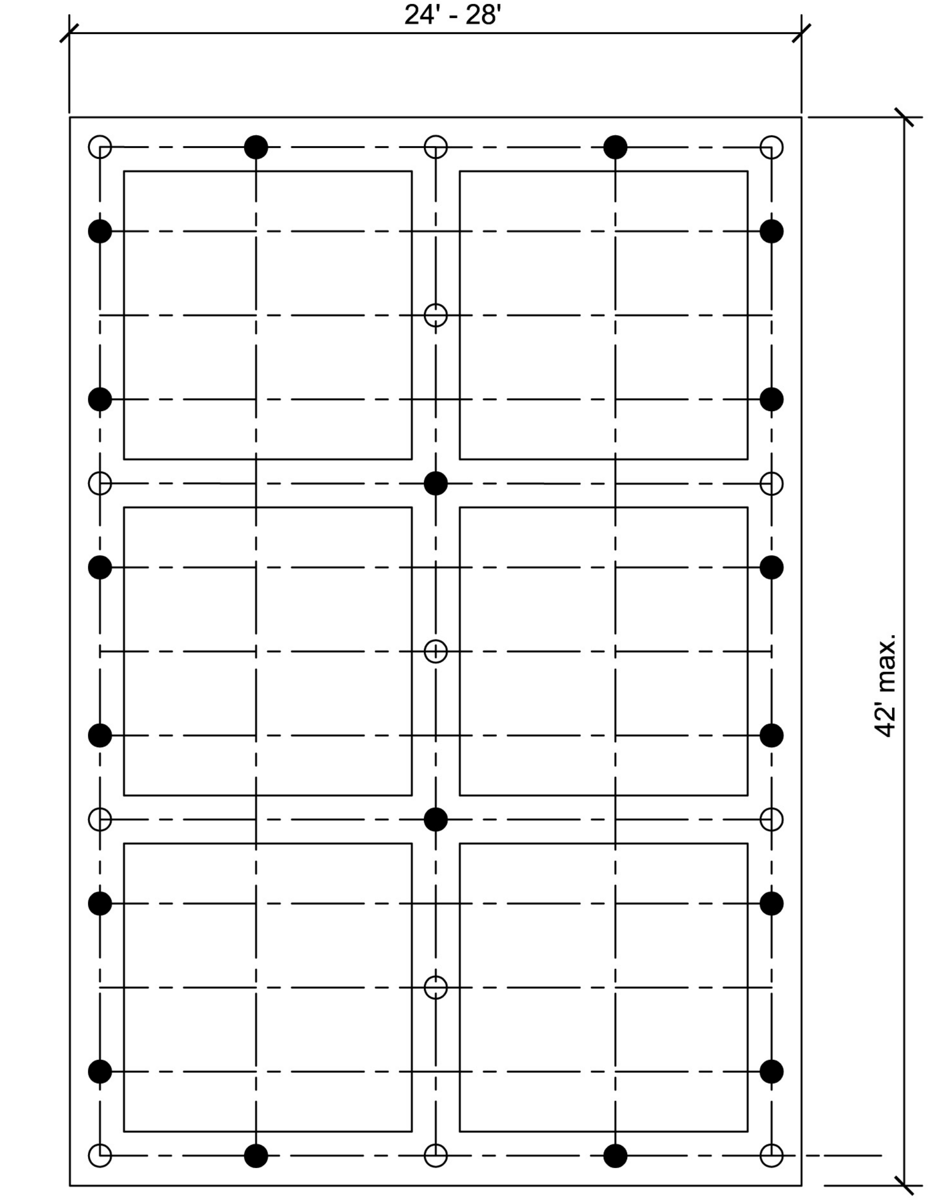
Notes:
1) Provide same number and size of dowels as main reinforcing. See splice table on Sheet GN-1.

3
C-3

Case C Open Foundation - Table 2
Column Reinforcement Schedule

Case- C Open Foundation Timber Pile with Concrete Column and Grade Beam	
DRAWING NO.: C-3	SHEET 18 OF 31
DATE: August 8, 2006	
REVISED:	REV. 9

FEMA



6 Bay Pile Plan

LEGEND

● Tension Pile--See 2/C-1

○ Non-Tension Pile--See 3/C-1

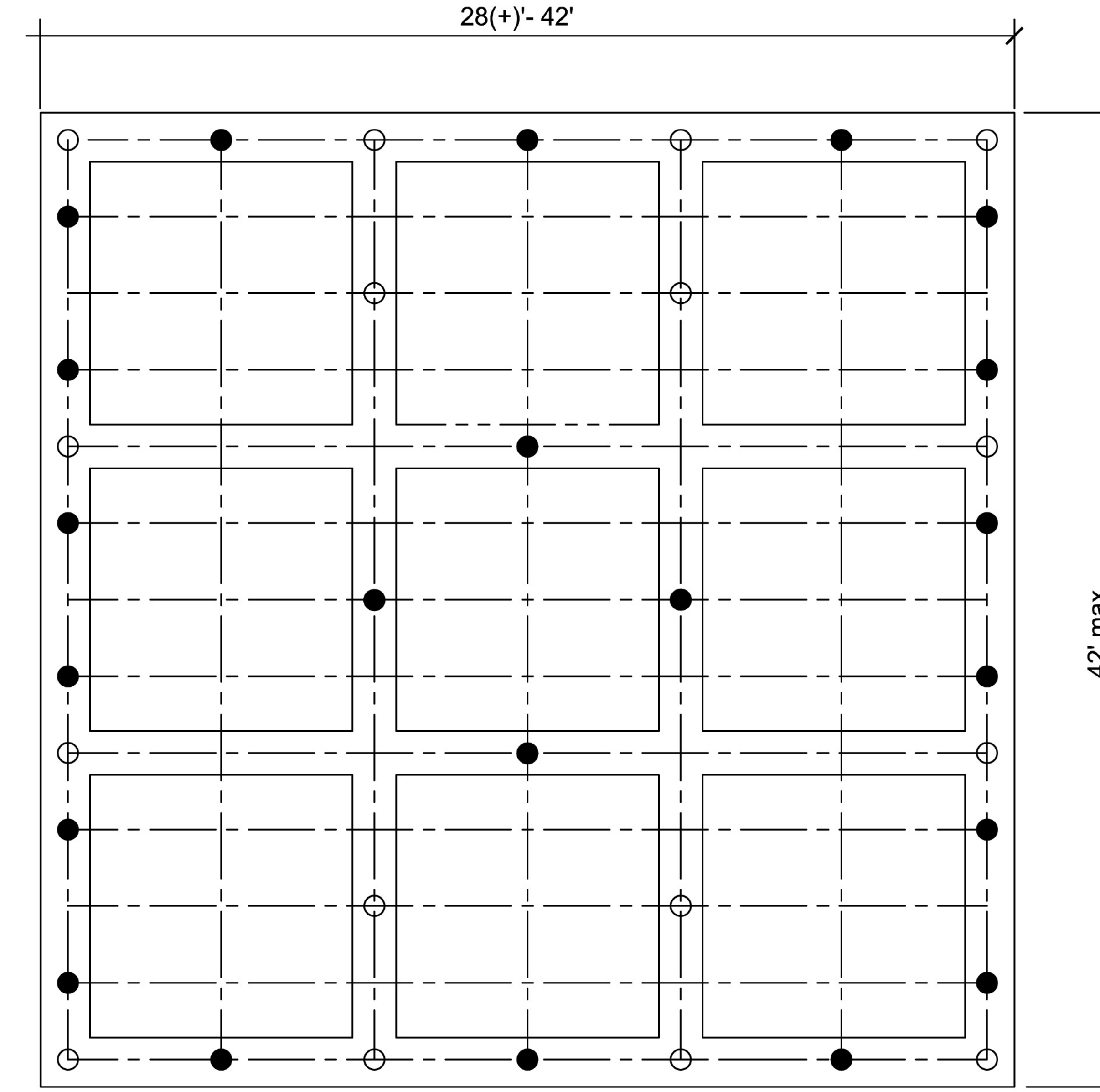
One and Two Story Residences Height H up to 10' - for winds up to 140 mph

1
C-4

Case C Open Foundation - Timber Pile with Concrete Column & Grade Beam

Pile Plan

31 PILES
SCALE: NTS



9 Bay Pile Plan

LEGEND

● Tension Pile--See 2/C-1

○ Non-Tension Pile--See 3/C-1

One and Two Story Residences Height H up to 10' - for winds up to 140 mph

2
C-4

Case C Open Foundation - Timber Pile with Concrete Column & Grade Beam

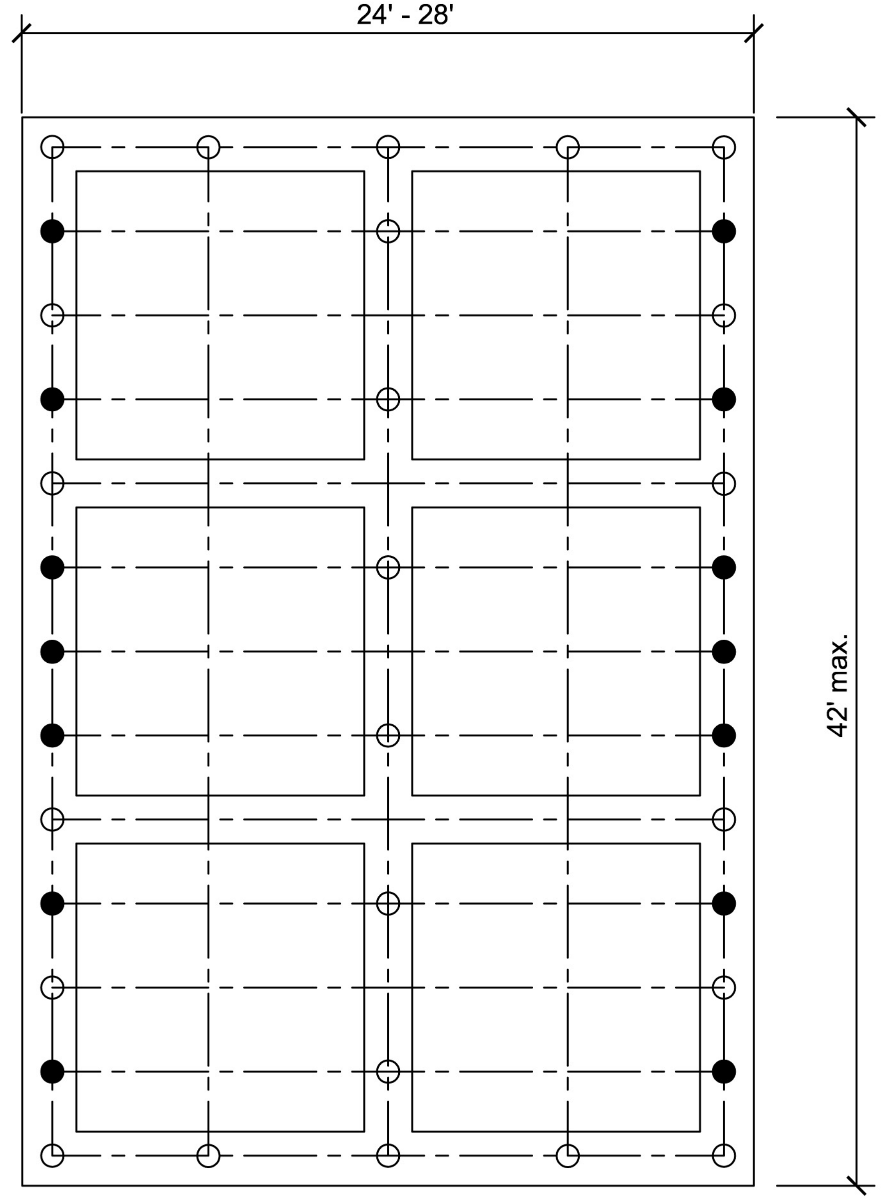
Pile Plan

38 PILES
SCALE: NTS

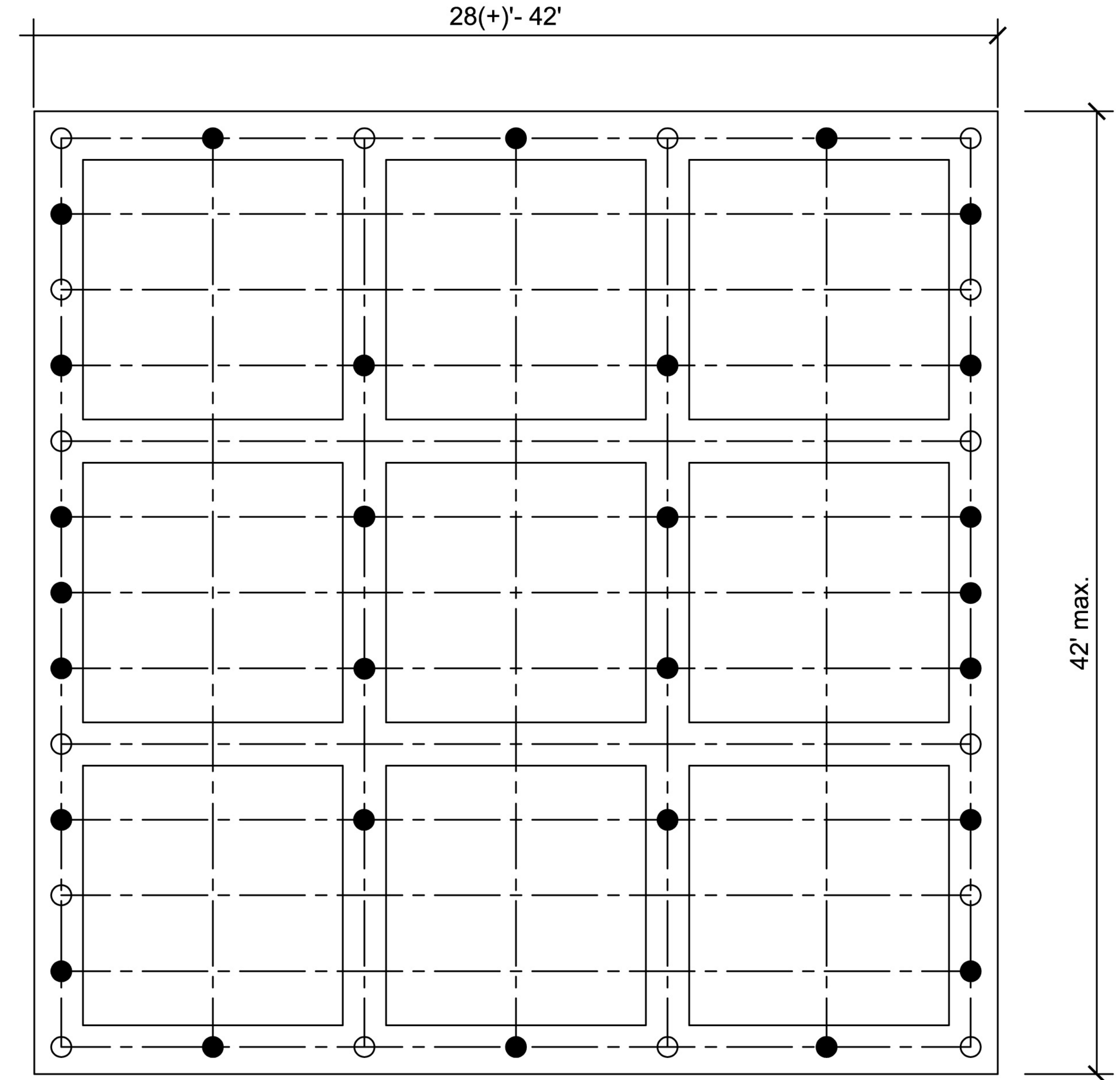
Case- C Open Foundation Timber Pile with Concrete Column and Grade Beam	
DRAWING NO.: C-4	SHEET 19 OF 31
DATE: August 8, 2006	
REVISED:	REV. 9

U.S. DEPARTMENT OF HOMELAND SECURITY

FEMA



6 Bay Pile Plan



9 Bay Pile Plan

LEGEND

● Tension Pile--See 2/C-1

○ Non-Tension Pile--See 3/C-1

One and Two Story Residences Height H up to 10' - for winds up to 150 mph

1 C-5 Case C Open Foundation - Timber Pile with Concrete Column & Grade Beam

Pile Plan

38 PILES

SCALE: NTS

LEGEND

● Tension Pile--See 2/C-1

○ Non-Tension Pile--See 3/C-1

One and Two Story Residences Height H up to 10' - for winds up to 150 mph

2 C-5 Case C Open Foundation - Timber Pile with Concrete Column & Grade Beam

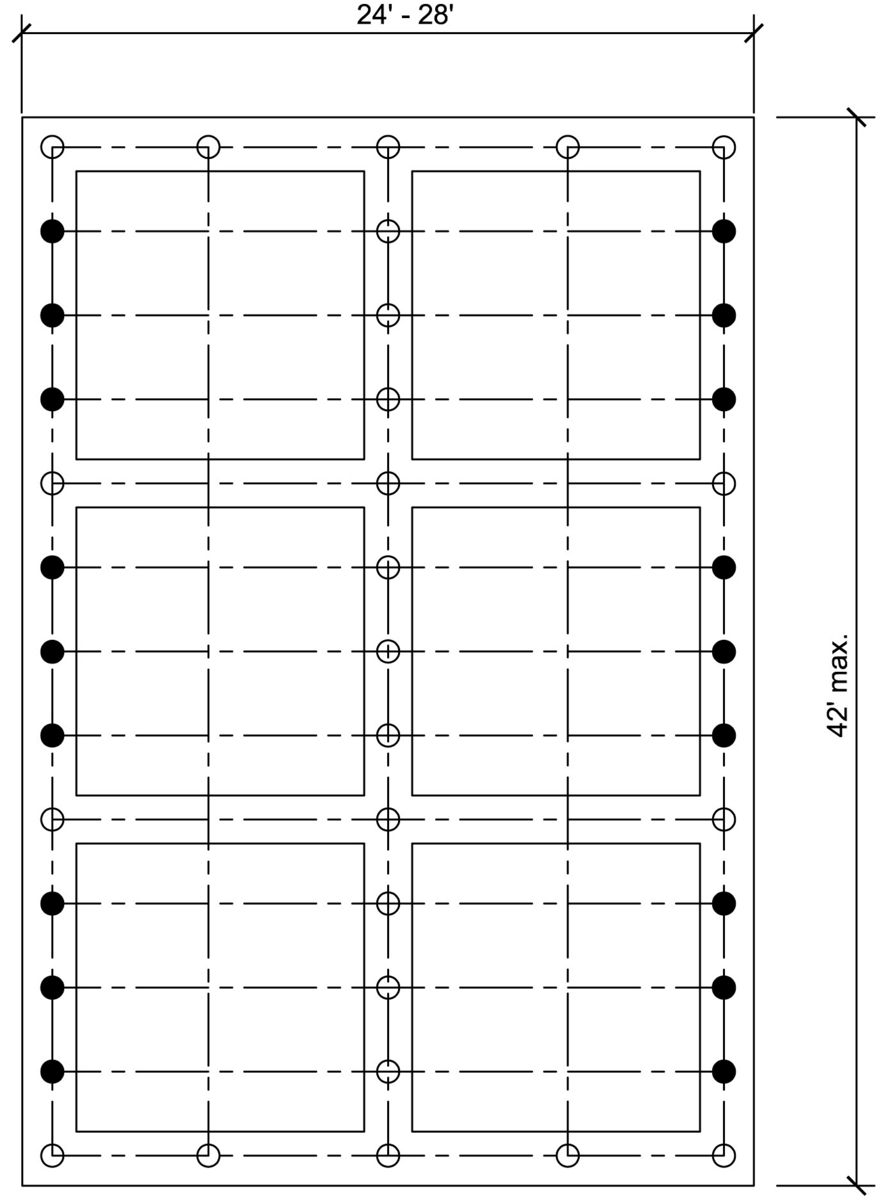
Pile Plan

44 PILES

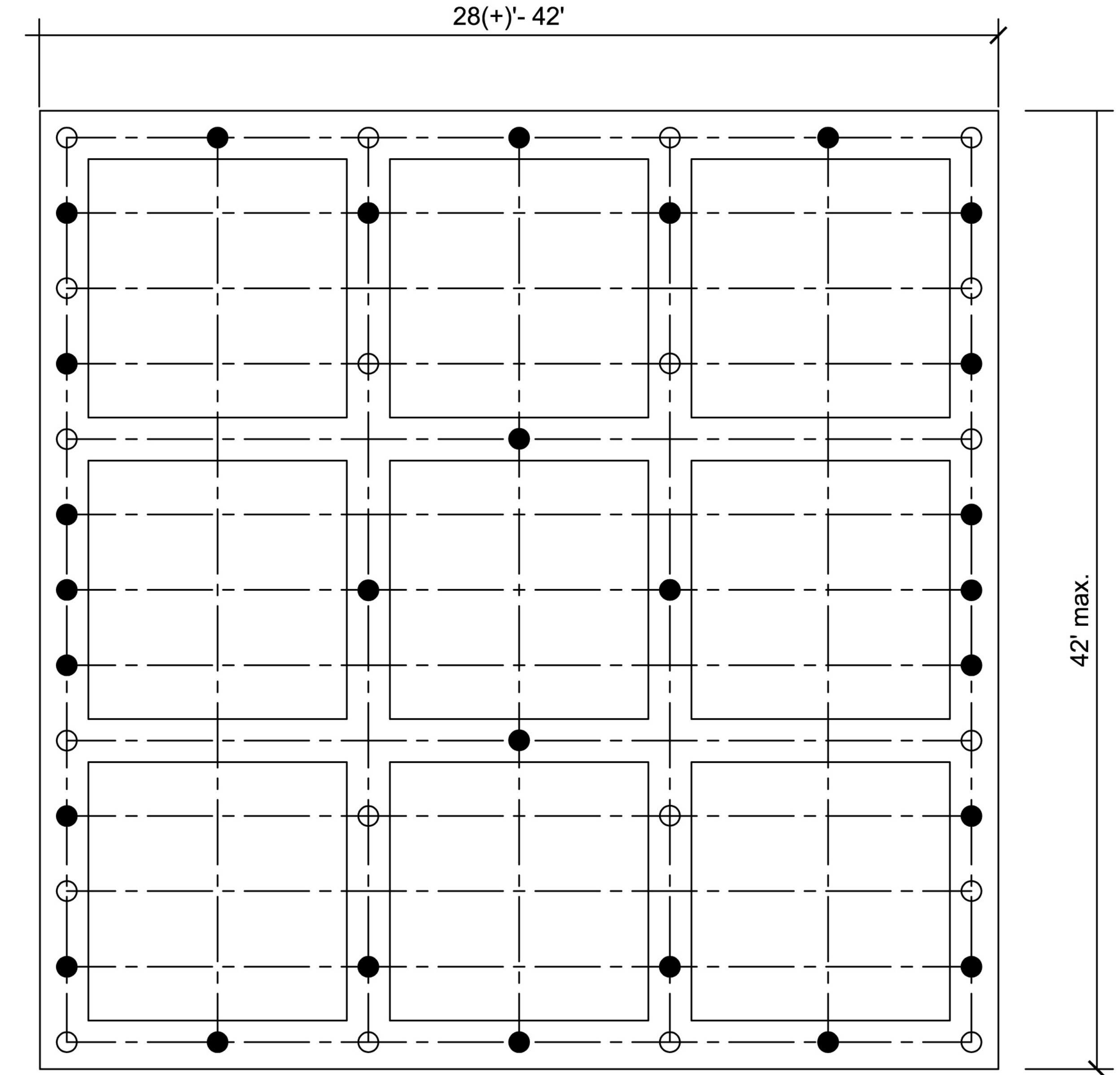
SCALE: NTS

Case- C Open Foundation Timber Pile with Concrete Column and Grade Beam	
DRAWING NO.: C-5	SHEET 20 OF 31
DATE: August 8, 2006	
REVISED:	REV. 9

FEMA



6 Bay Pile Plan



9 Bay Pile Plan

LEGEND

- ● Tension Pile--See 2/C-1
- ○ Non-Tension Pile--See 3/C-1

One Story & Two Story Residences Height H
up to 15' - for winds up to 150 mph

1 C-6 Case C Open Foundation - Timber Pile with Concrete Column & Grade Beam Pile Plan

43 PILES
SCALE: NTS

LEGEND

- ● Tension Pile--See 2/C-1
- ○ Non-Tension Pile--See 3/C-1

One Story & Two Story Residences Height H
up to 15' - for winds up to 150 mph

2 C-6 Case C Open Foundation - Timber Pile with Concrete Column & Grade Beam Pile Plan

48 PILES
SCALE: NTS

Case- C Open Foundation Timber Pile with Concrete Column and Grade Beam	
DRAWING NO.: C-6	SHEET 21 OF 31
DATE: August 8, 2006	
REVISED:	REV. 9

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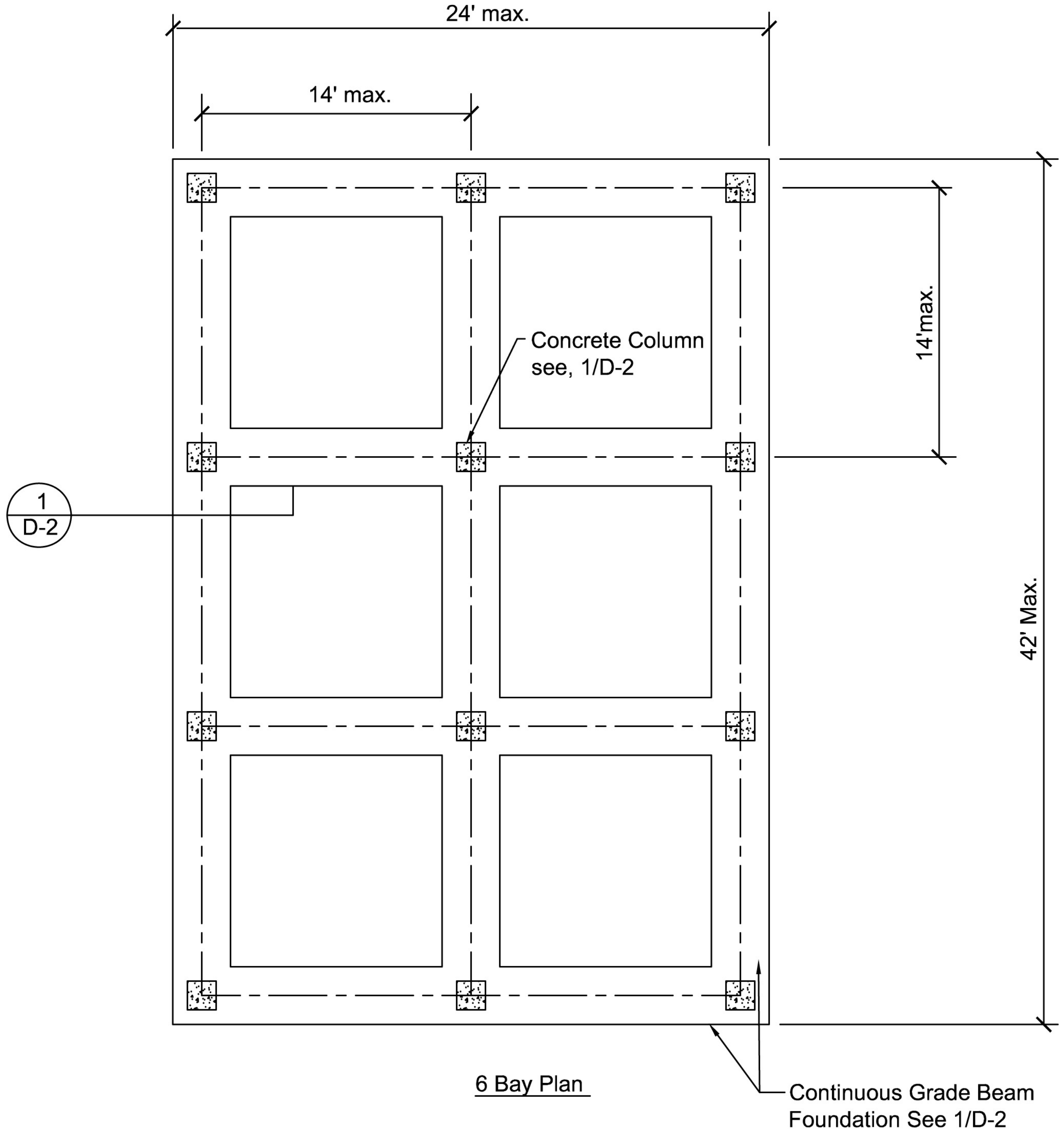
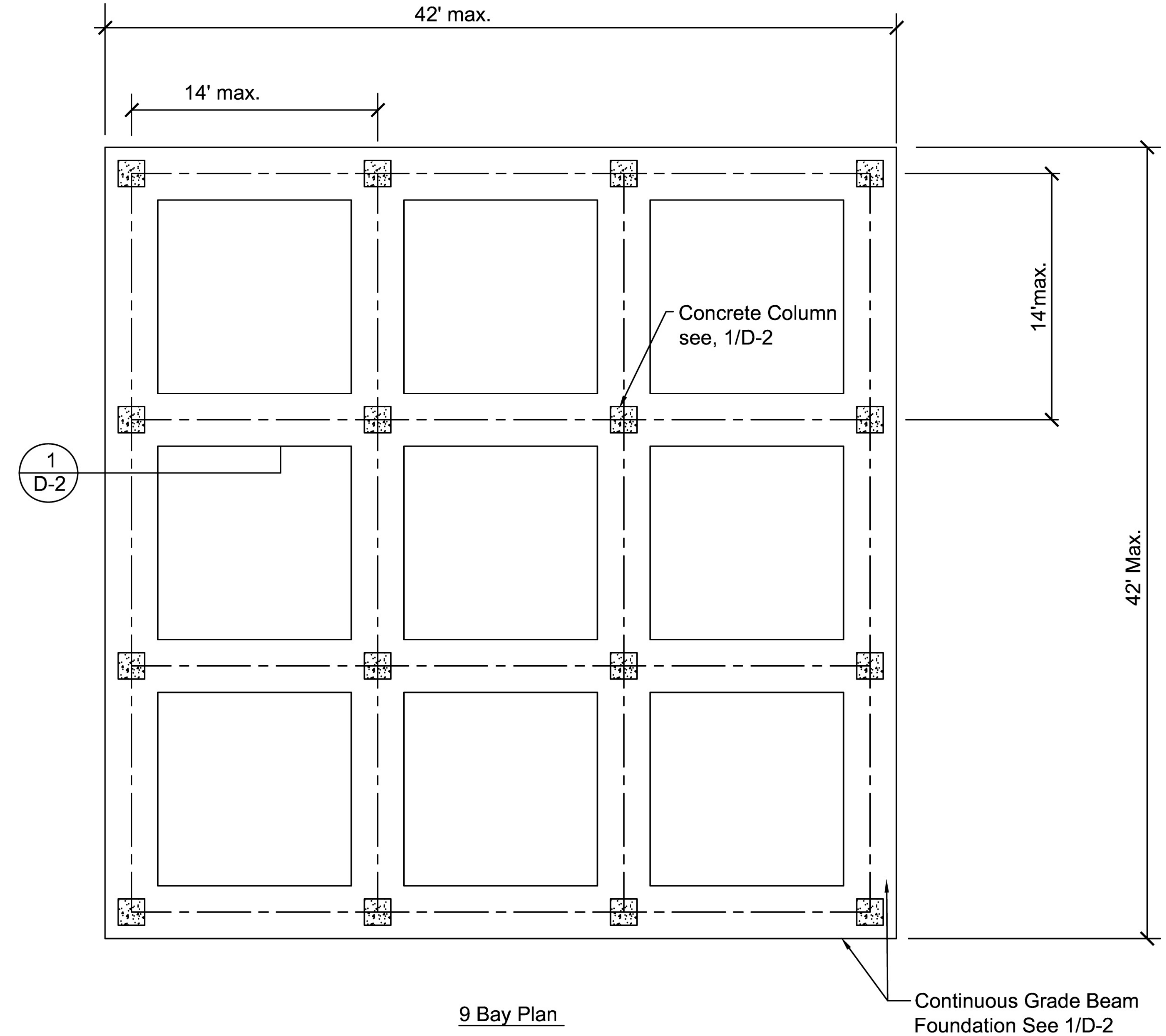
FEMA



6 Bay Plan

1 / D-1 Case D - Open Foundation Concrete Column & Grade Beam

SCALE: NTS



9 Bay Plan

2 / D-1 Case D - Open Foundation Concrete Column & Grade Beam

SCALE: NTS

See Sheet GN -1 through GN-6 for General Notes

Case D - Open Foundation
Concrete Column and Grade Beam

DRAWING NO.: D-1	SHEET 22 OF 31
DATE: August 8, 2006	
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FEMA

Wind Speed (mph)				
One Story				
Height H	150	140	130	120
5'	2'-6" x 2'-0" (4) - # 6 Column 16 x 16 A	2'-3" x 2'-0" (4) - # 6 Column 16 x 16 A	2'-0" x 2'-0" (4) - # 6 Column 16 x 16 A	2'-0" x 2'-0" (4) - # 6 Column 16 x 16 A
6'	2'-9" x 2'-0" (5) - # 6 Column 16 x 16 A	2'-6" x 2'-0" (4) - # 6 Column 16 x 16 A	2'-3" x 2'-0" (4) - # 6 Column 16 x 16 A	2'-0" x 2'-0" (4) - # 6 Column 16 x 16 A
8'	3'-3" x 2'-0" (5) - # 6 Column 16 x 16 B	2'-6" x 2'-0" (4) - # 6 Column 16 x 16 B	2'-3" x 2'-0" (4) - # 6 Column 16 x 16 A	2'-0" x 2'-0" (4) - # 6 Column 16 x 16 A
Two Story				
5'	3'-6" x 2'-3" (6) - # 6 Column 16 x 16 A	2'-9" x 2'-3" (5) - # 6 Column 16 x 16 A	2'-6" x 2'-0" (5) - # 6 Column 16 x 16 A	2'-6" x 2'-0" (4) - # 6 Column 16 x 16 A
6'	4'-0" x 2'-3" (5) - # 7 Column 16 x 16 A	3'-0" x 2'-3" (6) - # 6 Column 16 x 16 A	3'-0" x 2'-0" (6) - # 6 Column 16 x 16 A	2'-6" x 2'-0" (4) - # 6 Column 16 x 16 A
8'	4'-0" x 2'-3" (5) - # 7 Column 16 x 16 B	3'-3" x 2'-3" (5) - # 6 Column 16 x 16 B	3'-0" x 2'-0" (5) - # 6 Column 16 x 16 A	2'-6" x 2'-0" (5) - # 6 Column 16 x 16 A
Height H	150	140	130	120
Wind Speed (mph)				

1 D-2

Case D - Open Foundation Concrete Column & Grade Beam

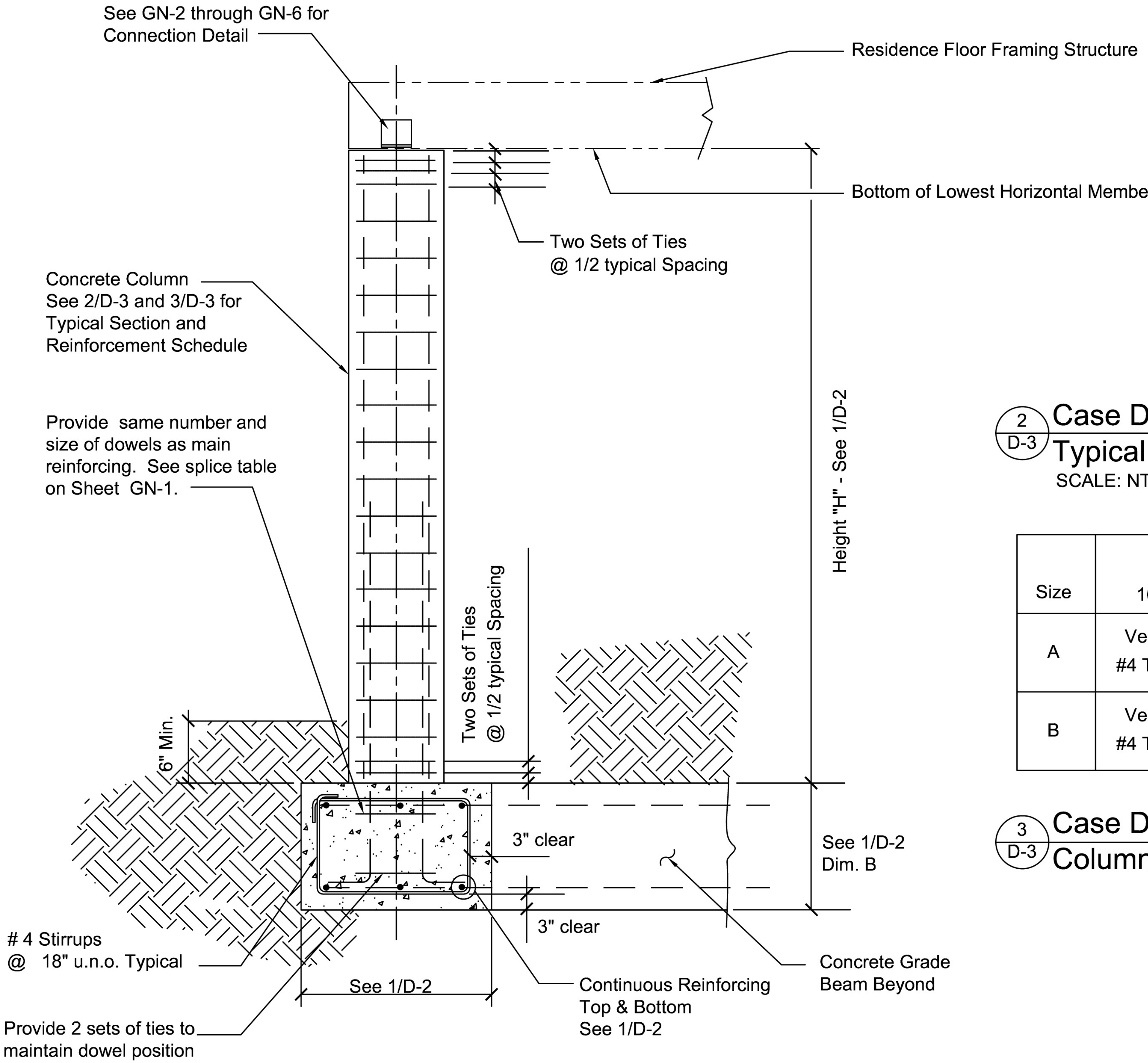
Table 1 Continuous Grade Beam Size and Concrete Column Schedule

Notes:
1) Continuous reinforcing top and bottom. Use longest bar lengths that are practical. Place top bar splices at quarter point of span and bottom bar splices at columns.
2) See Table 3/D3 for reinforcement schedule.
3) Legend: 2'-6"x2'-0" - Footing Size A (width) x B (height)
(4) - #6 - Footing Rebar, top & bottom
Column 16 x 16 B - Column Size; see 1/D-2

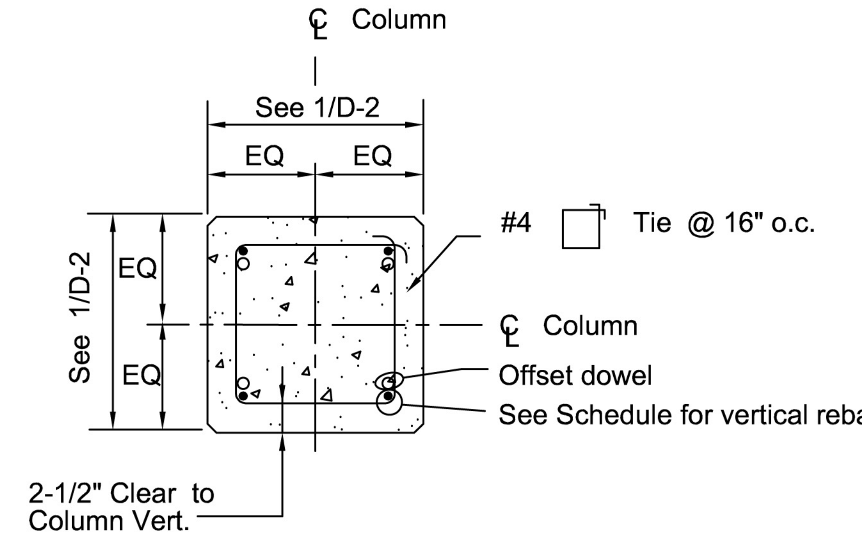
Case D - Open Foundation
Concrete Column and Grade Beam

DRAWING NO.: D-2	SHEET 23 OF 31
DATE: August 8, 2006	
REVISED:	REV. 9

FEMA



1
D-3
Case D Open Foundation - Concrete Column & Grade Beam
Typical Exterior Section
SCALE: NTS



2
D-3
Case D Open Foundation - Concrete Column & Grade Beam
Typical Column Section
SCALE: NTS

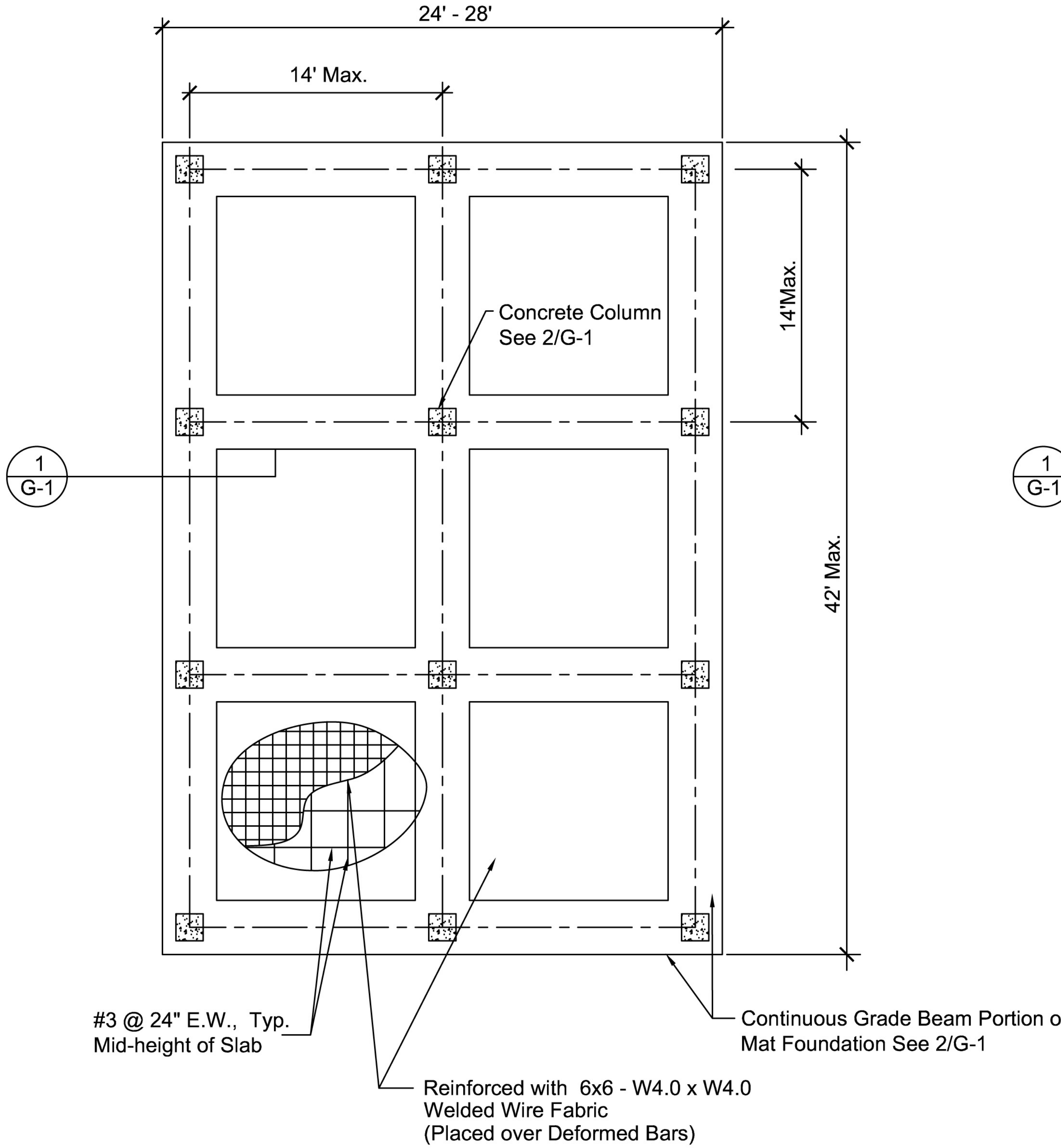
Size	16" x 16"
A	Verts (4) # 8 #4 Ties @ 16"
B	Verts (4) # 9 #4 Ties @ 16"

3
D-3
Case D Open Foundation - Concrete Column & Grade Beam
Column Reinforcement Schedule

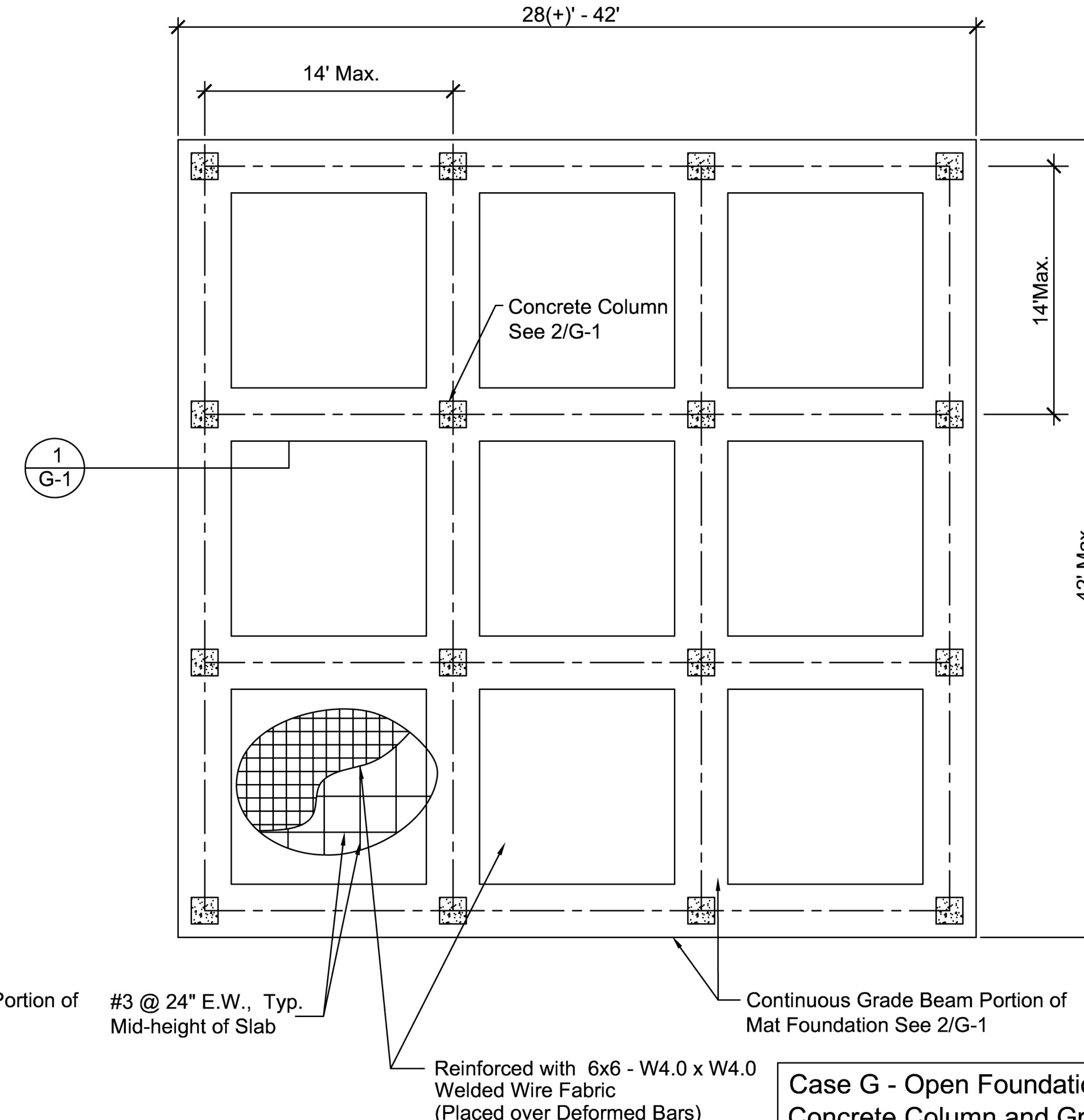
Case D - Open Foundation
Concrete Column and Grade Beam

DRAWING NO.: D-3	SHEET 24 OF 31
DATE: August 8, 2006	
REVISED:	REV. 9

FEMA



6 Bay Plan



9 Bay Plan

1
G-1

Case G - Open Foundation Concrete Column & Grade Beam with Slab

Plan

SCALE: NTS

Notes:
1) Continuous reinforcing top and bottom. Use longest bar lengths that are practical. Place top bar splices at quarter point of span and bottom bar splices at columns.
2) See 3/G-2 for reinforcement details.

2
G-1

Case G - Open Foundation Concrete Column & Grade Beam with Slab

Table 1 Continuous Grade Beam Size and Concrete Column Schedule

Case G - Open Foundation Concrete Column and Grade Beam with Slab	
DRAWING NO.: G-1	SHEET 25 OF 31
DATE: August 8, 2006	
REVISED:	REV. 9

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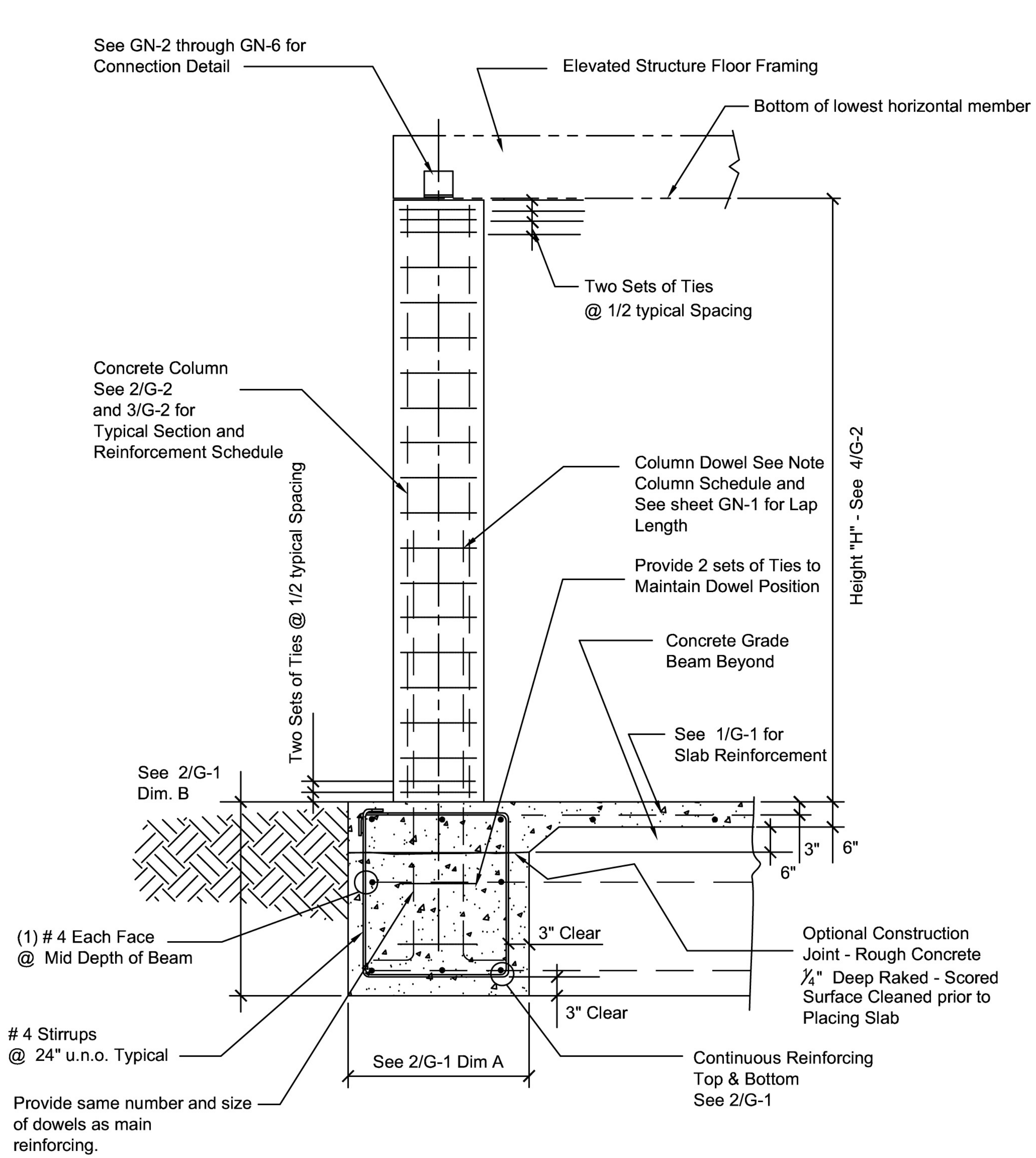
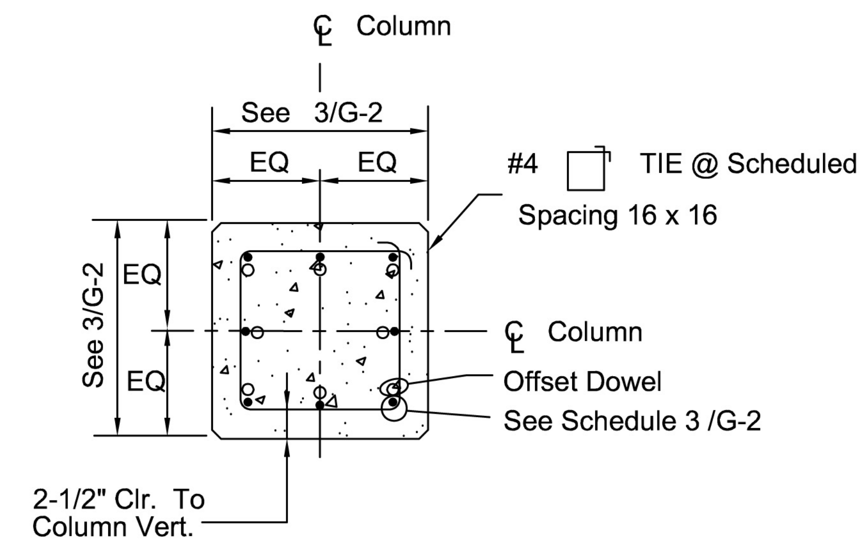


1/G-2 Case G - Open Foundation Concrete Column & Grade Beam with Slab
Typical Exterior Section
SCALE: NTS



2/G-2 Case G Open Foundation Concrete Column & Grade Beam
Typical Column Section
SCALE: NTS

Size	16 16" x 16"
A	Verts (4) # 8 #4 Ties @ 16"
B	Verts (8) # 7 #4 Ties @ 14"
C	Verts (8) # 8 #4 Ties @ 14"

3/G-2 Case G - Open Foundation Column and Grade Beam
Column Reinforcement Schedule

	Wind Speed mph			
	One Story			
Height H	150	140	130	120
8'	2'-6" x 4' (4) - # 6 Column 16 x 16 A	2' x 4' (3) - # 6 Column 16 x 16 A	2' x 4' (3) - # 6 Column 16 x 16 A	2' x 4' (3) - # 6 Column 16 x 16 A
10'	2'-9" x 4' (4) - # 6 Column 16 x 16 A	2' x 4' (3) - # 6 Column 16 x 16 A	2' x 4' (3) - # 6 Column 16 x 16 A	2' x 4' (3) - # 6 Column 16 x 16 A
12'	3' x 4' (4) - # 6 Column 16 x 16 B	2'-3" x 4' (3) - # 6 Column 16 x 16 B	2' x 4' (3) - # 6 Column 16 x 16 A	2' x 4' (3) - # 6 Column 16 x 16 A
15'	3'-6" x 4' (5) - # 6 Column 16 x 16 C	2'-9" x 4' (4) - # 6 Column 16 x 16 B	2'-3" x 4' (3) - # 6 Column 16 x 16 B	2' x 4' (3) - # 6 Column 16 x 16 B
	Two Story			
8'	3' x 4' (4) - # 6 Column 16 x 16 B	3' x 4' (4) - # 6 Column 16 x 16 A	2'-3" x 4' (3) - # 6 Column 16 x 16 A	2' x 4' (3) - # 6 Column 16 x 16 A
10'	4'-3" x 4' (5) - # 6 Column 16 x 16 B	3'-6" x 4' (5) - # 6 Column 16 x 16 B	2'-6" x 4' (4) - # 6 Column 16 x 16 B	2' x 4' (3) - # 6 Column 16 x 16 B
12'	4'-6" x 4' (4) - # 7 Column 16 x 16 C	4' x 4' (5) - # 6 Column 16 x 16 C	2'-9" x 4' (4) - # 7 Column 16 x 16 B	2'-3" x 4' (3) - # 6 Column 16 x 16 B
Height H	150	140	130	120
	Wind Speed mph			

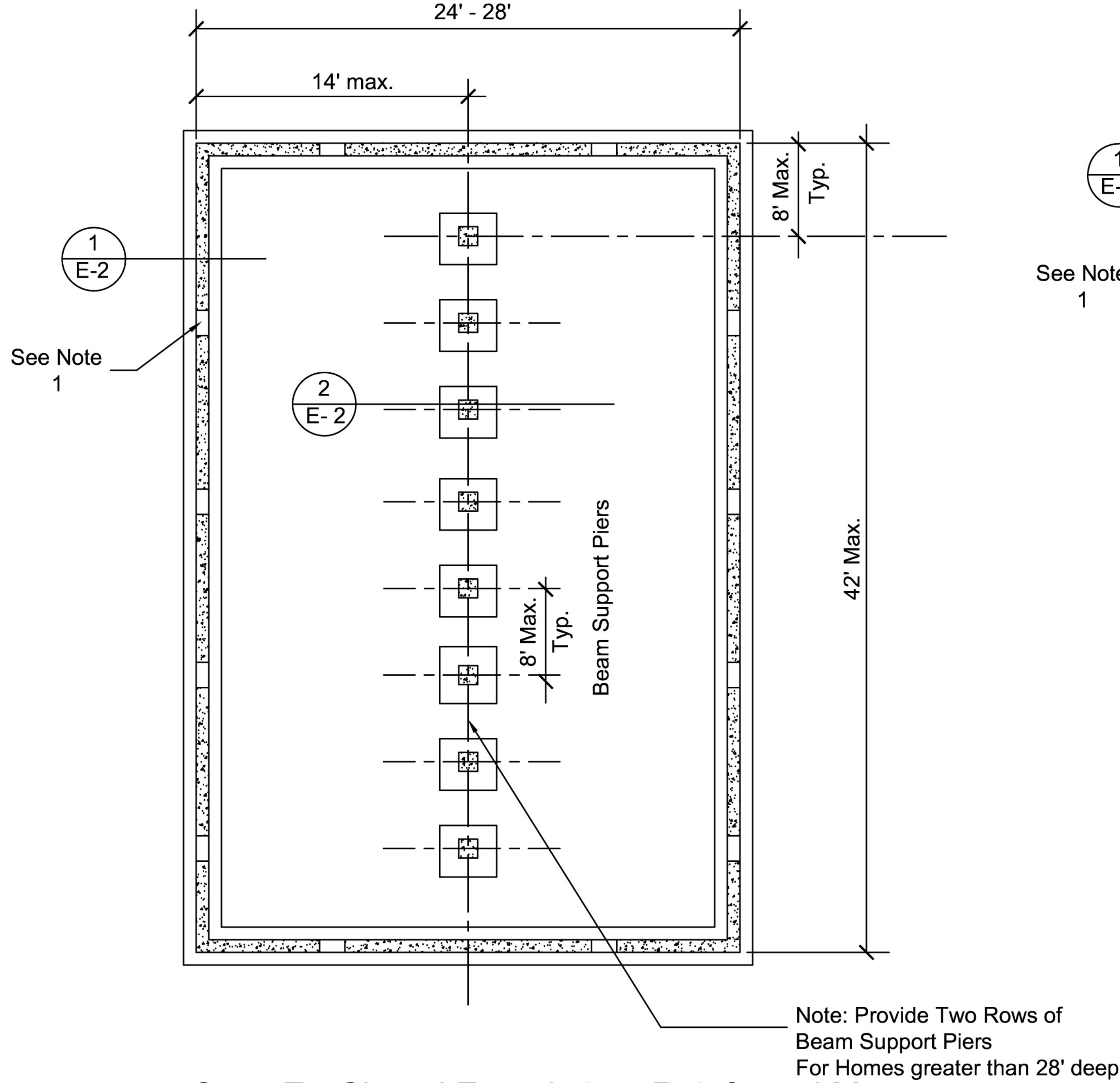
Legend:
2'-6"x4' - Footing Size A (width) x B (height)
(3) - #6 - Footing Rebar, Top & Bottom
Column 16 x 16 A - Column Size; see 3/G-2

4/G-2 Case G - Open Foundation Concrete Column & Grade Beam with Slab
Table 1 Continuous Grade Beam Size and Concrete Column Schedule

Case G - Open Foundation Concrete Column and Grade Beam with Slab

DRAWING NO.: G-2	SHEET 26 OF 31
DATE: August 8, 2006	
REVISED:	REV. 9

FEMA

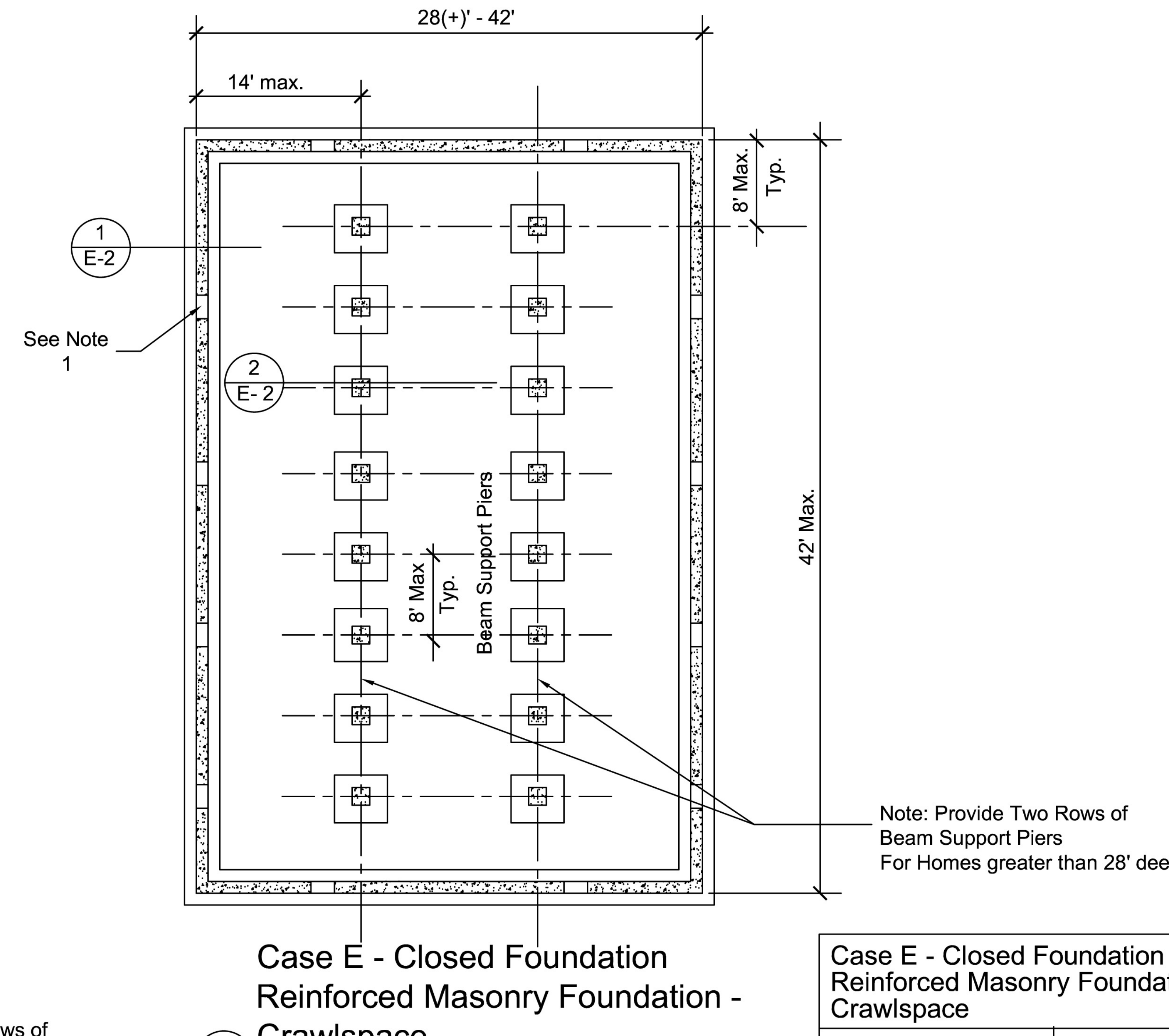


1/E-1 Case E - Closed Foundation Reinforced Masonry Foundation - Crawlspace

Typical Module Plan

SCALE: NTS

See Sheet GN-1 for General Notes



2/E-1 Case E - Closed Foundation Reinforced Masonry Foundation - Crawlspace

Typical Module Plan

SCALE: NTS

See Sheet GN-1 for General Notes

Note 1:

1) Total area of all Flood Relief Openings shall be a minimum of 1 square inch per square foot of floor area.
2) Bottom of Flood Relief Opening shall be located no more than 1' above adjacent grade.
3) Flood Relief Opening shall comply with NFIP Standards.

Case E - Closed Foundation Reinforced Masonry Foundation - Crawlspace	
DRAWING NO.: E -1	SHEET 27 OF 31
DATE: August 8, 2006	
REVISED:	REV. NO.

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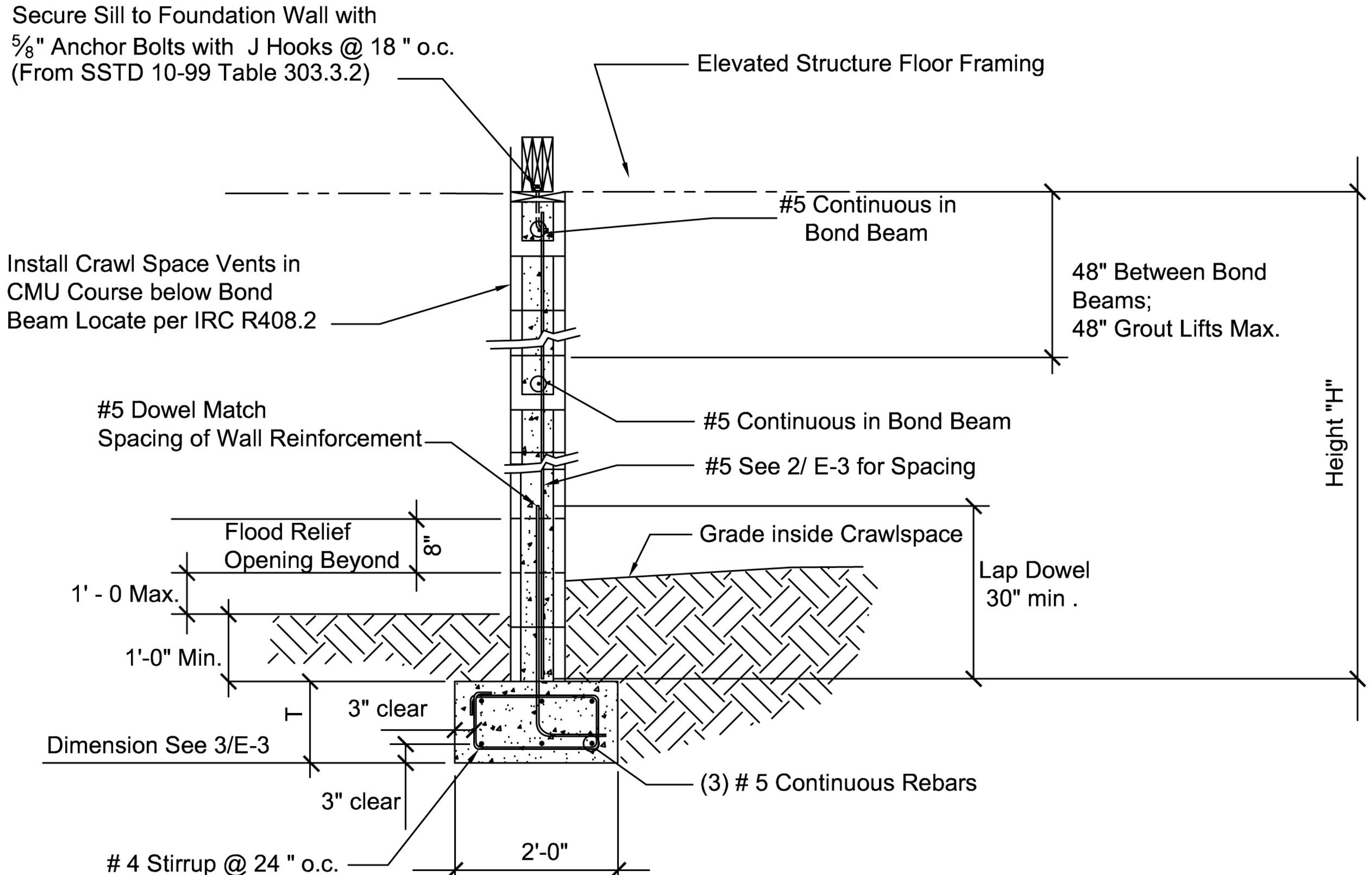
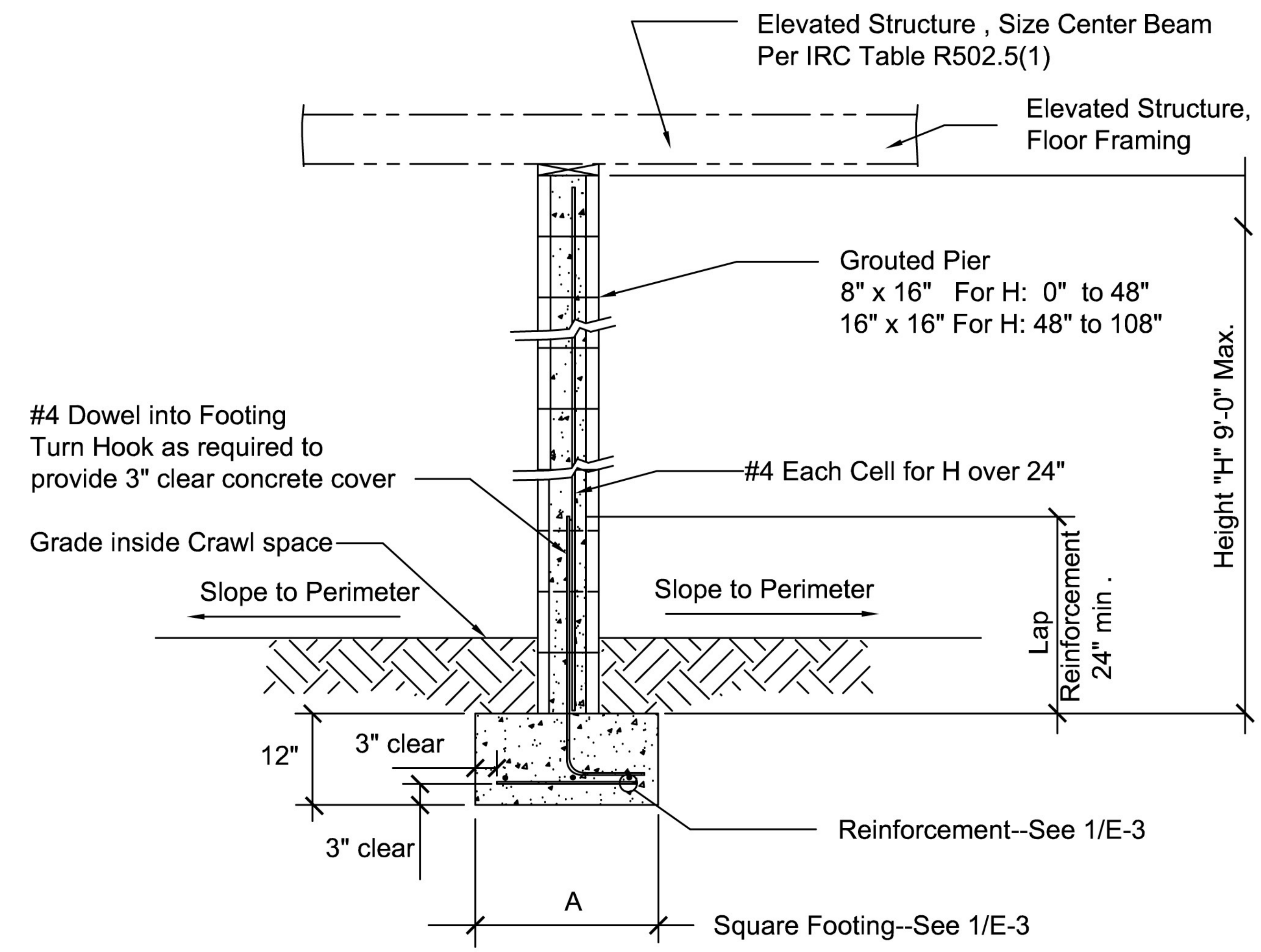


1
E-2

Case E - Closed Foundation Reinforced Masonry Foundation - Crawlspace

Typical Section

SCALE: NTS



2
E-2

Case E - Closed Foundation Reinforced Masonry Foundation - Crawlspace

Typical Pier & Footing Section

SCALE: NTS

Note 1:

1) Total area of all Flood Relief Openings shall be a minimum of 1 square inch per square foot of floor area.
2) Bottom of Flood Relief Opening shall be located no more than 1'-0" above adjacent grade.
3) Flood Relief Opening shall comply with NFIP Standards.

Case E - Closed Foundation Reinforced Masonry Foundation - Crawlspace	
DRAWING NO.: E -2	SHEET 28 OF 31
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FEMA

	Single Story		Two Story	
Column Spacing	Footing Size - A	Reinf. Size	Footing Size - A	Reinf. Size
4'-0"	24"	(3) # 4	30"	(3) # 4
5'-0"	26"	(3) # 4	32"	(3) # 4
6'-0"	28"	(3) # 4	34"	(3) # 4
7'-0"	28"	(3) # 5	36"	(3) # 5
8'-0"	30"	(3) # 5	38"	(3) # 5

1 / E-3

Case E - Closed Foundation Reinforced Masonry Foundation - Crawlspace

Size and Reinforcement Schedule

	Single Story		Two Story	
Wall Height	8" CMU	12" CMU	8" CMU	12" CMU
2'-0"	72"	72"	56"	72"
4'-0"	56"	72"	48"	56"
6'-0"	40"	48"	32"	40"
8'-0"	24"	32"	24"	32"

2 / E-3

Case E - Closed Foundation Reinforced Masonry Foundation - Crawlspace

Spacing (Vertical Bars) Crawl Space Foundation Wall #5 bars

	Wind Speed (mph)			
Wall Height	150	140	130	120
0'-8"	40"	32"	24"	18"
1'-4"	38"	30"	24"	16"
2'-0"	36"	28"	22"	16"
2'-8"	34"	26"	22"	14"
3'-4"	34"	26"	22"	12"
4'-0"	32"	24"	20"	12"
6'-0"	28"	20"	18"	12"
8'-0"	24"	12"	14"	12"

Notes:

1) Grout all cells in foundations for homes placed in 140 mph and 150 mph wind zones and all cells in foundations that are 4 feet tall or greater.

2) In 120 mph and 130 mph wind zones, grout all cells containing rebar in crawl space foundations

3 / E-3

Case E - Closed Foundation Reinforced Masonry Foundation Crawlspace

Table 2 Perimeter Footing Thickness (T) Required to Resist Uplift

Case E - Closed Foundation Reinforced Masonry Foundation - Crawlspace

DRAWING NO.: E -3	SHEET 29 OF 31
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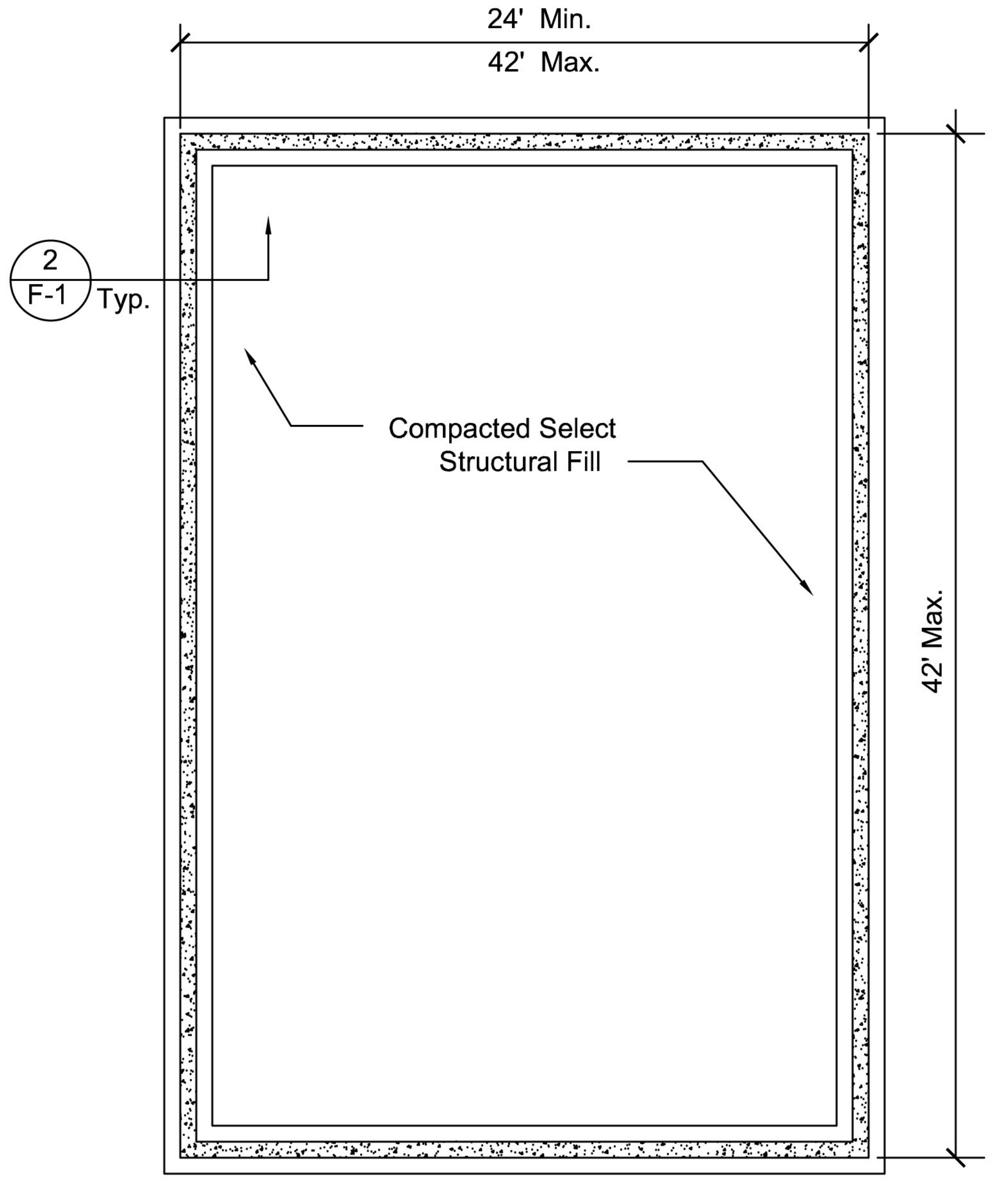
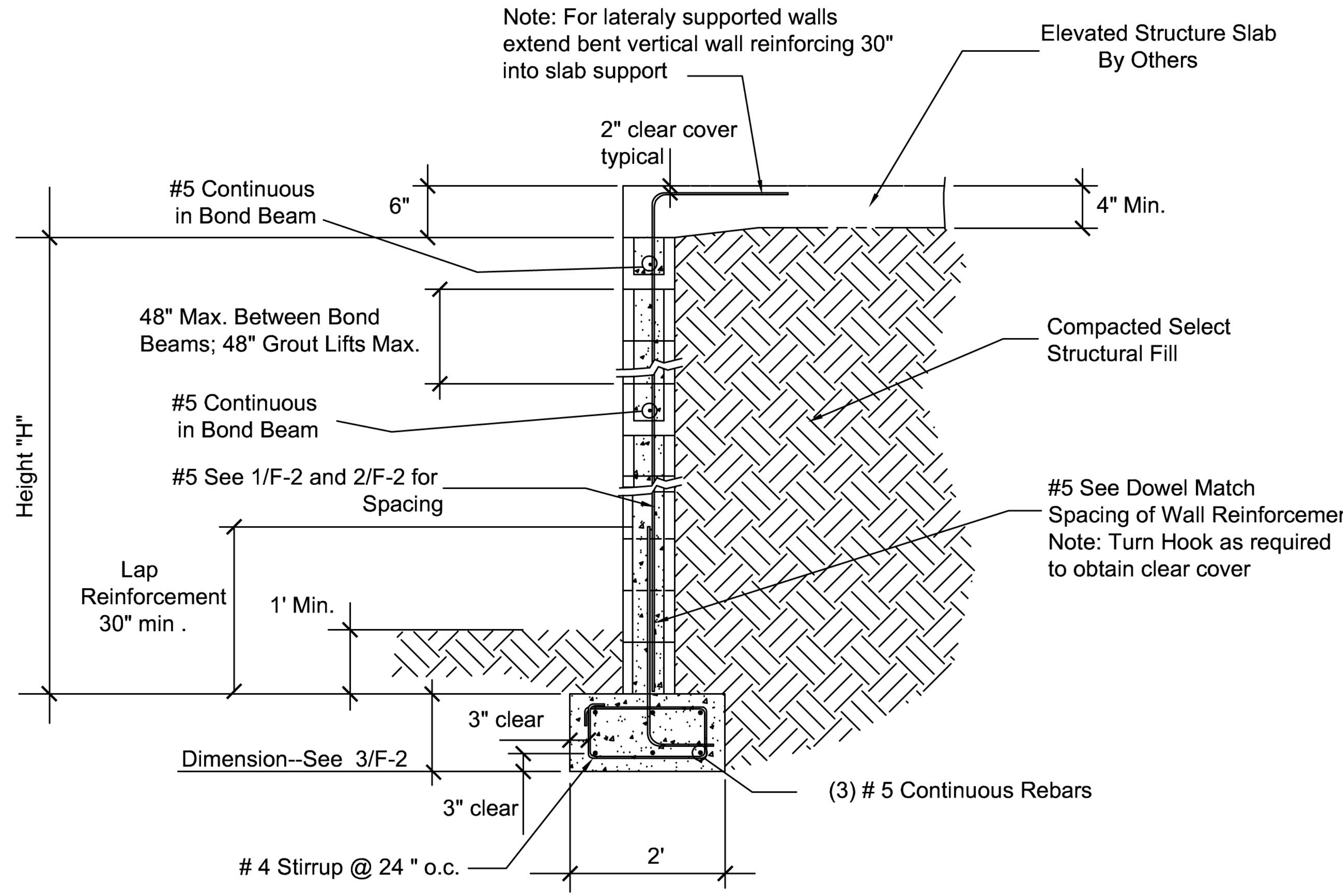


See Sheet G-1 for General Notes

Note :
1) Provide lateral bracing to wall during placement and compaction of fill until slab is installed and cured except as noted in 1/F-2.

1/F-1 Case F - Closed Foundation Reinforced Masonry Foundation - Stem Wall
Backfilled Typical Plan
SCALE: NTS



Note: Grout All Cells

2/F-1 Case F - Closed Foundation Reinforced Masonry Foundation - Stem Wall
Typical Section
SCALE: NTS

Case F - Closed Foundation Reinforced Masonry Foundation - Stem Wall	
DRAWING NO.: F-1	SHEET 30 OF 31
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	Single & Two Story	
Wall Height	8" CMU	12" CMU
1'-0"	48"	48"
2'-0"	32"	48"
3'-0"	24"	32"
4'-0"	8"	16"

Note:
Use for Foundation Wall not tied into Floor Slab

Case F - Closed Foundation Reinforced Masonry Foundation - Stem Wall

1 F-2 Table 1 Wall Reinforcement Spacing

Backfilled - Unbraced Construction - Stem Wall #5 bars

Wall Height	Single & Two Story 8" CMU
1'-0"	48"
2'-0"	48"
3'-0"	48"
4'-0"	48"

Note:
Use for Foundation Wall that is tied into Floor Slab

Case F - Closed Foundation Reinforced Masonry Foundation - Stem Wall

2 F-2 Table 2 Wall Reinforcement Spacing

Backfilled - Laterally Supported at Top of Stem Wall #5 bars

	Wind Speed (mph)			
Wall Height	150	140	130	120
0'-8"	40"	32"	24"	18"
1'-4"	38"	30"	24"	16"
2'-0"	36"	28"	22"	16"
2'-8"	34"	26"	22"	14"
3'-4"	34"	26"	22"	12"
4'-0"	32"	24"	20"	12"
6'-0"	28"	20"	18"	12"
8'-0"	24"	12"	14"	12"

Case F - Closed Foundation Reinforced Masonry Foundation - Stem Wall

3 F-2 Table 3 Perimeter Footing Thickness Required to Resist Uplift

Case F - Closed Foundation Reinforced Masonry Foundation - Stem Wall	
DRAWING NO.: F-2	SHEET 31 OF 31
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REVISED:	REV. 9

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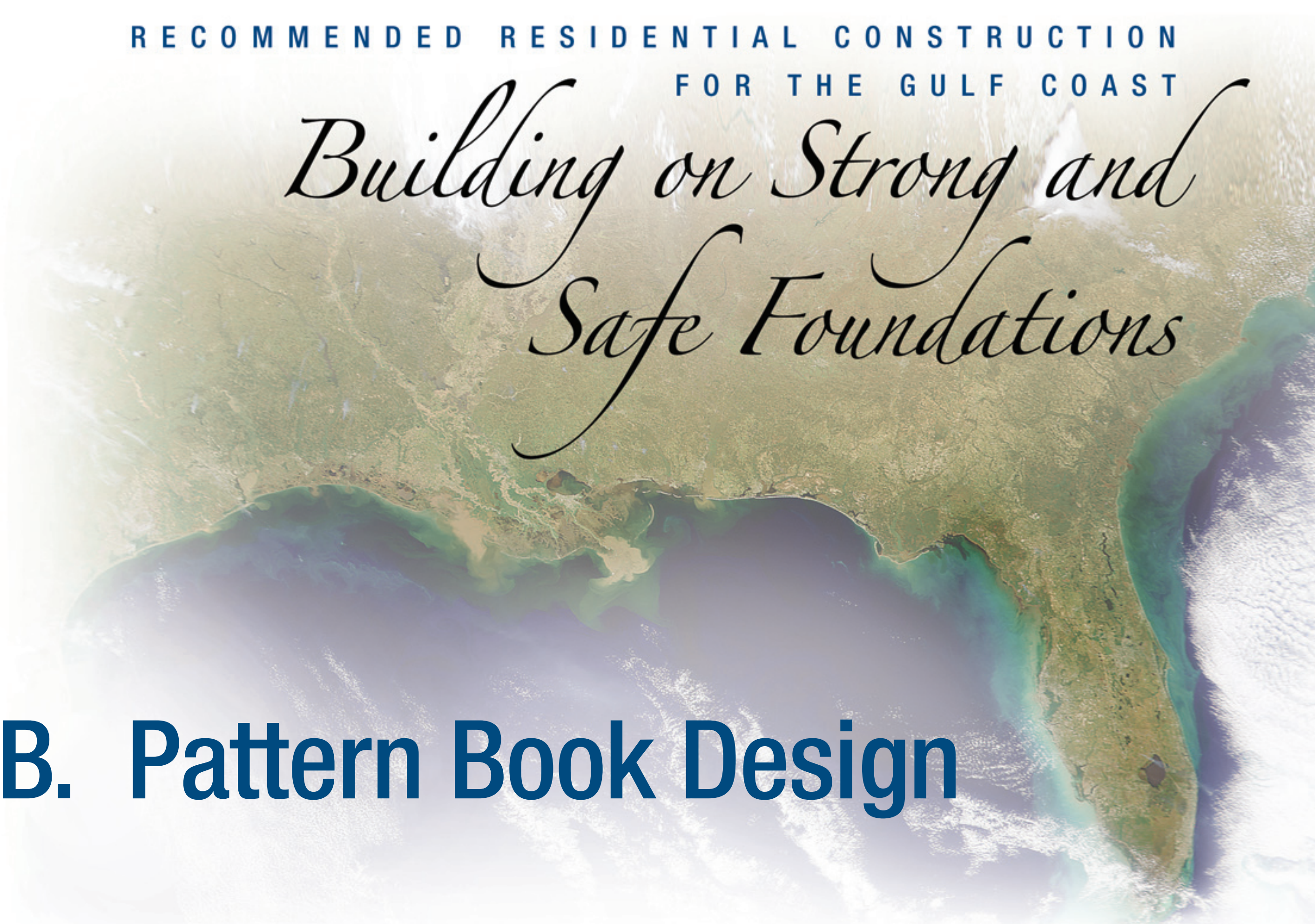
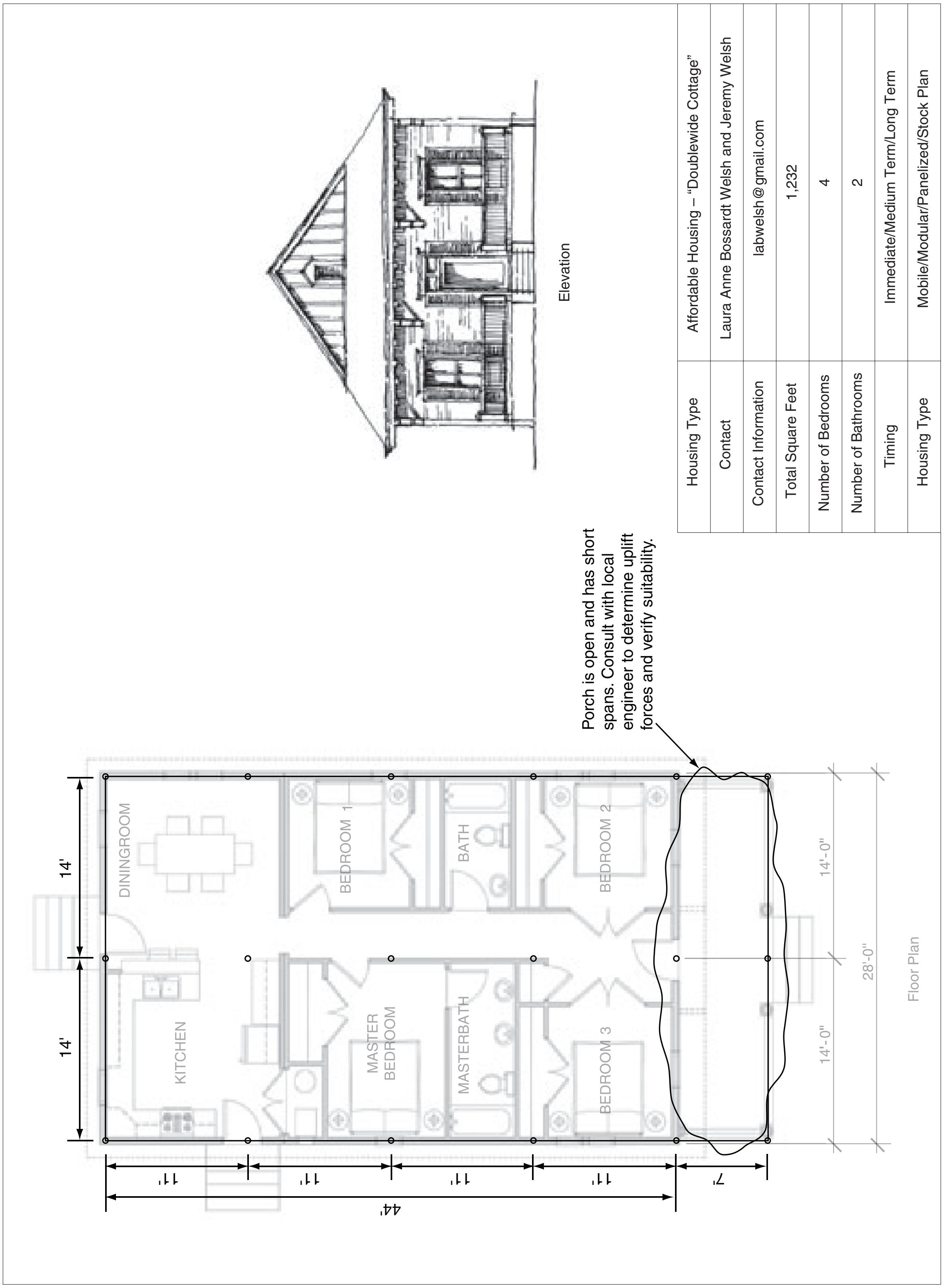
Building on Strong and Safe Foundations



B. Pattern Book Design

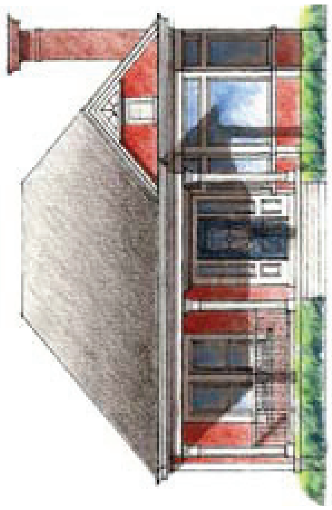
The illustrations in this appendix are from *A Pattern Book for Gulf Coast Neighborhoods* prepared for the Mississippi Governor's Rebuilding Commission on Recovery, Rebuilding and Renewal by Urban Design Associates (UDA) of Pittsburgh, Pennsylvania, in November 2005.

http://www.mississippirenewal.com/info/plansReports.html



Housing Type	Affordable Housing – "Doublewide Cottage"
Contact	Laura Anne Bossardt Welsh and Jeremy Welsh
Contact Information	labwelsh@gmail.com
Total Square Feet	1,232
Number of Bedrooms	4
Number of Bathrooms	2
Timing	Immediate/Medium Term/Long Term
Housing Type	Mobile/Modular/Panelized/Stock Plan

Figure B-1.
Pattern Book for Gulf Coast Neighborhoods
Page 63 Top



Housing Type	Detached Single-Family
Contact	Urban Design Associates
Contact Information	http://www.urbandesignassociates.com/
Total Square Feet	1,311
Number of Bedrooms	3
Number of Bathrooms	2
Timing	Medium Term/Long Term
Housing Type	Stock Plan

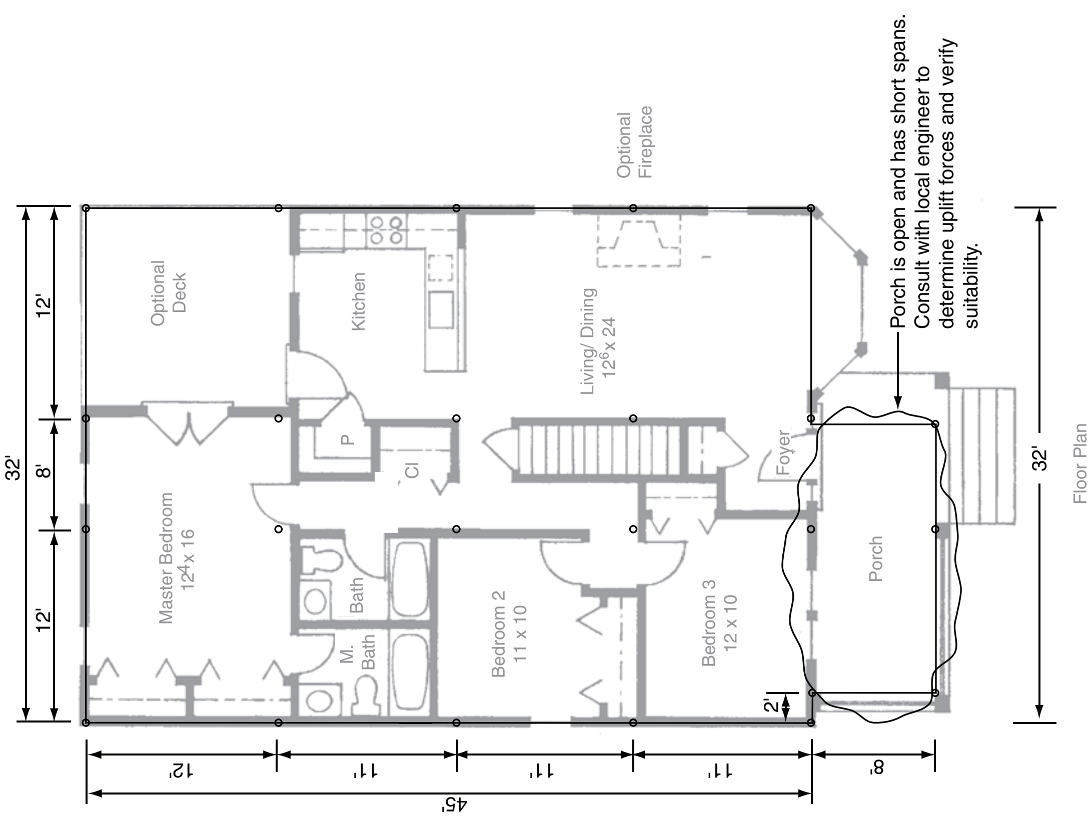
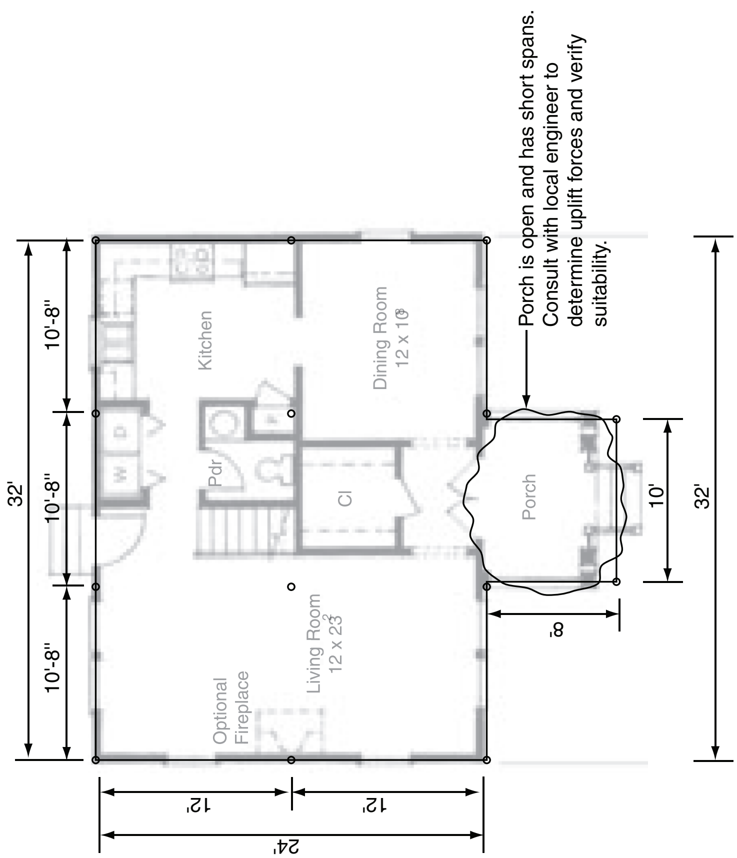


Figure B-2.
Pattern Book for Gulf Coast Neighborhoods
Page 63 Bottom

Housing Type	Detached Single-Family
Contact	Urban Design Associates
Contact Information	http://www.urbandesignassociates.com
Total Square Feet	1,536
Number of Bedrooms	3
Number of Bathrooms	2.5
Timing	Medium Term/Long Term
Housing Type	Stock Plan



First Floor Plan

Figure B-3.
Pattern Book for Gulf Coast Neighborhoods
Page 64 Bottom

Housing Type	Detached Single-Family
Contact	Urban Design Associates
Contact Information	http://www.urbandesignassociates.com/
Total Square Feet	1,630
Number of Bedrooms	4
Number of Bathrooms	2
Timing	Medium Term/Long Term
Housing Type	Stock Plan

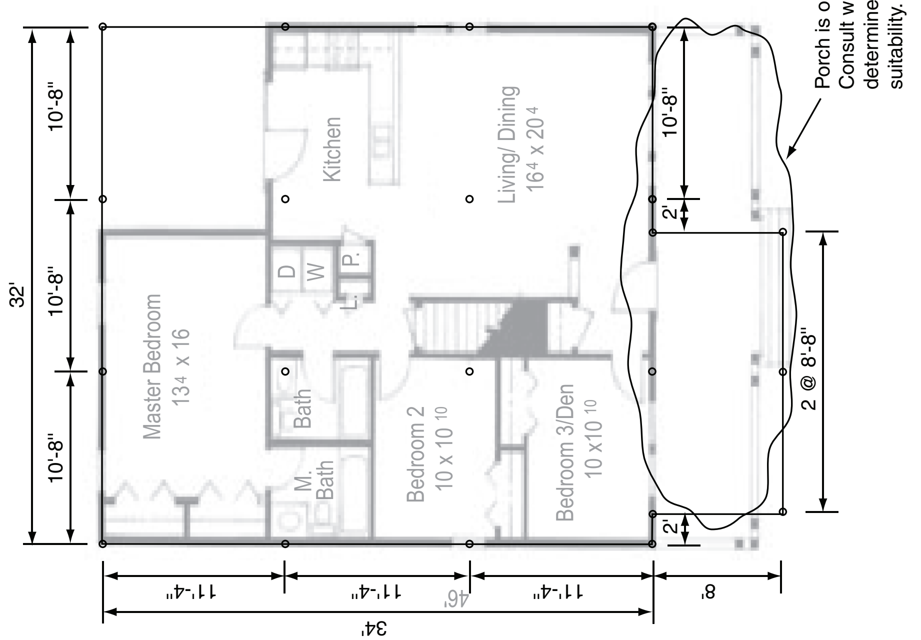
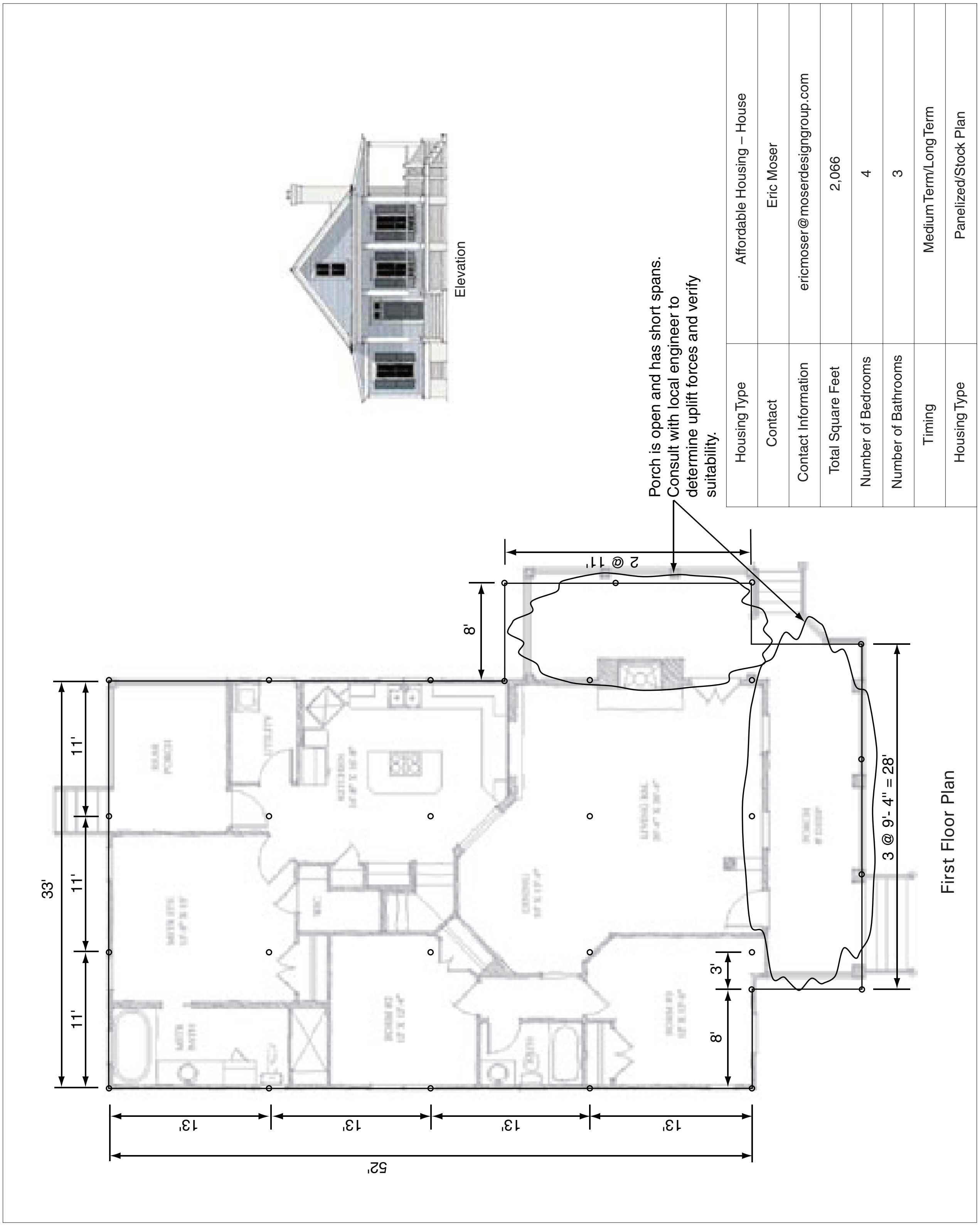


Figure B-4.
Pattern Book for Gulf Coast Neighborhoods
Page 65 Bottom



Housing Type	Affordable Housing – House
Contact	Eric Moser
Contact Information	ericmoser@moserdesigngroup.com
Total Square Feet	2,066
Number of Bedrooms	4
Number of Bathrooms	3
Timing	Medium Term/Long Term
Housing Type	Panelized/Stock Plan

Figure B-5.
Pattern Book for Gulf Coast Neighborhoods
Page 67 Top

C. Assumptions Used in Design

Gulf Coast Foundation Designs

The foundation designs proposed in Appendix A are based on the following standards and codes:

ASCE 7-02

Minimum Design Loads for Buildings and Other Structures
American Society of Civil Engineers (ASCE)

ACI 530-02/ASCE 5-02/TMS 402-02

Building Code Requirements for Masonry Structures
American Society of Civil Engineers (ASCE)
American Concrete Institute (ACI)
The Masonry Society (TMS)

ACI 318-02

Building Code Requirements for Structural Concrete
American Concrete Institute

ANSI/AFPA NDS-2001

National Design Specifications for Wood Construction
American Forest & Paper Association (AF&PA)
American Wood Council

IRC-2003

2003 International Residential Code for One- and Two-Family Dwellings
International Code Council (ICC)

To provide flexibility for the builder, a range of dead loads and building dimensions was used for calculating reactions on the foundation elements. For uplift and overturning analyses, the structure was assumed to be relatively light and narrow, and constructed with a relatively low-sloped roof. For sliding analyses, the home was considered relatively deep and constructed with a steeper roof slope. For the gravity loading analysis, a heavier structure was assumed.

Dead Loads

For Use in ASCE 7-02 ASD Uplift/Overturning Load Combination #7 (0.6D + W +H)

First Floor	8 psf	Vinyl flooring, 5/8-inch plywood sub-floor and 2 by 8 joists 16 inches on centers
Second Floor	10 psf	First floor components plus 1 layer of ½-inch gypsum drywall
Wall	9 psf	Wood siding, 2 by 4 studs 16 inch on centers, ½-inch plywood wall sheathing, and one layer of ½-inch gypsum drywall
Roof	12 psf	200 lb/sq asphalt roofing, 15 lb/sq felt, ½-inch plywood decking, 2 by 4 top and bottom truss chords 24 inches on centers, ½-inch gypsum drywall ceiling finish

Dead Loads

For Use in ASCE 7-05 ASD Gravity Load Combination #2 (D + H + F + L + T)

First Floor	16 psf	Dead loads increased 8 lb/sf to account for additional finishes like hardwood flooring (4 lb/sf), ½-inch slate (7 lb/sf), or thin set tile (5 lb/sf)
Second Floor	18 psf	
Wall	10 psf	Wall weight increased to account for cement composite siding
Roof	12 psf	

Concrete	150 psf	Normal weight concrete. Footings for continuous perimeter walls were also sized to support full height brick veneer at 40 psf.
Masonry	115 psf	Medium weight block
Grout	105 psf	
Brick Veneer	40 psf	

Wind Loads

Designs provided for 120 mph, 130 mph, 140 mph, and 150 mph zones (3-second gust wind speeds per ASCE 7-02). Wind analysis used Method 2 for buildings of all heights.

Exposure

Category C	Open terrain with scattered obstructions generally less than 30 feet in height; shorelines in hurricane-prone areas
$K_{zt} = 1$	No topographic effects (i.e., no wind speedup effects from hills, ridges, or escarpments)
$K_d = 0.85$	Wind directionality factor (for use with ASCE 7-02 load combinations)
K_z, K_h	Velocity pressure coefficients for Exposure Category C

Flood Loads

V Zone	Breaking wave load from a wave with height 78 percent of stillwater depth (d_s) Flood velocity (fps) equal to $(gd_s)^{1/2}$ up to a maximum of 10 fps (FEMA 55 Upper Bound)
Coastal A Zone	Breaking wave load from 1½ foot up to a 3 foot high wave Flood velocity (fps) equal to $(gd_s)^{1/2}$ up to a maximum of 5 fps (FEMA 55 Upper Bound)
Non-Coastal A Zone	Breaking wave load up to a 1½ foot high wave Flood velocity (fps) equal to stillwater flood depth (d_s) (in feet) (FEMA 55 lower bound)

Lateral Loads (on stem walls)

Lateral earth pressures from saturated soils	100 pounds per cubic foot (pcf)
Surcharge for slab weight and first floor live load	65 pounds per square foot (psf)

Live Loads

First Floor	40 psf
Second Floor	30 psf
Roof	20 psf

Soil Bearing Capacity

1,500 psf Presumptive value for clay, sandy clay, silty clay, clayey silt, silt, and sandy silt (CI, ML, MH and CH) (2003 IRC)

Building Dimensions

Building Width	14 ft (per module)	
Building Depth	max 42 ft min 24 ft	
Shear Wall Spacing	max 42 ft	
Floor Height	10 ft (floor to floor dimension)	
Roof Pitch Ratio	min 3:12 max 12:12	Uplift and overturning calculation Sliding calculation
Roof Overhang	2 ft	

RECOMMENDED RESIDENTIAL CONSTRUCTION FOR THE GULF COAST

Building on Strong and Safe Foundations

D. Foundation Analysis and Design Examples

Chapter 3 described the types of loads considered in this manual. This appendix demonstrates how these loads are calculated using a sample building and foundation. The reactions from the loads imposed on the example building are calculated, the loads on the foundation elements are determined, and the total loads are summed and applied to the foundation.

There is a noteworthy difference between the approach taken for designing the foundations included in this manual and the analyses that a designer may undertake for an individual building. The analyses used for the designs in this manual were based on the "worst case" loading scenario for a "range of building sizes and weights." This approach was used to provide designers and contractors with some flexibility in selecting the home footprint and characteristics for which these pre-engineered foundations would apply. This also makes application of the pre-engineered foundations simpler, reducing the number of pre-engineered foundations, and results in conservative designs.

For example, the designs presented were developed to resist uplift and overturning for a relatively light structure with a flat roof (worst case uplift and overturning) while gravity loads were based on a relatively heavy structure to simulate worst case gravity loads. Sliding forces were determined for a relatively deep home with a steep roof to simulate the largest lateral loads. The range of building weights and dimensions applicable to the designs are listed in Appendix C.

Since the designs are inherently conservative for some building dimensions and weights, a local design professional may be consulted to determine if reanalyzing to achieve a more efficient design is warranted. If a reanalysis is determined to be cost-effective, the sample calculations will aid the designer in completing that analysis.

D.1 Sample Calculations

The sample calculations have been included to show one method of determining and calculating individual loads, and calculating load combinations.

Type of Building

The sample calculation is based on a two-story home with a 28-foot by 42-foot footprint and a mean roof height of 26 feet above grade. The home is located on Little Bay in Harrison County, Mississippi, approximately 1.5 miles southwest of DeLisle (see Figure D-1). The site is located on the Harrison County Flood Recovery Map in an area with an Advisory Base Flood Elevation (ABFE) of 18 feet, located between the 1.5-foot wave contour and the 3-foot wave contour (Coastal A Zone). The local grade elevation is 15 feet North American Vertical Datum (NAVD). The calculations assume short- and long-term erosion will occur and the ground elevation will drop 1 foot during the life of the structure. This places the home in a Coastal A Zone with the flood elevation approximately 4 feet above the eroded exterior grade. Based on ASCE 7-02, the 3-second gust design wind speed at the site is 128 miles per hour (mph) Exposure Category C. To reduce possible damage and for greater resistance to high winds, the home is being designed for a 140-mph design wind speed.

The home has a gabled roof with a 3:12 roof pitch. The home is wood-framed, contains no brick or stone veneer, and has an asphalt shingled roof. It has a center wood beam supporting the first floor and a center load bearing wall supporting the second floor. Clear span trusses frame the roof and are designed to provide a 2-foot overhang. No vertical load path continuity is assumed to exist in the center supports, but vertical and lateral load path continuity is assumed to exist elsewhere in the structure.

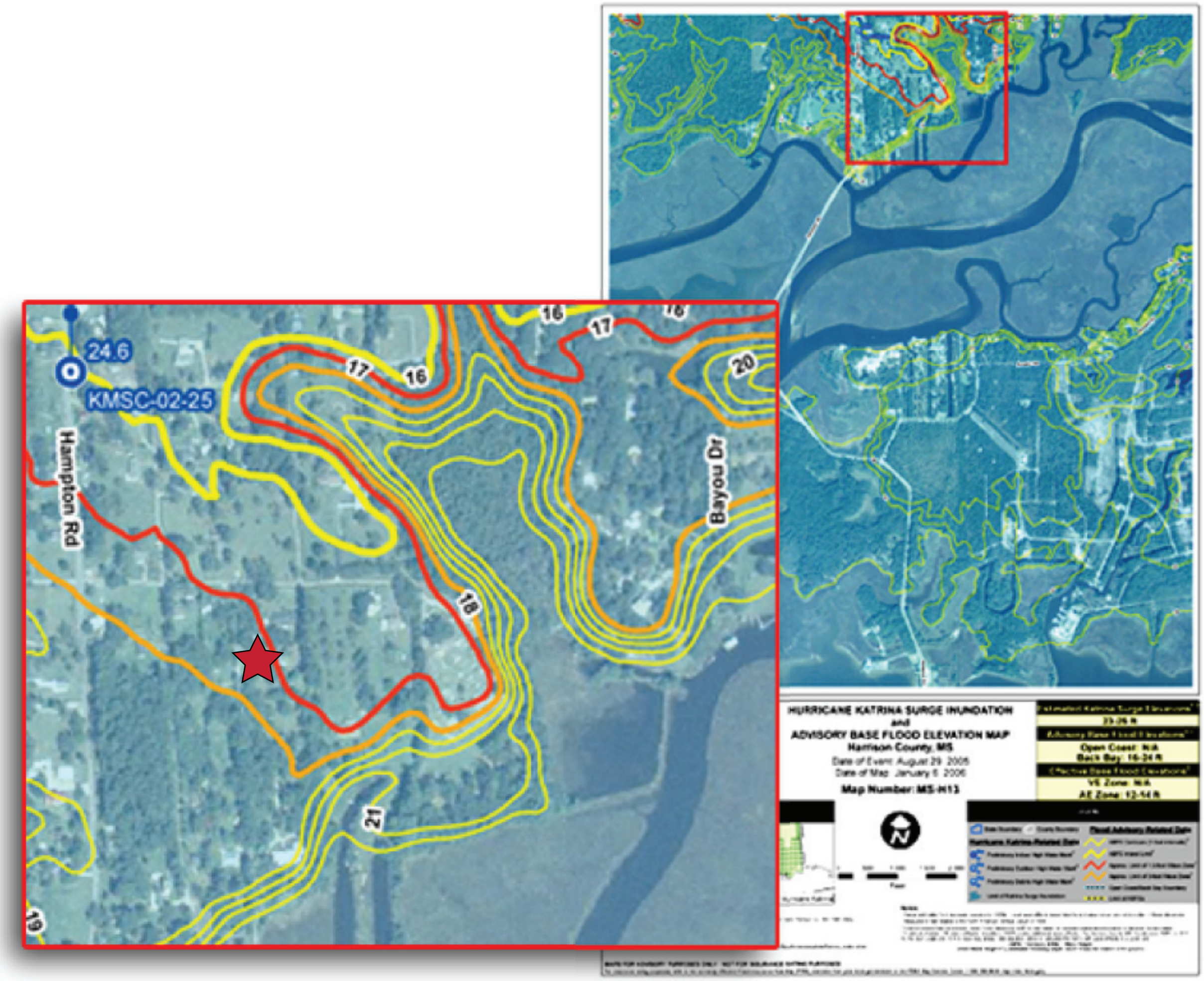


Figure D-1.
Star indicates the location of the sample calculation home on Little Bay in Harrison County, Mississippi, approximately 1.5 miles southwest of DeLisle. Inset on the left (from the map) is enlarged.

The proposed foundation for the home is a system of steel pipe piles, a reinforced concrete grade beam, and concrete columns extending from the grade beam to the elevated structure.

Methodology

1. Determine the loads based on the building's parameters (Section D.1.1)

2. Calculate wind and flood loads using ASCE 7-02 (Section D.1.2)

3. Consider the structure as a rigid body, and use force and moment equilibrium equations to determine reactions at the perimeter foundation elements (Section D.2)

D.1.1 Determining Individual Loads on a Structure

Building Dimensions and Weights (pulled from the text of the example problem)

B	= 42	Building width (ft)
L	= 28	Building depth (ft)
F_1	= 10	First floor height (ft)
F_2	= 10	Second floor height (ft)
r	= 3	3:12 roof pitch
W_{ovhg}	= 2	Width of roof overhang (ft)

Dead Loads

W_{rfDL}	= 12	Roof dead load including upper level ceiling finish (in pounds per square foot [psf])
W_{1stDL}	= 8	First floor dead load (psf)
W_{2ndDL}	= 10	Second floor dead load, including first floor ceiling finish (psf)
W_{wlDL}	= 9	Exterior wall weight (psf of wall area)

Live Loads

W_{1stLL}	= 40	First floor live load (psf)
W_{2ndLL}	= 30	Second floor live load (psf)
W_{rfLL}	= 20	Roof live load (psf)

Wind Loads

Building Geometry

h/L	= 1
L/B	= 0.7

Site Parameters (ASCE 7-02, Chapter 6)

K_{zt}	= 1	Topographic factor (no isolated hills, ridges, or escarpments)
K_d	= 0.85	Directionality factor (for use with ASCE 7-02, Chapter 2, Load Combinations)
Kh	= 0.94	For simplicity, Velocity Pressure Coefficient used at the 26 foot mean roof height was applied at all building surfaces. See ASCE 7-02, Table 6-3, Case 2.
I	= 1	Importance factor (residential occupancy)
V	= 140	3-second gust design wind speed (mph)
G	= 0.85	Gust effect factor (rigid structure, ASCE 7-02, Section 6.5.8.1)

External Pressure Coefficients (Cp) (ASCE 7-02, Figure 6-6)

C_{Pwwrf}	= -1.0	Windward roof (side facing the wind)
C_{Plwrf}	= -0.6	Leeward roof
C_{Pwwl}	= 0.8	Windward wall
C_{Plwwl}	= -0.5	Leeward wall (side away, or sheltered, from the wind)
C_{Peave}	= -0.8	Windward eave

Positive coefficients indicate pressures acting on the surface. Negative coefficients indicate pressures acting away from the surface.

Velocity Pressure (qh) (ASCE 7-02, Section 6.5.10)

Velocity pressure at mean roof height:

$$q_h = 0.00256\, K_h K_{zt}\, K_d\, V^2\, I$$

$$= 0.00256\,(0.94)\,(1)\,(0.85)\,(140)^2(1)$$

$$q_h = 40 \text{ psf}$$

Wind Pressures (P)

Determine external pressure coefficients for the various building surfaces. Internal pressures, which act on all internal surfaces, do not contribute to the foundation reactions. For sign convention, positive pressures act inward on a building surface and negative pressures act outward.

P_{wwrfV} $= q_h\, GC_{pwwrf}$ Windward roof

$= (40)\,(0.85)\,(-1)$

P_{wwrfV} $= -34$ psf

Likewise

P_{lwrfV} $= q_h\, GC_{plwrf}$ Leeward roof

P_{lwrfV} $= -20$ psf

P_{wwwl} $= q_h\, GC_{pwwwl}$ Windward wall

P_{wwwl} $= 27$ psf

P_{lwwl} $= q_h\, GC_{plwwl}$ Leeward wall

P_{lwwl} $= -17$ psf

P_{wweave} $= q_h\, GC_{peave}$ Windward roof overhang

P_{wweave} $= -27$ psf - eave

$= -34$ psf - upper surface

$= -61$ psf - total

Wind Forces (F) (on a 1-foot wide section of the home)

F_{wwrfV} $= P_{wwrfV}\ L/2$ Windward roof vertical force

$= (-34\text{ psf})\,(14\text{ sf/lf})$

$= -476$ lb/lf

F_{lwrfV} $= P_{lwrfV}\ L/2$ Leeward roof vertical force

$= (-20\text{ psf})\,(14\text{ sf/lf})$

$= -280$ lb/lf

F_{wwrfH} $= P_{wwrfH}\ L/2\ (r/12)$ Windward roof horizontal force

$= (-34\text{ psf})\,(14\text{ sf/lf})\,(3/12)$

$= -119$ lb/lf

F_{lwrfH} $= P_{lwrfH}\ L/2\ (r/12)$ Leeward roof horizontal force

$= (-20\text{ psf})\,(14\text{ sf/lf})\,(3/12)$

$= -70$ lb/lf

$F_{wwwl1st}$ $= P_{wwwl}\ (F_1)$ Windward wall on first floor

$= (27\ psf)\ (10\ sf/lf)$

$= 270\ lb/lf$

$F_{wwwl2nd}$ $= P_{wwwl}\ (F_2)$ Windward wall on second floor

$= (27\ psf)\ (10\ sf/lf)$

$= 270\ lb/lf$

$F_{lwwl1st}$ $= P_{lwwl}\ (F_1)$ Leeward wall on first floor

$= (-17\ psf)\ (10\ sf/lf)$

$= -170\ lb/lf$

$F_{lwwl2nd}$ $= P_{lwwl}\ (F_2)$ Leeward wall on second floor

$= (-17\ psf)\ (10\ sf/lf)$

$= -170\ lb/lf$

F_{wweave} $= P_{wweave} w_{owhg}$ Eave vertical force (lb)

$= -(61\ psf)\ (2\ sf/lf)$ *horizontal projected areas is negligible so horizontal force is neglected*

$= -122\ lb/lf$

D.1.2 Calculating Reactions from Wind, and Live and Dead Loads

Sum overturning moments (M_{wind}) about the leeward corner of the home. For sign convention, consider overturning moments as negative. Since vertical load path continuity is assumed not to be present above the center support, the center support provides no resistance to overturning (see Figure D-2).

M_{wind} $= (-476\ lb/lf)\ (21\ ft) + (-280\ lb/lf)\ (7\ ft) + (119\ lb/lf)\ (21.75\ ft) + (-70\ lb/lf)\ (21.75\ ft) + (-270\ lb/lf)\ (5\ ft) + (-270\ lb/lf)\ (15\ ft) + (-170\ lb/lf)\ (5\ ft) + (-170\ lb/lf)\ (15\ ft) + (-122\ lb/lf)\ (29\ ft)$

$= -23{,}288\ ft\text{-}lb/lf$

Solving for the windward reaction, therefore:

W_{wind} $= M_{wind} \div L$

W_{wind} $= -23{,}228\ ft\ (lb/lf \div 28\ ft)$

W_{wind} $= -830\ lb/lf$

The leeward reaction is calculated by either summing vertical loads or by summing moments about the windward foundation wall. Leeward reaction equals -48 lb/lf.

Lateral Wind Loads

Sum horizontal loads (Flat) on the elevated structure (Forces to the left are positive. See Figure D-2).

$$F_{lat} = (-119 \text{ lb/lf}) + (70 \text{ lb/lf}) + (270 \text{ lb/lf}) + (270 \text{ lb/lf}) + (170 \text{ lb/lf}) + (170 \text{ lb/lf})$$

$$= 831 \text{ lb/lf}$$

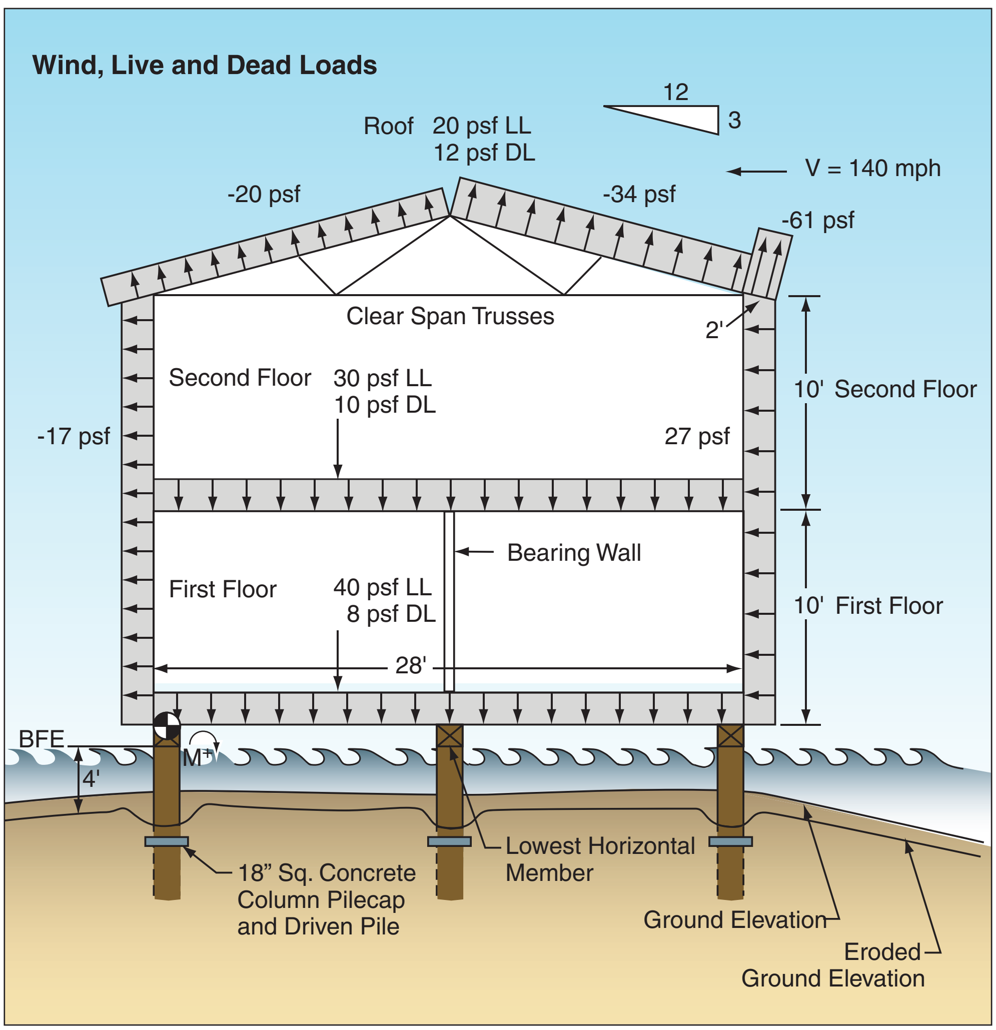


Figure D-2. Paths for wind, live, and dead loads

Dead Loads

In this example, dead load reactions (W_{dead}) are determined by summing loads over the tributary areas. Since the roof is framed with clear-span trusses and there is a center support in the home, each exterior foundation wall supports ½ of the roof load, all of the exterior wall load, and ¼ of the first and second floor loads. This approach to analysis is somewhat conservative since it does not consider the entire dead load of the structure to resist overturning. Standard engineering practice often considers the entire weight of the structure (i.e., not just the portion supported by the perimeter foundation walls) available to resist overturning. The closed foundations in this guidance were developed considering only the tributary dead load to resist uplift. The open foundations were developed considering all dead loads to resist uplift.

$$W_{dead} = L/2\,(w_{rfDL}) + L/4\,(w_{1stDL} + w_{2ndDL}) + (F_1 + F_2)\,w_{wlDL}$$
$$= [14\text{ sf/lf }(12\text{ psf})] + [7\text{ sf/lf }(8\text{psf} + 10\text{ psf})] + [(10\text{ sf/lf} + 10\text{ sf/lf})\ 9\text{ psf}]$$
$$= 474\text{ lb/lf}$$

Live Loads

Floor

Live loads (W_{live}) are calculated in a similar fashion

$$W_{live} = L/4(W_{1stLL} + W_{2ndLL})$$
$$= (7\text{ sq ft/lf})\,(40 + 30)\text{ psf}$$
$$= 490\text{ lb/lf}$$

Roof

$$W_{liveroof} = L/2(W_{rfLL})$$
$$= (14\text{ sq ft/lf})\,(20\text{ psf})$$
$$= 280\text{ lb/lf}$$

D.2 Determining Load Combinations

Combine loads as specified in Chapter 2 of ASCE 7-02. For this example, an allowable stress design approach was used. A strength-based design is equally valid.

Other loads (such as snow, ice, and seismic) are listed in the ASCE 7-02 Load Combinations, but were considered to be too rare in the Gulf Coast of the United States to be considered in the design. ASCE 7-02 also lists rain loads that are appropriate for the Gulf Coast region. Since a minimum roof slope ratio of 3:12 was assumed for the homes, rain loading was not considered.

Table D-1. Design Reactions on Base of Elevated Home

ASCE 7-02 Load Combination	Vertical (lb/lf)	Horizontal (lb/lf)
#1 D	474	--
#2 D + L	964	--
#3 D + L_r	754	--
#4 D + 0.75(L) + 0.75(L_r)	**{1,052}**	--
#5 D + W	-356	831
#6 D + 0.75(W) + 0.75(L) + 0.75(L_r)	1,016	623
#7 0.6D + W	**{-546}**	**{831}**
#8 0.6D	284	--

Where

D = Dead Load

L = Live Load

L_r = Roof Live Load

W = Wind Load

NOTE: Critical loads are in bold and with brackets (**{ }**).

Flood Load Effects on a Foundation

In this example, since the foundation selected is a system of steel pipe piles, the equations used to calculate flood loads are based on open foundations. Some of the equations used to calculate flood loads will be different if the building has a closed foundation system.

Many flood calculations depend on the stillwater flooding depth (d_s). While not listed on FIRMs, d_s can be calculated from the BFE by knowing that the breaking wave height (H_b) equals 78 percent of the stillwater depth and that 70 percent of the breaking wave exists above the stillwater depth (see Figure 11-3 of FEMA 55). Stated algebraically:

BFE $= GS + d_s + 0.70\ H_b$

$= GS + d_s + 0.70(0.78\ d_s)$

$= GS + 1.55\ d_s$

GS = 15 ft NAVD (initial elevation) – 1 ft (short- and long- term erosion)

= 14 ft NAVD

d_s = (BFE – GS) ÷ 1.55

= (18 feet NAVD – 14 feet NAVD)÷ 1.55

$= 4 \text{ ft} \div 1.55$

$= 2.6 \text{ ft}$

Hydrostatic Loads

Hydrostatic loads act laterally and vertically on all submerged foundation elements. On open foundations, lateral hydrostatic loads cancel and do not need to be considered but vertical hydrodynamic forces (buoyancy) remain. The buoyancy forces reduce the effective weight of the foundation by the weight of the displaced water and must be considered in uplift calculations. For example, normal weight concrete which typically weighs 150 lb/ft^3 only weighs 86 lb/ft^3 when submerged in saltwater (slightly more in freshwater).

In this example, calculations are based on an 18-inch square normal weight concrete column that extends 4 feet above eroded ground elevation. The column weighs 1,350 pounds dry ((1.5 ft) (1.5 ft) (4 ft) (150 lb/ft^3). Under flood conditions, the column displaces 9 ft^3 of saltwater that, at 64 lb/ft^3, weighs 576 pounds so the column weighs only 774 pounds when submerged.

Hydrodynamic Loads

Flood Velocity

Since a Coastal A Zone is close to the flood source, flood velocity is calculated using the ASCE 7-02 Equation C5-2:

$V = (g\, d_s)^{1/2}$ Upper bound flood velocity

Where

g = Gravitational acceleration (32.2 ft/sec^2)

d_s = Design stillwater depth (ft)

Hence

$V = [(32.2)(2.6)]^{1/2}$

$= 9.15$ feet per second (fps)

Hydrodynamic Forces

A modified version of ASCE 7-02 Equation C5-4 can be used to calculate the hydrodynamic force on a foundation element as

$F_{dyn} = \frac{1}{2} C_d\, \rho\, V^2 A$

Where

F_{dyn} = Hydrodynamic force (lb) acting on the submerged element

C_d = 2.0 Drag coefficient (equals 2.0 for a square or rectangular column)

$\rho = 2$ Mass density of salt water (slugs/cubic foot)

$A = 1.5\ d_s$ Surface area of obstruction normal to flow (ft^2)

For open foundation, "A" is the area of pier or column perpendicular to flood direction (calculated for an 18-inch square column).

Hence

F_{dyn} = (½) (2)(2)(9.15)2(1.5)(2.6)

= 653 lb/column

The force is assumed to act at a point $d_s/2$ above the eroded ground surface.

The formula can also be used for loads on foundation walls. The drag coefficient, however, is different. For foundation walls, C_d is a function of the ratio between foundation width and foundation height or the ratio between foundation width and stillwater depth. For a building with dimensions equal to those used in this example, C_d for a closed foundation would equal 1.25 for full submersion (42 feet by 4 feet) or 1.3 if submersed only up to the 2.6-foot stillwater depth.

Dynamic loads for submersion to the stillwater depth for a closed foundation are as follows:

F_{dyn} = ½ $C_d\ \rho\ V^2\ A$

F_{dyn} = (½) (1.3)(2)(9.15)2(1)(2.6)

= 283 lb/lf of wall

Floodborne Debris Impacts

The loads imposed by floodborne debris were approximated using formula 11-9 contained in FEMA 55.

The *Commentary* of ASCE 7-02 contains a more sophisticated approach for determining debris impact loading, which takes into account the natural period of the impacted structure, local debris sources, upstream obstructions that can reduce the velocity of the floodborne debris, etc.

For ease of application and consistency, debris loads in this example have been calculated using the guidance contained in FEMA 55 that are based on ASCE 7-98, not the 2002 version of ASCE 7. It is suggested that designers of coastal foundations review the later standards to determine if they are more appropriate to use in their particular design.

The FEMA 55 Formula 11.9 estimates debris impact loads as follows:

F_i = $wV \div (g\ \Delta\ t)$

Where

F_i	= impact force (lb)
w	= weight of the floodborne debris (lb)
V	= velocity of floodborne debris (ft/sec)
g	= gravitational constant = 32.2 ft/sec^2
Δt	= impact duration (sec)

Floodborne debris velocity is assumed to equal the velocity of the moving floodwaters and acting at the stillwater level. For debris weight, FEMA 55 recommends using 1,000 pounds when no other data are available. The impact duration depends on the relative stiffness of the foundation and FEMA 55 contains suggested impact durations for wood foundations, steel foundations, and reinforced concrete foundations. For this example, the suggested impact duration of 0.1 second was used for the reinforced concrete column foundation.

F_i = wV ÷ gt

F_i = [1,000 lb (9.15 ft/sec)] ÷ [(32.2 ft/sec^2) (0.1 sec)]

F_i = 2,842 lb

Breaking Wave Loads

When water is exposed to even moderate winds, waves can build quickly. When adequate wind speed and upstream fetch exist, floodwaters can sustain wave heights equal to 78 percent of their stillwater depths. Depending on wind speeds, maximum wave height for the stillwater depth at the site can be reached with as little as 1 to 2 miles of upwind fetch.

Breaking wave forces were calculated in this example using ASCE 7-02 formulae for wave forces on continuous foundation walls (ASCE 7-02 Equations 5-5 and 5-6) and on vertical pilings and columns (ASCE 7-02 Equation 5-4).

The equation for vertical pilings and columns from ASCE 7-02 is

$F_{brkp} = \frac{1}{2} C_{db}\, \gamma\, D H_b^2$

Where

F_{brkp}	= Breaking wave force (acting at the stillwater level) (lb)
C_{db}	= Drag coefficient (equals 2.25 for square or rectangular piles/columns)
γ	= Specific weight of water (64 lb/ft^3 for saltwater)
D	= Pile or column diameter in ft for circular sections, or for a square pile or column, 1.4 times the width of the pile or column (ft). For this example, since the column is 18-inch square, D = (1.4) (1.5ft) = 2.1 ft

H_b = Breaking wave height $(0.78\ d_s)$ (ft) = (0.78) (2.6) = 2.03 ft

Note: The critical angle of a breaking wave occurs when the wave travels in a direction perpendicular to the surface of the column. Waves traveling at an oblique angle (α) to the surface of the waves are attenuated by the factor $\sin^2\alpha$.

$$F_{brkp} = \tfrac{1}{2}\, C_{db}\, \gamma\, D H_b^2$$

$$= \tfrac{1}{2}\,(2.25)\,(64\ \text{lb/ft}^3)\,(2.1\ \text{ft})\,(2.03\ \text{ft})^2$$

$$= 623\ \text{lb}$$

For closed foundations, use equations in Section 5.3.3.4.2 of ASCE 7-02 to calculate F_{brkp}. FEMA 55 contains the following two equations for calculating loads on closed foundations:

$$f_{brkw} = 1.1\, C_p\, \rho\, d_s^2 + 2.41\, \gamma\, d_s^2 \quad \text{Case 1}$$

and

$$f_{brkw} = 1.1\, C_p\, \rho\, d_s^2 + 1.91\, \gamma\, d_s^2 \quad \text{Case 2}$$

Where γ and d_s are the specific weights of water and design stillwater depths as before. C_p is the dynamic pressure coefficient that depends on the type of structure. C_p equals 2.8 for residential structures, 3.2 for critical and essential facilities, and 1.6 for accessory structures where there is a low probability of injury to human life. The term f_{brkw} is a distributed line load and equals the breaking wave load per foot of wall length where f_{brkw} is assumed to act at the stillwater elevation.

Case 1 of Formula 11.6 represents a condition where floodwaters are not present on the interior of the wall being designed or analyzed. Case 1 is appropriate for foundation walls that lack flood vents (see Figure D-3). The less stringent Case 2 is appropriate for walls where NFIP required flood vents are in place to equalize hydrostatic loads and reduce forces (see Figure D-4).

In non-Coastal A Zones, the maximum wave height is 1.5 feet. This corresponds to a stillwater depth (d_s) of approximately 2 feet (i.e., 1.5 foot/0.78 for a depth limited wave). For closed foundations in coastal areas with flood vents, a 1.5-foot breaking wave creates 1,280 lbs per linear foot of wall and 1,400 lbs per linear foot of wall on foundations that lack flood vents.

Wind Load on Columns

Wind loads have been calculated per ASCE 7-02, Section 6.5.13 (Wind Loads on Open Buildings and Other Structures). The velocity pressure (q_h) calculated previously was used, although this is a conservative figure based on the 26-foot mean roof height. The force coefficient (C_f) was determined from ASCE 7-02, Figure 6-19 (chimneys, tanks, and other structures); ASCE 7-02, Figure 6-20 (walls and solid signs) could have been used as well.

From ASCE 7-02 Equation 6-25:

F_{wind} $= q_z \, G \, C_f \, A_f$

$= 40 \text{ psf } (0.85)(1.33^*)(1.5 \text{ ft})(4 \text{ ft})$

$= 270 \text{ lb}$

*Interpolated C_f

Wind loads on the foundation elements are not considered in combination with flood loads since the elements are submerged during those events.

Flood Load Combinations

Section 11.6.12 of FEMA 55 provides guidance on combining flood loads. In Coastal A Zones, FEMA 55 suggests two scenarios for combining flood loads. Case 1 involves analyzing breaking wave loads on all vertical supports and impact loading on one corner or critical support and Case 2 involves analyzing breaking wave loads applied to the front row of supports (row closest to the flood source), and hydrodynamic loads applied to all other supports and impact loads on one corner or critical support.

Depending on the relative values for dynamic and breaking waves, Case 1 often controls for designing individual piers or columns within a home. Case 2 typically controls for the design of the assemblage of piers or columns working together to support a home. Because of the magnitude of the load, it is not always practical to design for impact loads. As an alternative, structural redundancy can be provided in the elevated home to allow one pier or column to be damaged by floodborne debris impact without causing collapse or excessive deflection.

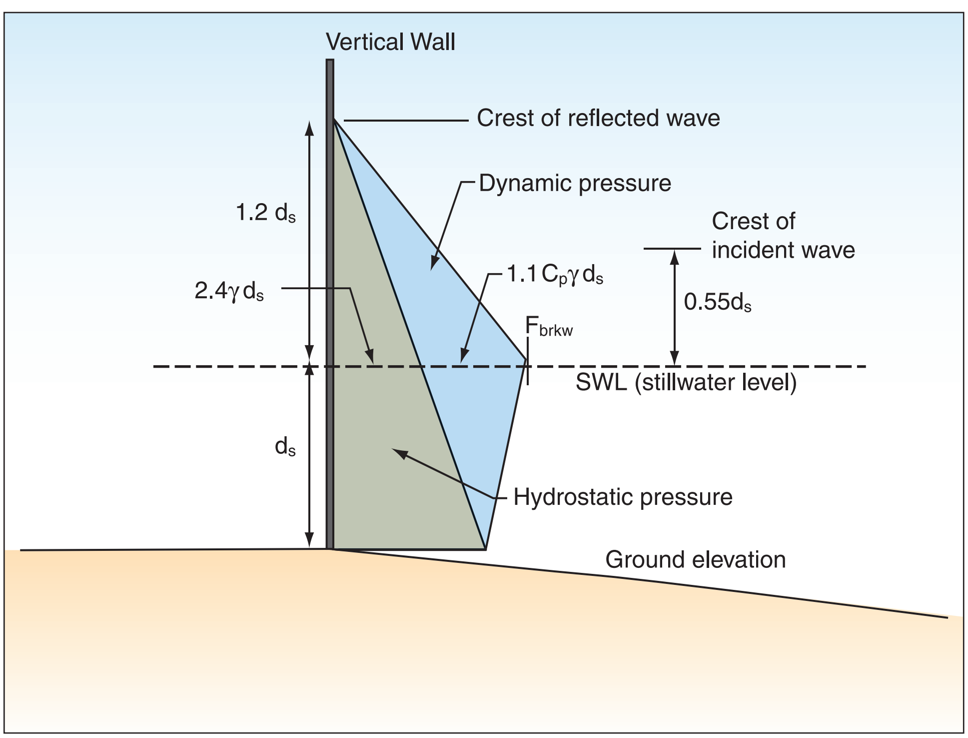


Figure D-3. Case 1. Normally incident breaking wave pressures against a vertical wall (space behind vertical wall is dry)

SOURCE: ASCE 7-02

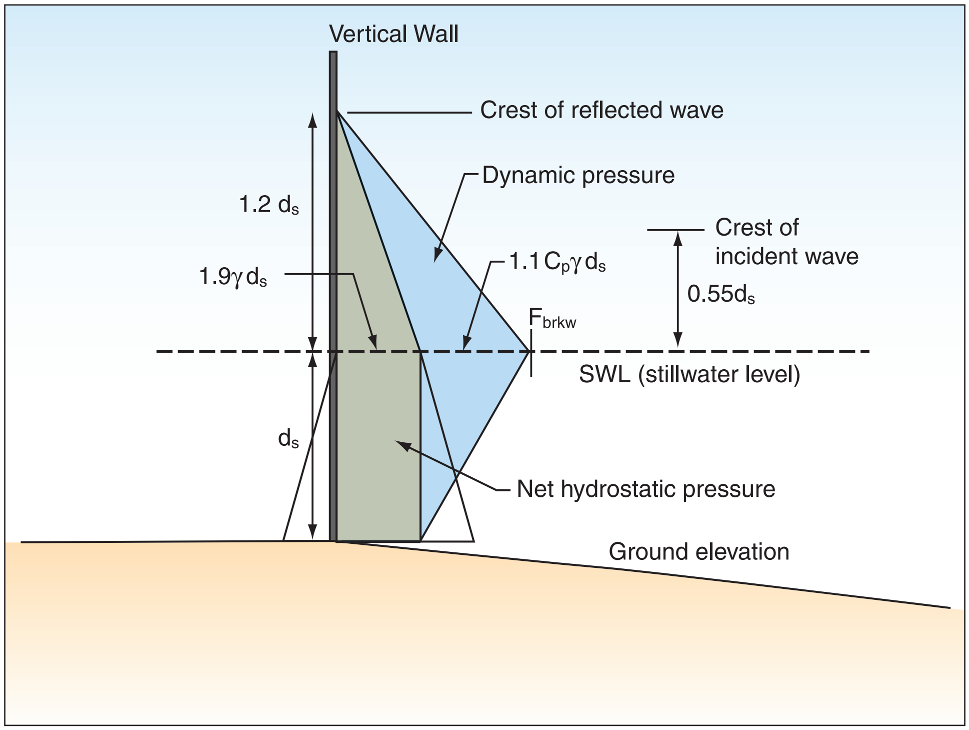


Figure D-4. Case 2. Normally incident breaking wave pressures against a vertical wall (stillwater level equal on both sides of wall)

SOURCE: ASCE 7-02

For the sample calculations, Case 1 was used (see Figure D-5) with a breaking wave load of 623 pounds applied to a non-critical column. The loads were then determined and summarized. Since the calculations must combine distributed loads on the elevated structure and discrete loads on the columns themselves, a column spacing of 7 feet is assumed in the calculations. For lateral loads on the structure, calculations are based on three rows of columns sharing lateral loads.

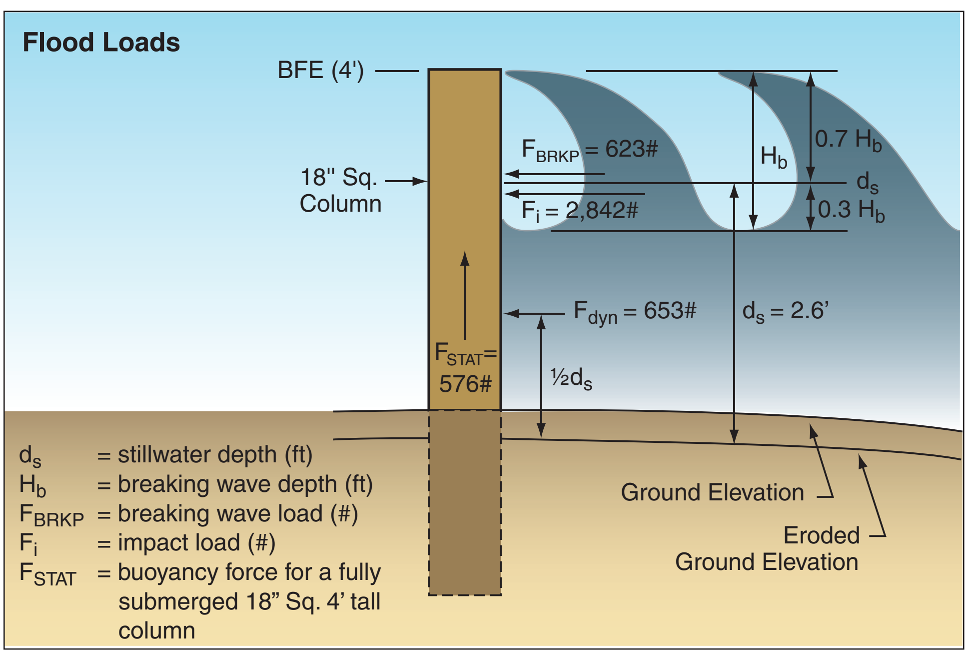


Figure D-5. Flood loads

Table D-2. Loads on Columns Spaced 7 Feet on Center (for three rows of columns)

ASCE 7-02 Load Combination	Vertical (lb)	Horizontal (lb)
#1 D + F	1,350 + [7(474]) = 4,668	--
#2 D + F + L	1,350 + [7(964)] = 8,098	--
#3 D + F + L_r	1,350 + [7(754)] = 6,628	--
#4 D + F + 0.75(L) + 0.75(L_r)	774 + 7(1,052) = **{8,138}**	--
#5 D + F + W + 1.5(F_a)	774 + [7(474 - 48)] = 3,756	[(1/3)7(831)] + [1.5(623)] = **{2,874}**
#6 D + F + 0.75(W) + 0.75(L) + 0.75(L_r) + 1.5(F_a)	774 + 7[474 + 0.75 (-48+490+280)] = 7,883	[(1/3)7(0.75)(831)] + [1.5(623)] = 2,388
#7 0.6D + W + 1.5(F_a)	0.6[774 + 7(474)] + [7(-830)] = **{-3,555}**	[(1/3)7(831)] + [1.5(623)] = **{2,874}**
#8 0.6D	[0.6(1,350)] + [7(306)] = 3,000	--

Where

D = Dead Load

F = Load due to fluids with well-defined pressures and maximum heights (see Section D.2 for additional information)

F_a = Flood Load

L = Live Load

L_r = Roof Live Load

W = Wind Load

Note: Critical loads are in bold with brackets ({ }).

Results

Each perimeter column needs to support the following loads:

Vertical Load = 8,138 lb

Uplift = 3,555 lb

Lateral Load = 2,874 lb

With the critical loads determined, the foundation elements and their connections to the home can be designed.

The following two examples are to demonstrate designs using information provided in this manual. The first example is based on a closed foundation; the second example is based on an open foundation.

D.3 Closed Foundation Example

A structure to be supported by the closed foundation is identical to the structure analyzed in the example from Section D.1. The site, however, is different. For the closed foundation design, the structure is to be placed in a non-Coastal A Zone where breaking waves are limited to 1.5 feet. The design stillwater depth is 2 feet, and the BFE is 3 feet above exterior grade. While the structure could be placed on a 3-foot foundation, the property owner requested additional protection from flooding and a 4-foot tall foundation is to be built. Since the home elevation is identical to that in the example, the loads and load combinations listed in Table D-1 are identical. However, since the foundation is closed, flood forces must first be analyzed.

Like the previous analysis example, flood forces consist of hydrodynamic loads, debris loads, and breaking wave loads. Since the home is located in a non-Coastal A Zone, it is appropriate to use lower bound flood velocities. This will significantly reduce hydrodynamic and debris loads. From FEMA 55, the following equation is used:

$V_{lower} = d_s$

$= 2$ ft/sec

Hydrodynamic Loads

$F_{dyn} = ½\, C_d\, \rho\, V^2\, A$

$= ½\, C_d\, \rho\, V^2\, (1)\, d_s$

$F_{dyn} = (½)\ (1.4)(2)(2)^2(1)(2)$

$= 11$ lb/lf of wall

Where C_d of 1.4 is for a (width of wall/d_s) ratio of 21 (42 ft/2 ft)

(From FEMA 55, Table 11.2)

The hydrodynamic load can be considered to act at the mid-depth of the stillwater elevation. The hydrodynamic load is less than the 27 psf wind load on the windward wall.

Debris Loads

$F_i = wV \div gt$

$F_i = [1{,}000 \text{ lb } (2 \text{ ft/sec})] \div [(32.2 \text{ ft/sec}^2)(0.1 \text{ sec})]$

$F_i = 620$ lb

Due to load distribution, the impact load will be resisted by a section of the wall. Horizontal shear reinforcement will increase the width of the section of wall available to resist impact. For this example, a 3-foot section of wall is considered to be available to resist impact. The debris impact load becomes

F_{iwall} = (1/3) 620 lb

F_{iwall} = 210 lb/ft

Breaking Wave Loads

The home is to be constructed in a SFHA; hence, the NFIP required flood vents will be installed. The breaking wave load can be calculated using formulae for equalized flood depths (Case 2).

$f_{brkw} = 1.1\ C_p\ \gamma\ d_s^2 + 1.91\ \gamma\ d_s^2$

$f_{brkw} = \gamma\ d_s^2\ (1.1\ C_p + 1.91)$

$f_{brkw} = (64)(2^2)\{(1.1)(2.8) + 1.91\}$

f_{brkw} = 1,280 lb/lf

The breaking wave load can be considered to act at the 2-foot stillwater depth (d_s) above the base of the foundation wall.

The foundation must resist the loads applied to the elevated structure plus those on the foundation itself. Chapter 2 of ASCE 7-02 directs designers to include 75 percent of the flood load in load combinations 5, 6, and 7 for non-Coastal A Zones. Table D-1 lists the factored loads on the elevated structure.

Critical loads from Table D-1 include 546 lb/lf uplift, 1,052 lb/lf gravity, and 831 lb/lf lateral from wind loading. The uplift load needs to be considered when designing foundation walls to resist wind and flood loads and when sizing footings to resist uplift; the gravity load must be considered when sizing footings and the lateral wind and flood loads must be considered in designing shear walls.

Extending reinforcing steel from the footings to the walls allows the designer to consider the wall as a propped cantilever fixed at its base and pinned at the top where it connects to the wood-framed floor framing system. The foundation wall can also be considered simply supported (pinned at top and bottom). The analysis is somewhat simpler and provides conservative results.

The 1,280 lb/lf breaking wave load is the controlling flood load on the foundation. The probability that floodborne debris will impact the foundation simultaneously with a design breaking wave is low so concurrent wave and impact loading is not considered. Likewise, the dynamic load does not need to be considered concurrently with the breaking wave load and the 27 lb/sf wind load can not occur concurrently on a wall submerged by floodwaters.

The breaking wave load is analyzed as a point load applied at the stillwater level. When subjected to a point load (P), a propped cantilevered beam of length (L) will produce a maximum moment of 0.197 (say 0.2) PL. The maximum moments occur when "P" is applied at a distance 0.43L from the base. For the 4-foot tall wall, maximum moment results when the load is applied near the stillwater level (d_s). In this example, the ASCE 7-02 required flood load of 75 percent of the breaking wave load will create a bending moment of

$M = (0.2)\ f_{brkw}\ (L)$

$= (0.2)(0.75)(1{,}280 \text{ lb/ft})\ (4 \text{ ft})$

$= 768$ ft-lb/lf or

$= 9{,}200$ in-lb/lf

The reinforced masonry wall is analyzed as a tension-compression couple with moment arm "jd," where "d" is the distance from the extreme compression fiber to the centroid of the reinforcing steel, and "j" is a factor that depends on the reinforcement ratio of the masonry wall. While placing reinforcing steel off center in the wall can increase the distance (d) (and reduce the amount of steel required), the complexity of off-center placement and the inspections required to verify proper placement make it disadvantageous to do so. For this design example, steel is considered to be placed in the center of the wall and "d" is taken as one half of the wall thickness. For initial approximation, "j" is taken as 0.85 and a nominal 8-inch wall with a thickness of 7-5/8 inches is assumed.

Solving the moment equation is as follows:

$M = T\ (jd)$

$T = M/(jd) =$ Tension force

$= M/(j)(t/2)$ (t = thickness of wall)

$T = (9{,}200 \text{ in-lbs/lf}) \div \{(0.85)(7.63 \text{ in})(0.5)\}$

$= 2{,}837$ lb/lf

For each linear foot of wall, steel must be provided to resist 2,837 pounds of bending stress and 546 pounds of uplift.

$F_{steel} = 2{,}837$ lbs/lf (bending) + 546 lbs/lf (uplift)

$= 3{,}383$ lbs/lf

The American Concrete Institute (ACI) 530 allows 60 kips per square inch (ksi) steel to be stressed to 24 ksi so the reinforcement needed to resist breaking wave loads and uplift is as follows:

$A_{steel} = 3{,}383 \text{ lbs/lf} \div 24{,}000 \text{ lb/in}^2$

$= 0.14 \text{ in}^2\text{/lf}$

Placing #5 bars (at 0.31 in^2/bar) at 24 inches on centers will provide the required reinforcement. To complete the analysis, the reinforcement ratio must be calculated to determine the actual "j" factor and the stresses in the reinforcing steel need to be checked to ensure the limits dictated in ACI 530 are not exceeded. The wall design also needs to be checked for its ability to resist the lateral forces from flood and wind.

Footing Sizing

The foundation walls and footings must be sized to prevent overturning and resist the 546 lb/lf uplift. ASCE 7-02 load combination 6 allows 60 percent of the dead load to be considered in resisting uplift. Medium weight 8-inch masonry cores grouted at 24 inches on center weigh 50 lb/sf or, for a 4-foot tall wall, 200 lbs/lf. Sixty percent of the wall weight (120 lb/lf) reduces the amount of uplift the footing must resist to 426 lb/lf. At 90 lb/ft^3 (60 percent of 150 lb/ft^3 for normal weight concrete), the footing would need to have a cross-sectional area of 4.7 square feet. Grouting all cores increases the dead load to 68 lb/sf and reduces the required footing area to 4.25 square feet. The bearing capacity of the soils will control footing dimensions. Stronger soils can allow narrower footing dimensions to be constructed; weaker soils will require wider footing dimensions.

The design also needs to be checked to confirm that the footings are adequate to prevent sliding under the simultaneous action of wind and flood forces. If marginal friction resistance exists, footings can be placed deeper to benefit from passive soil pressures.

D.4 Open Foundation Example

For this example, the calculations are based on a two-story home raised 8 feet above grade with an integral slab-grade beam, mat-type foundation and a 28-foot by 42-foot footprint. The home is sited approximately 800 feet from the shore in a Coastal A Zone with a calculated DFE of 6 feet above the eroded exterior grade (6 inches below top of slab). The DFE was determined by subtracting an estimated grade elevation, shown on advisory topographic map ms-g15, from the ABFE elevation indicated on advisory flood map ms-g15. It is important to note, however, that submittal of an elevation certificate and construction plans to local building code and floodplain officials in many jurisdictions will require that the elevation be confirmed by a licensed surveyor referencing an established benchmark elevation.

The wood-framed home has a 3:12 roof pitch with a mean roof height of 30 feet, a center wood beam supporting the first floor, and a center load bearing wall supporting the second floor. Clear span trusses frame the asphalt-shingled roof and are designed to provide a 2-foot overhang. This home is a relatively light structure that contains no brick or stone veneers.

The surrounding site is flat, gently sloping approximately 1 foot in 150 feet. The site and surrounding property have substantial vegetation, hardwood trees, concrete sidewalks, and streets. A four-lane highway and a massive concrete seawall run parallel to the beach and the established residential area where the site is located. The beach has been replenished several times in the last 50 years. Areas to the west of the site that have not been replenished have experienced beach erosion to the face of the seawall. The ASCE 7-02, 3-second gust design wind speed is 140 mph and the site is in an Exposure Category C.

The proposed foundation for the home incorporates a monolithic carport slab placed integrally with a system of grade beams along all column lines (see Figure D-6). The dimensions of the grade beam were selected to provide adequate bearing support for gravity loads, resistance to overturning and sliding, and mitigate the potential of undermining of the grade beams and slab due to scour action. The home is supported by concrete columns, extending from the top of the slab to the lowest member of the elevated structure, spaced at 14 feet on center (see Figure D-7).

Figure D-6.
Layout of Open Foundation Example

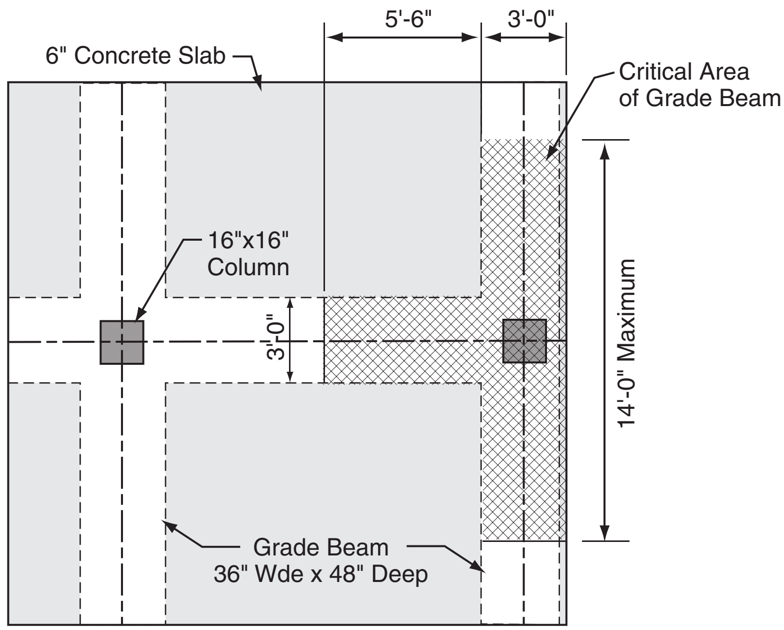
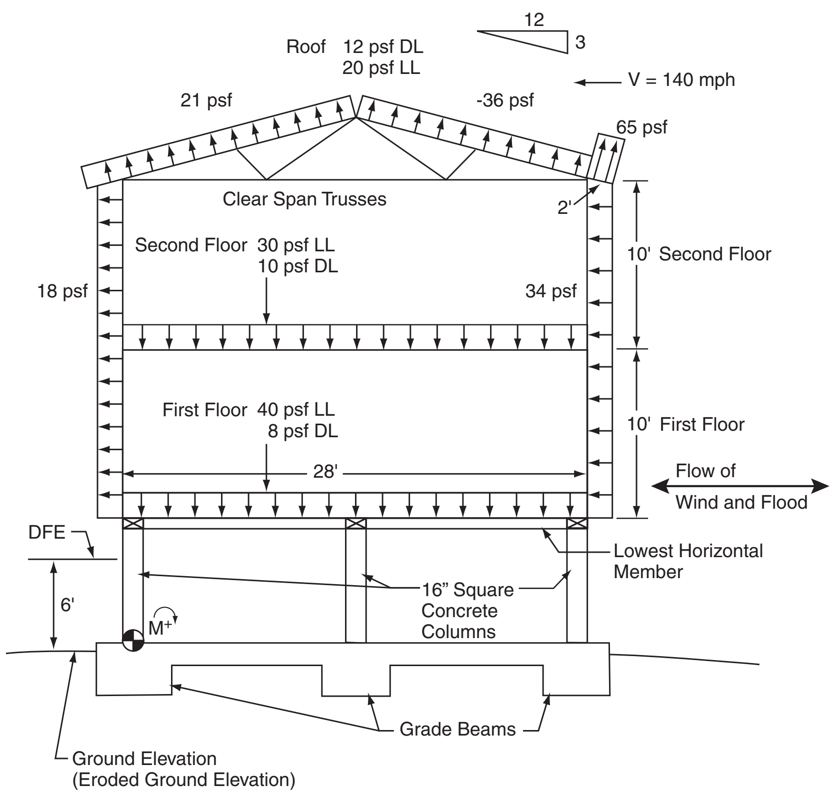


Figure D-7.
Loading Diagram for Open Foundation Example



Lateral Wind Loads

Sum horizontal loads (F_{lat}) on the elevated structure (forces to the left are positive)

F_{lat} = (-126 lb/lf) + (74 lb/lf) + (280 lb/lf) + (280 lb/lf) + (180 lb/lf) + (180 lb/lf)

= 868 lb/lf

Dead Loads

Dead load reactions (W_{dead}) are determined by summing loads over the tributary areas. For the anterior columns:

W_{dead} = $L/2\ (w_{rfDL}) + L/4\ (w_{1stDL} + w_{2ndDL}) + (F_1 + F_2)\ w_{wlDL}$

= [14 sf/lf (12 psf)] + [7 sf/lf (8psf + 10 psf)] + [(10 sf/lf + 10 sf/lf) 9 psf]

= 474 lb/lf

Live Loads

Floor

Live loads (W_{live}) are calculated in a similar fashion

W_{live} = $L/4(W_{1stLL} + W_{2ndLL})$

= (7 sq ft/lf) (40 + 30) psf

= 490 lb/lf

Roof

$W_{liveroof}$ = $L/2(W_{rfLL})$

= (14 sq ft/lf) (20 psf)

= 280 lb/lf

A minimum roof slope of 3:12 was assumed for the homes; rain loading was not considered.

Flood Effects

Since the foundation selected is a system of concrete columns, the equations used to calculate flood loads are based on open foundation. The stillwater flooding depth (d_s) is as follows:

d_s = DFE ÷ 1.55

= 6 ft ÷ 1.55

= 3.9 ft

Hydrostatic Loads

Calculations are based on a 16-inch square normal weight concrete column that extends 8 feet above the concrete slab.

The column weighs 2,123 pounds dry ((1.33 ft) (1.33 ft) (8 ft) (150 lb/ft^3).

Under flood conditions, the column displaces 10.6 ft^3 of saltwater which, at 64 lb/ft^3, weighs 679 pounds so the column weighs 1,444 pounds when submerged.

Hydrodynamic Loads

Flood Velocity

Since a Coastal A Zone is close to the flood source, flood velocity is calculated using the ASCE 7-02 Equation C5-2 as follows:

$$V = [(32.2 \text{ ft/sec}^2)(3.9 \text{ ft})]^{1/2}$$

$$= 11.21 \text{ feet per second (fps)}$$

Flood Force

ASCE 7-02 Equation C5-4 is as follows:

$$F_{dyn} = ½ C_d \rho V^2 A$$

$$= (½)\ (2)(2)(11.21\text{fps})^2(1.33\text{ft})(3.9\text{ft})$$

$$= 1{,}303 \text{ lb/column}$$

Floodborne Debris Impact

The flood debris impact can be estimated, per FEMA 55 Formula 11.9, as follows:

$$F_i = wV \div gt$$

$$= [1{,}000 \text{ lb } (11.21 \text{ ft/sec})] \div [(32.2 \text{ ft/sec}^2)(0.1 \text{ sec})]$$

$$= 3{,}478 \text{ lb}$$

Breaking Wave Load

The equation for vertical pilings and columns from ASCE 7-02 is as follows:

$$F_{brkp} = ½ C_{db} \gamma D H_b^2$$

$$= ½\ (2.25)(64 \text{ lb/ft}^3)(1.82 \text{ ft})(3.04\text{ft}^*)^2$$

$$= 1{,}211 \text{ lb}$$

Wind Load on Columns

For a load case combining both wind and flood forces, the column would be almost completely submerged; therefore, the wind load on the column shall not be included.

* A wave height of 3.04 ft suggests a V Zone but, in this example, the depth of water is increased by erosion which is not considered in mapping A Zones. The deeper water supports a bigger wave, which in this case exceeds the V Zone wave height minimum.

Calculating Reactions from Wind, Live, and Dead Loads

Sum overturning moments (M_{wind}) and (M_{flood}) about the leeward corner of the mat foundation. For sign convention, consider overturning moments as negative. Note in this example the home is slightly higher above grade and hence the wind loads are slightly higher.

M_{wind} = (-504 lb/lf) (21 ft) + (-294 lb/lf) (7 ft) + (126 lb/lf) (21.75 ft) + (-74 lb/lf) (21.75 ft) + (-280 lb/lf) (13 ft) + (-280 lb/lf) (23 ft) + (-180 lb/lf) (13 ft) + (-180 lb/lf) (23 ft) + (-130 lb/lf) (29 ft)

= -31,841 ft-lb/lf

The vertical components of the reaction caused by the wind overturning moment is:

R_x = 31,841 lb ÷ 28 ft = +/- 1,137 lb/ft

M_{flood} = 1.5[((-1,211lb) (3.9ft)) + (2(-1,303lb) (3.9ft/2)) + ((-3,478lb) (3.9ft))] = 35,053 ft-lb/ft

The vertical component of the reaction caused by the flood overturning moment is:

R_x = 35,053 lb ÷ 28 ft = +/- 1,252 lb outboard columns

Load Combinations

Table D-3. Loads at Base of Columns Spaced 14 Feet on Center (for three rows of columns per bay)

ASCE 7-02 Load Combination	Vertical (lb)	Horizontal (lb)
#1 D + F	1,444 + 14(474) = 8,080	--
#2 D + F + L	1,444 + 14(964) = 14,940	--
#3 D + F + L_r	1,444 + 14(754) = 12,000	--
#4 D + F + 0.75(L) + 0.75(L_r)	8,080 + (.75)[(14)(490+280)] = 16,165	--
#5 D + F + W + 1.5(F_a)	8,080 +/- 14(1,137) +/- 1,252 = 25,876; -9,716 windward; leeward	wind + (1.5)[F_{dyn} + F_i] [(14(868)(1/3)] + (1.5) [(1,303+3,478)] = 11,222
#6 D + F + 0.75(W) + 0.75(L) + 0.75(L_r) + 1.5(F_a)	8,080 +/- (.75)(14)(1,137) +(.75)(14)([(490+280)] +/- 1,252 = 2,348; **29,982** windward; leeward	(.75) wind + (1.5)[F_{dyn} + F_i] [(0.75)(14)(868)(1/3)] + (1.5)[(1,303+3,478)] = 10,210
#7 0.6D + W + 1.5(F_a)	0.6 [2,123+14(474)] +/- 14(1,137) +/- (1.5)1,252 = **-12,541**; 23,051 windward; leeward	wind + (1.5)[F_{dyn} + F_i] [(14(868)(1/3)] + (1.5) [(1,303+3,478)] = **11,222**
#8 0.6D	[0.6((2,123) + 14(474))] = 5,255	--

Critical loads are in bold.

Where

D	= Dead Load
F	= Fluid (Buoyancy) Load
L	= Live Load
L_r	= Roof Live Load
W	= Wind Load
ww	= windward
lw	= leeward

Results

Each perimeter column needs to support the following loads:

Vertical load	= 29,982 lb
Uplift	= 12,541 lb
Lateral Load	= 11,222 lb
Moment wind + f_{dyn}	= [(1/3)(14)(1,314)(8) + (1,303)(3.9/2)] ÷ 1,000 lb/kip
	= 51.6 ft-kip
Moment wind + f_{brkp}	= [(1/3)(14)(1,314)(8) + (1,113)(3.9)] ÷ 1,000 lb/kip
	= 96.9 ft-kip
Moment wind + f_{dyn}+ debris	= 51.6 ft-kip + (3,478)(3.9) ÷ 1,000 lb/kip
	= 65.1 ft-kip
	= 13.6 ft-kip

The force is assumed to act at a point $d_s/2$ above the eroded ground surface. For concrete design we use load factors per ASCE 7-02.

Ultimate Moment wind + f_{dyn}	= (48.6)(1.2)+(2.5)(2.0)
	= 63.4 ft-kip
Ultimate Moment wind + f_{brkp}	= (48.6)(1.2)+(4.3)(2.0)
	= 66.9 ft-kip
Ultimate Moment wind + f_{dyn} + debris	= (63.4)+13.6(2)
	= 90.6 ft-kip

Foundation Design

Overturning

The overturning moment due to wind with a typical bay of 14 feet wide is as follows:

M_{wind} = (-31,841ft-lb/lf) (14 ft)

= -445,774 ft-lb

M_{Fa} (1.5) = (1.5) [(1,211lb) (3.9 ft) + (2) (1,303 lb) (3.9 ft/2)]

= -14,707 ft-lb

M_o = -445,774 ft-lb - 14,707 ft-lb

= -460,481 ft-lb

In this example, it is assumed that the home and the foundation slab are reasonably symmetrical and uniform; therefore, it is assumed the center of gravity for the dead loads is at the center of the bay.

Dead Load at perimeter columns

D_{ext} = (474 lb/ft) (14 ft) (2 columns)

= 13,272 lb

Dead Load at an interior column:

D_{int} = (14 ft) (14 ft) (8 psf)

= 1,568 lb

Dead Load of 3 columns: (3) (8 ft) (1.33 ft x 1.33 ft) (150) lb cubic ft

= 6,368 lb

Assume that only the grade beams are sufficiently reinforced to resist overturning (neglect weight of slab)

Dead Load of the grade beams (area) (depth) (density of concrete)
[(28 ft x3ft) +(3) ((11 ft) (3 ft)] (4 ft) (150 lb cubic ft) = 109,800 lb

Summing the Dead Loads = 13,272+1,568+6,368+109,800 = 131,008 lb

Allowable Dead Load Moment of 60%

M_d = (0.6) (131,008 lb) (14 ft)

= 1,100,476 ft-lb

Since M_{ot} = 460,481 ft-lb is very much less than 0.6 M_d = 1,100,476 ft-lb, the foundation can be assumed to resist overturning.

Sliding

The maximum total lateral load of wind and flood acting on the entire typical bay is as follows:

L_{wfa} = W + 1.5 F_a

= [(14 ft (868 lb/ ft) + 1.5(7,203 lb)]

= 23,375 lb

Sliding Resistance = (tanΦ)N + Passive Resistance at Vertical Foundation Surfaces

Φ = internal angle of soil friction, assume Φ = 25 degrees

N = net normal force (building weight - uplift forces)

N = (131,008) + (14 ft)[((16 ft)(-21 psf)+(14 ft)(-36 psf)+(2 ft)(-65psf)]

= 117,428 lb

Ignore passive soil pressure

Dead Load Sliding Resistance = (tan 25)(117,428 lb)

= 54,758 lb

Since L_{wfa} = 23,371 lb is less than 60% of Dead Load Sliding Resistance = 54,758, the foundation can be assumed to resist sliding.

Soil Bearing Pressure

The simplified approach for this mat foundation assumes that only the grade beams carry loads to the soil, the slab between grade beams is not considered to contribute support. It is further assumed that the bearing pressure is uniform in the absence of wind and flood loading. The areas of the grade beams along the outboard column lines, in the direction of the flow of wind and flood, are considered the "critical areas" of the grade beam. The load combination table below indicates the bearing pressures for the ASCE 7- 02 load combinations for the critical grade beam area. These load combinations are calculated to ensure that downward forces of the wind and flood moment couple do not overstress the soil. The factored dead load moment that resists overturning is of a magnitude such that there is no net uplift along critical grade beams.

Self Weight of 1 square of foot Grade Beam = (4 ft)(150 lb/cubic ft) = 650 psf

Area of Critical Grade Beam = [(3ft)(14 ft)] + [(3 ft)(5.5 ft)]

= 58.5 ft^2

Weight of Critical Grade Beam = (58.5 ft^2)(4 ft)(150 lb/cubic ft)

= 35,100 lb

Critical Column Uplift = 12,541 lb (load combination 7)

Verification of Uplift Resistance = [35,100 lb(0.6)] – 12,541 lb

= 8,519 lb (positive load, no uplift)

Presumptive Allowable Bearing Pressure = 1,500 psf

Table D-4. Foundation Bearing Pressures Typical Bay (for three rows of columns per bay)

ASCE 7-02 Load Combination	Combined Loads (lb)	Bearing Pressures (psf)
#1 D + F	8,080	8,090 ÷ 58.5 + 650 = 788
#2 D + F + L	14,940	14,950 ÷ 58.5 + 650 = 905
#3 D + F + L_r	12,000	12,000 ÷ 58.5 + 650 = 855
#4 D + F + 0.75(L) + 0.75(L_r)	16,165	16,165 ÷ 58.5 + 650 = 926
#5 D + F + W + 1.5(F_a)	28,104	28,104 ÷ 58.5 + 650 = 1,130
#6 D + F + 0.75(W) + 0.75(L) + 0.75(L_r) + 1.5(F_a)	29,982	29,982 ÷ 58.5 + 650 = **1,163**
#7 0.6D + W + 1.5(F_a)	23,051	23,051 ÷ 58.5 + 650 = 1,044
#8 0.6D	5,255	5,255 ÷ 58.5 + 650 = 740

Where

D = Dead Load

F = Load due to fluids with well-defined pressures and maximum heights (See Section D.2 for additional information)

F_a = Flood Load

L = Live Load

L_r = Roof Live Load

W = Wind Load

NOTE: The maximum bearing pressure is in bold (1,163 psf) and is less than the assumed 1,500 psf bearing pressure.

Design of Concrete members per ACI-318-02 Code & ASCE 7-02; Sections 2.3.2 and 2.3.3-1

Column Design

Verify that 16-inch x 16-inch column design is adequate.

Concrete strength = 4,000 psi

Reinforced with (4) #8 bars, grade 60 reinforcing, with 2½-inch clear cover

Note: 1,000 lbs = 1.0 kip

Assume that the total wind load distributed through the floor uniformly to 3 columns.

Check combined axial and bending strength:

Ultimate Moment wind + f_{dyn} = (1.6) [(8 ft)((14 ft)(868 lb/ft)/(3))] + (2.0) [(3.9 ft/2)(1,303) lb)]

= 51,849 ft-lb + 5,082 ft-lb

= 56,931 ft-lb ÷ 1,000 lb/kip = 56.9 ft-kip

Ultimate Moment wind + f_{brkp} = (51,849 ft-lb) + (2.0) [(1,211 lb) (3.9 ft)]

= 61,295 ft-lb ÷ 1,000 lb/kip = 61.3 ft-kip

Ultimate Moment wind + f_{brkp} + debris = 61.3 ft-kip + (2.0) (3.5 kip) (3.9 ft)

= 88,6 ft-kip

Maximum Factored Moment = 88.6 ft-kip = 1,063 in kip

Refer to Table D-3, conservatively assume flood load factor of 2.0 for all axial loads

Maximum factored Axial Compression = (2.0) (30.0 kip) = 60.0 kip

Maximum factored Axial Tension = (2.0) (12.5 kip) = 25.0 kip

Based on a chart published by the Concrete Reinforced Steel Institute (CRSI), the maximum allowable moment for the column = 1,092 in kip for 0 axial load and 1,407 in kip for 102 kip axial load; therefore, the column is adequate.

Check Shear strength:

Critical Shear = wind + F_{dyn} + F_i

Ultimate Shear = V_u = [(14 ft) (.868 kip) (1/3)] (1.6) + [(1.3 kip)+(3.5 kip] (2.0)

= V_u = 16.0 kips

As the maximum unit tension stress is only 25.0 kips/16 in x16 in = .098 kip/in^2 and the maximum axial compression stress is only 60.0 kips/16 in x 16 in = .234 kip/in^2, we can conservatively treat the column as a flexural member or beam. The allowable shear of the concrete section then, per ACI-318-02 11.3.1.1, 11.3.1.3, and 11.5.5.1 with minimum shear reinforcing (tie/stirrup), would be as follows.

Allowable Shear = V_c = (0.75) (16 in-2.5 in) (16 in) (2) (4,000 psi)$^{1/2}$ (1/1,000) = 20.5 kips

The shear strength of the column is adequate with minimum shear reinforcement.

The minimum area of shear, A_v, per ACI 318-02, 11.5.5.3 would be:

A_v	= (50) (width of member) (spacing of reinforcing)/yield strength of reinforcing	
	= (50) (16 in) (16 in)/(60,000 psi)	= .21 in^2
2 pieces of # 4 bar A_s	= (2) (.2)	= .40 in^2

Use of #4 bar for column ties (shear reinforcement) is adequate.

Check spacing per ACI -318-02, 7.10.4

16 diameter of vertical reinforcing bar	= (16) (1 in)	= 16 in
48 diameter of column tie bar	= (48) (1/2 in)	= 24 in
Least horizontal dimension	= 16 in	

Therefore, #4 ties at 16 inch on center are adequate.

The column design is adequate.

Grade Beam Design

The size of the grade beam was configured to provide adequate bearing area, resistance to uplift, a reasonable measure of protection from damaging scour, and to provide a factor of redundancy and reserve strength should the foundation be undermined. A grade beam 36-inches wide and 48-inches deep was selected.

Maximum Bearing Pressure = 1,163 psf = 1.2 ksf (kip/square foot)

Assume a combined load factor of 2.0 (for flood)

Check Shear strength:

Maximum Factored Uniform Bearing Pressure = w_u = (2.0) (3.0 ft) (1.2 ksf) = 7.2 kips/ft

Maximum Factored Shear = V_u = (7.2 kips/ft) (14 ft/2) = 50.0 kips

Allowable Shear without minimum shear reinforcing (stirrups) = $V_c/2$

$V_c/2$= (0.75) (36 in) (48 - 3.5 in) (63 psi) (1/1,000) = 75.7 kips

Use nominal #4 two leg stirrups at 24-inch on center

Check flexural strength: Assume simple span condition

Maximum Factored Moment = M_u = (7.2 kips/ft) (14 ft)^2 (1/8) = 176 ft-kip

Concrete strength = 4,000 psi

Reinforcement grade = 60,000 psi

Try (4) #6 reinforcing bar continuous top and bottom

A_s = (4) (0.44 in^2) = 1.76 in^2 top or bottom

total A_s = (2) (1.76) = 3.52 in^2

Reinforcement ratio (ρ)

ρ = A_s ÷ [(section width) (section depth- clear cover- ½ bar diameter)]

ρ = A_s ÷ [(b_w) (d)]

ρ = (1.76 in^2) ÷ [(36) (48 - 3 - 0.375)]

ρ = 0.01096

One method of calculating the moment strength of a rectangular beam, for a given section and reinforcement, is illustrated in the 2002 edition of the CRSI Design Handbook. Referencing page 5-3 of the handbook, the formula for calculating the moment strength can be written as follows:

ΦM_n = (Φ) [((A_s) (f_y) (d)) – (((A_s) (f_y)) ÷ ((0.85) (f'c) (width of member) (2)))]

ΦM_n = (0.9) [((1.76) (60000) (44.63)) – (((1.76)(60,000)) ÷ ((0.85)(4,000)(36) (2)))]

= 4,241,634 in lb ÷ 12000 = 353 ft-kip

Φ = 0.9

Area of reinforcing steel (A_s) minimum flexural

= (0.0033) (24) (44.63)

= 3.6 in^2

or

(1.33) (A_s required by analysis) = ΦM_n is much greater than M_u

Area of steel for shrinkage and temperature required = (.0018) (48) (36) = 3.1 in^2

Total Area of steel provided = (8) #6 = (8) (0.44) = 3.52 in^2 adequate

Therefore, the grade beam design is adequate, use (4) #6 reinforcing bar continuous on the top and bottom with #4 stirrups at 24-inch spacing.

RECOMMENDED RESIDENTIAL CONSTRUCTION FOR THE GULF COAST

Building on Strong and Safe Foundations

E. Cost Estimating

Breakdown of Foundation Costs			
Foundation Type	Average Foundation Costs ($)	Elevation Above Grade	Unit Costs per Square Foot (sf)
Open			
Case A: Timber Pile	13,536	0 to 5	11
	17,554	5 to 10	15
	22,720	10 to 15	19
	Not Evaluated	Above 15	
Case B: Steel Pipe Pile with Concrete Column and Grade Beam	32,500	0 to 5	27
	36,024	5 to 10	30
	37,500	10 to 15	31
	Not Evaluated	Above 15	
Case C: Timber Pile with Concrete Column and Grade Beam	31,700	0 to 5	26
	36,288	5 to 10	30
	37,900	10 to 15	32
	Not Evaluated	Above 15	
Case D: Concrete Column and Grade Beam	13,500	0 to 5	11
	16,860	5 to 10	14
	18,500	10 to 15	15
	Not Evaluated	Above 15	
Case G: Concrete Column and Grade Beam with Slabs	18,000	0 to 5	15
	21,847	5 to 10	18
	24,000	10 to 15	20
	Not Evaluated	Above 15	
Closed			
Case E: Reinforced Masonry - Crawlspace	12,254	0 to 4	10
	14,000	4 to 8	12
Case F: Reinforced Masonry - Stem Wall	12,458	0 to 4	10

NOTES

1. This rough order of magnitude (ROM) cost estimate is based upon May 2006 figures for concrete, labor, equipment, and materials. Variations due to labor/equipment/materials shortages are anticipated and should be taken into account when using these costs.
2. Costs presented herein should not be construed to represent actual costs to the homebuilder, but should be utilized as an order of magnitude estimate only.
3. Pile driving mobilization/demobilization can be reduced if several homes are constructed at the same time in the same area, thereby realizing an economy of scale.

4. Costs presented are based upon the general designs in this document. A 1,200 sf footprint for a single-story home at an assumed 130-mph wind speed, elevated to the average height for that foundation, is the basis for the estimates. When differences in elements of construction occur, such as number of piles or amount of concrete, an alternate cost is presented. The cost estimate presented represents the conservative approach to the designs in this document. If value engineering, different materials, or a more cost-effective design are implemented, these costs may be reduced.
5. Costs presented herein include applicable taxes, contractor general and home office overhead, profit, and other sub-tier contract costs.
6. Concrete costs, unless otherwise noted, include bracing, reinforcing, formwork, finishing (if necessary), and mobilization and demobilization of the contractor. Due to the anticipated shortage of skilled labor for concrete, variability in this area should be anticipated.
7. Costs experienced by the builder or contractor will be dependent upon contract agreements, local price variations in labor, material, equipment, and availability.
8. Costs for steel are highly variable and dependent upon supply. Variability in costs for steel should be anticipated. Costs for steel include materials and labor for installation.
9. Costs for block in closed foundations is based upon standard natural gray medium weight masonry block walls, including blocks, mortar, typical reinforcing, normal waste, and walls constructed with 8” x 8” x 16” blocks laid in running bond. Add for grouting cores poured by hand to 4 foot heights.

Case A: Timber Pile									
	Unit of Measure	Material	Labor	Equip.	Subtotal	Number of Piles	Length of Piles Driven	Total lf to drive	Subtotal
Site Prep	ls				500.00	—	—	—	$500
Minimum job charge for Driving	ls	—	—	—	5,000.00	—	—	—	$5,000
Number of Piles: 60									
Over 30' to 40' (800 lf per day)	lf	3.3	1.7	0.9	5.90	60	30	1,800	$10,620
Bolts and Miscellaneous	Per Column				15.00	60			$900
Wood Pile Connection to House	Per Pile				55.00	60			$3,300
Galvanized Bracing Rod and Turnbuckles	Per Pile				40.00	60			$2,400
Total for Piles									**$22,720**
Number of Piles: 42									
Over 30' to 40' (800 lf per day)	lf	3.3	1.7	0.9	5.90	42	30	1260	$7,434
Bolts and Miscellaneous	Per Column				15.00	42			$630
Wood Pile Connection to House	Per Pile				55.00	42			$2,310
Galvanized Bracing Rod and Turnbuckles	Per Pile				40.00	42			$1,680
Total for Piles									**$17,554**
Number of Piles: 28									
Over 30' to 40' (800 lf per day)	lf	3.3	1.7	0.9	5.90	28	30	840	$4,956
Bolts and Miscellaneous	Per Column				15.00	28			$420
Wood Pile Connection to House	Per Pile				55.00	28			$1,540
Galvanized Bracing Rod and Turnbuckles	Per Pile				40.00	28			$1,120
Total for Piles									**$13,536**

ls = lump sum lf = linear foot

Case B: Steel Pipe Pile/Concrete Column/Grade Beam									
Site Prep	ls				500.00	—	—	—	$500
Minimum job charge for Driving	ls	—	—	—	5,000.00	—	—	—	$5,000
Steel Piles Driven									
	Unit of Measure	**Material**	**Labor**	**Equip.**	**Subtotal**	**Number of Piles**	**Length of Piles**	**Total lf to drive**	**Subtotal**
Steel Piles Driven	lf	11	3.1	0.9	15.00	28	30	840	$12,600
Bolts and Miscellaneous	Per Column				25.00	28			$700
Total for Piles									**$13,300**
Concrete Grade Beam									
	Unit of Measure	**Material**	**Labor**	**Equip.**	**Subtotal**	**Number of cy**	**Equip-ment Charge**		**Subtotal**
Soil Excavation, Medium material, 75 cy per hour (57 m3/hr)	cy	--	0.54	1.29	1.83	55	500		$601
Grade beams	cy	225	22	7.5	254.50	32			$8,144
Steel	ea				100.00	32			$3,200
Total for Grade Beams									$11,945
Concrete Columns @ 10 feet									
	Unit of Measure	**Material**	**Labor**	**Equip.**	**Subtotal**	**Number of cy/ Columns**	**Number of Columns**		**Subtotal**
18” (46 cm) square or round columns	cy	225	35	7.5	267.50	0.74	12		$2,375
Steel	Column				150.00		12		$1,800
Anchors	Column				49.55		12		$595
Angles	Column				42.45		12		$509
Subtotal for Concrete Columns									**$5,279**
Total for Case B									**$36,024**

ls = lump sum   lf = linear foot   cy = cubic yard   ea = each

Case C: Timber Pile/Concrete Column/Grade Beam								
	Unit of Measure	Material	Labor	Equip.	Subtotal	Number of Piles	Length of Piles	Total lf to Drive
Site Prep	ls				500.00	—	—	—
Minimum job charge for Driving	ls	—	—	—	5,000.00	—	—	—
Timber Piles Driven								
Number of Wooden Piles: 42								
Over 30' to 40' (800 lf per day)	lf	3.3	1.7	0.9	5.90	42	30	1,260
Bolts and Miscellaneous	Per Column				15.00	42		
Total for Piles								
Concrete Grade Beam								
	Unit of Measure	Material	Labor	Equip.	Subtotal	Number of cy	Equipment Charge	
Soil Excavation, Medium material, 75 cy per hour (57 m3/hr)	cy	--	0.54	1.29	1.83	55	500	
Grade beams	cy	225	22	7.5	254.50	32		
Steel	ea				100.00	32		
Total for Grade Beams								
Concrete Columns including Pile Caps @ 10 feet								
	Unit of Measure	Material	Labor	Equip.	Subtotal	Number of cy/ Columns	Number of Columns	
18" (46 cm) square or round columns	cy	225	35	7.5	267.50	0.74	12	
Steel	Column				150.00		12	
Anchors	Column				49.55		12	
Angles	Column				42.45			
Subtotal for Concrete Columns								
Grand Total for Foundation Shown								

ls = lump sum lf = linear foot cy = cubic yard ea = each

Case D: Concrete Column/Grade Beam								
	Unit of Measure	Material	Labor	Equip.	Subtotal	Number of cy	Equipment Charge	Subtotal
Soil Excavation, Medium material, 75 cy per hour (57 m3/hr)	cy	--	0.54	1.29	1.83	50	500	$592
Grade beams	cy	225	22	7.5	254.50	31		$7,890
Steel	ea				100	31		$3,100
Total for Grade Beams								**$11,582**
Concrete Columns @ 10 feet Elevation								
	Unit of Measure	**Material**	**Labor**	**Equip.**	**Subtotal**	**Number of cy per Column**	**Number of Columns**	**Subtotal**
18" (46 cm) square or round columns	cy	225	35	7.5	267.50	0.74	12	$2,375
Steel	Column				150.00		12	$1,800
Anchors	Column				49.55		12	$595
Angles	Column				42.45		12	$509
Subtotal for Concrete Columns								**$5,279**
Grand Total for Foundation Shown								**$16,861**

cy = cubic yard

Case G: Concrete Column/Grade Beam with Slab								
	Unit of Measure	Material	Labor	Equip.	Subtotal	Number of cy	Equipment Charge	Subtotal
Soil Excavation, Medium material, 75 cy per hour (57 m3/hr)	cy	--	0.54	1.29	1.83	75	500	$637
Interior Concrete	cy	225	35	7.50	267.50	15		$4,013
Grade Beams	cy	225	35	7.50	267.50	31		$8,293
Steel	ea				100.00	31		$3,100
WWF	ea				35.00	15		$525
Total for Grade Beams								**$16,568**
Concrete Columns @ 10 feet Elevation								
	Unit of Measure	**Material**	**Labor**	**Equip.**	**Subtotal**	**Number of cy per Column**	**Number of Columns**	**Subtotal**
18” (46 cm) square or round columns	cy	225	35	7.50	267.50	0.74	12	$2,375
Steel	Column				150		12	$1,800
Anchors	Column				49.55		12	$595
Angles	Column				42.45		12	$509
Subtotal for Concrete Columns								**$5,279**
Grand Total for Foundation Shown								**$21,847**

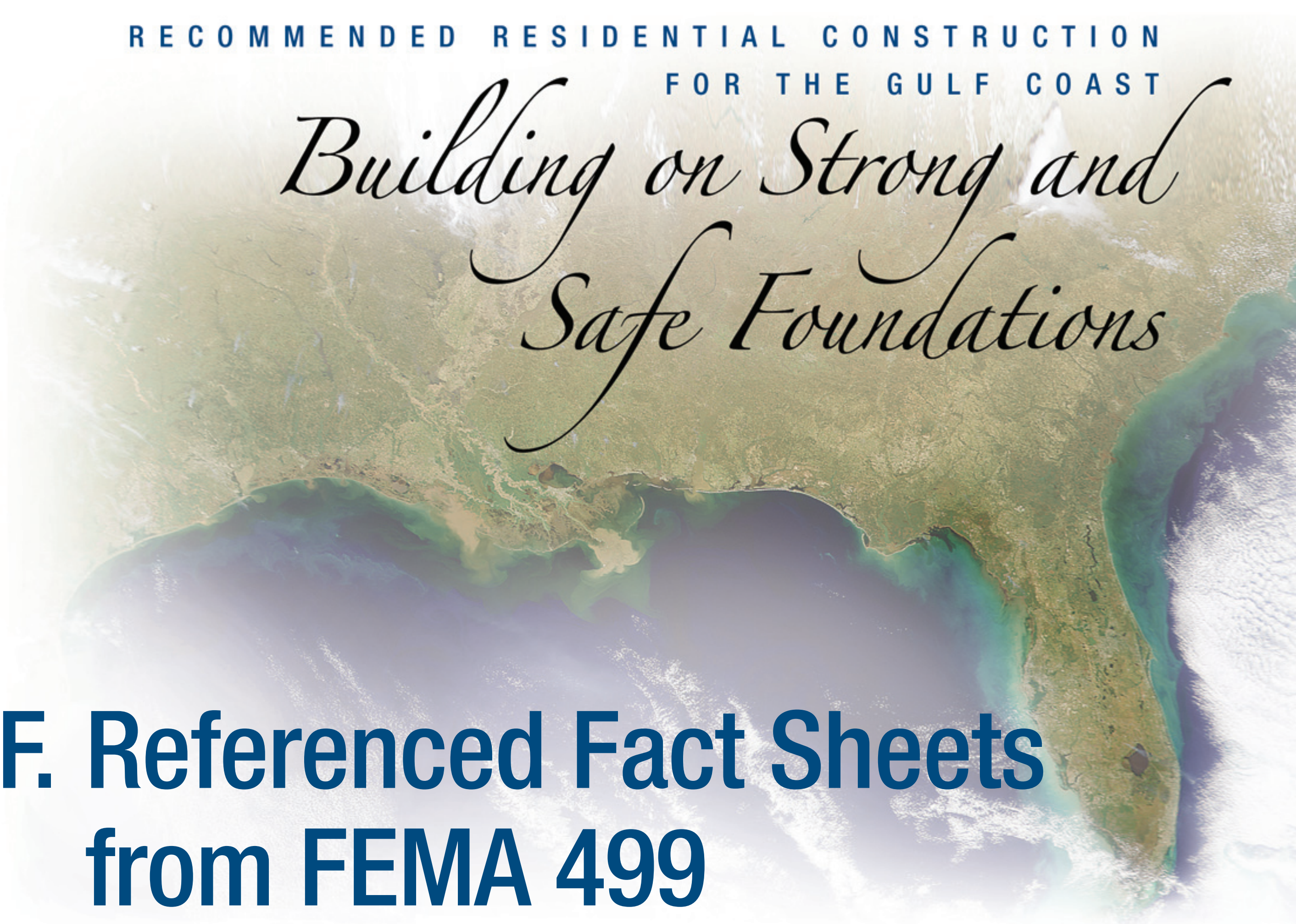
cy = cubic yard ea = each

Case E: Reinforced Masonry								
Crawlspace								
	Unit of Measure	Material	Labor	Equip.	Subtotal	Number of cy	Equipment Charge	Subtotal
Soil Excavation, Medium material, 75 cy per hour (57 m3/hr)	cy	--	0.68	1.43	2.11	24	500	$551
Footings	cy	225	22	7.5	254.50	20		$5,090
Steel	cy				100.00	20		$2,000
Total for Footings (not including steel)								**$5,641**
Concrete Columns @ 4 feet								
	Unit of Measure	Material	Labor	Equip.	Subtotal	Number of cy per Column	Number of Columns	Subtotal
16” (46 cm) square or round columns piers	cy	225	35	7.5	267.50	0.40	6	$642
Steel	Column				150.00		6	$900
Anchors	Column				49.55		6	$297
Angles	Column				42.45		6	$255
Subtotal for Concrete Columns								$2,094
Concrete Walls								
	Unit of Measure	Material	Labor	Equip.	Subtotal	Number of sf		Subtotal
Concrete Block Walls	sf	5.23	4.53	1	10.76	420		$4,519
Grand Total for Foundation Shown (Footings + Concrete Columns + Concrete Walls)								$12,254

cy = cubic yard sf = square foot

Case F: Reinforced Masonry Stem Wall								
	Unit of Measure	Material	Labor	Equip.	Subtotal	Number of cy	Equipment Charge	Subtotal
Soil Excavation, Medium material, 75 cy per hour (57 m3/hr)	cy	--	0.54	1.29	1.83	34	500	$562
Footings	cy	225	22	7.5	254.50	20		$5,090
Steel	cy				100.00	20		$2,000
Bracing	ls							$1,500
Backfill	cy	4	0.6	1.45	6.05	130		$787
Total for Stem Wall Footings								**$9,152**
Concrete Walls								
	Unit of Measure	Material	Labor	Equip.	Subtotal	Number of sf		Subtotal
Concrete Block Walls	sf	5.23	4.53	1	10.76	420		$4,519
Grand Total for Foundation Shown								**$13,671**

cy = cubic yard ls = lump sum sf = square foot



RECOMMENDED RESIDENTIAL CONSTRUCTION FOR THE GULF COAST

Building on Strong and Safe Foundations

F. Referenced Fact Sheets from FEMA 499

Fact Sheet No.	Title
1	Coastal Building Successes and Failures
2	Summary of Coastal Construction Requirements and Recommendations
4	Lowest Floor Elevation
5	V-Zone Design and Construction Certification
6	How Do Siting and Design Decisions Affect the Owner's Costs?
7	Selecting a Lot and Siting the Building
8	Coastal Building Materials
9	Moisture Barrier Systems
11	Foundations in Coastal Areas
12	Pile Installation

13	Wood-Pile-to-Beam Connections
14	Reinforced Masonry Pier Construction
15	Foundation Walls
16	Masonry Details
26	Shutter Alternatives
27	Enclosures and Breakaway Walls
29	Protecting Utilities

Coastal Building Successes and Failures

Purpose: To discuss how coastal construction requirements are different from those for inland construction. To discuss the characteristics that make for a successful coastal building.

Is Coastal Construction That Different From Inland Construction?

The short answer is ***yes,*** building in a coastal environment is different from building in an inland area:

- ***Flood levels, velocities,*** and ***wave*** action in coastal areas tend to make coastal flooding more damaging than inland flooding.
- Coastal ***erosion*** can undermine buildings and destroy land, roads, utilities, and infrastructure.
- ***Wind speeds*** are typically higher in coastal areas and require stronger engineered building connections and more closely spaced nailing of building sheathing, siding, and roof shingles.
- ***Wind-driven rain, corrosion,*** and ***decay*** are frequent concerns in coastal areas.

In general, homes in coastal areas must be designed and built to withstand ***higher loads*** and ***more extreme conditions***. Homes in coastal areas will require ***more maintenance*** and upkeep. Because of their exposure to higher loads and extreme conditions, homes in coastal areas will cost more to design, construct, maintain, repair, and insure.

Figure 1. Well-built but poorly sited building.

Building Success

In order for a coastal building to be considered a "success," four things must occur:

- The building must be designed to withstand coastal forces and conditions.
- The building must be constructed as designed.
- The building must be sited so that erosion does not undermine the building or render it uninhabitable.
- The building must be maintained/repaired.

A well-built but poorly sited building can be undermined and will not be a success (see Figure 1). Even if a building is set back or situated farther from the coastline, it will not perform well (i.e., will not be a success) if it is incapable of resisting high winds and other hazards that occur at the site (see Figure 2).

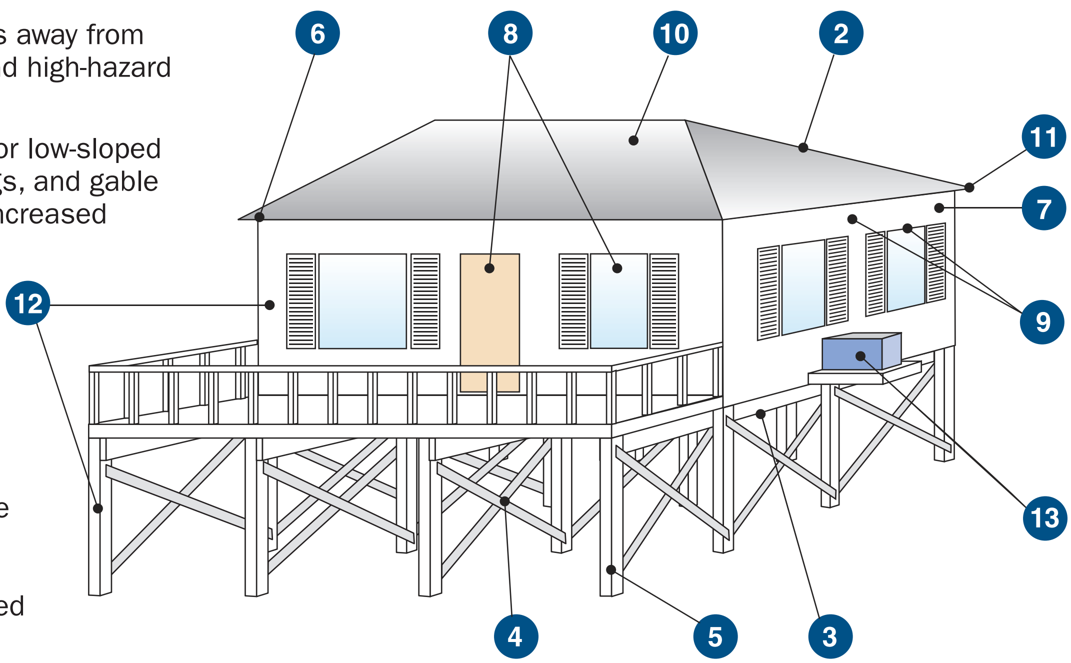
Figure 2. Well-sited building that still sustained damage.

What Should Owners and Home Builders Expect From a "Successful" Coastal Building?

In coastal areas, a building can be considered a success only if it is capable of resisting damage from coastal hazards and coastal processes over a period of decades. This statement does not imply that a coastal residential building will remain undamaged over its intended lifetime. It means that the impacts of a design-level flood, storm, wind, or erosion event (or series of lesser events with combined impacts equivalent to a design event) will be limited to the following:

- The building **foundation** must remain intact and functional.
- The **envelope** (walls, openings, roof, and lowest floor) must remain structurally sound and capable of minimizing penetration by wind, rain, and debris.
- The **lowest floor** elevation must be sufficient to prevent floodwaters from entering the elevated building envelope during the design event.
- The **utility connections** (e.g., electricity, water, sewer, natural gas) must remain intact or be restored easily.
- The building must be **accessible** and **usable** following a design-level event.
- Any damage to **enclosures** below the Design Flood Elevation (DFE)* must not result in damage to the foundation, the utility connections, or the elevated portion of the building.

Recommended Practice



1. **Siting –** Site buildings away from eroding shorelines and high-hazard areas.

2. **Building Form –** Flat or low-sloped porch roofs, overhangs, and gable ends are subject to increased uplift in high winds. Buildings that are both tall and narrow are subject to overturning. Each of these problems can be overcome through the design process, but each must receive special attention. In the design process, chose moderate-sloped hip roofs (4/12 to 6/12) if possible.

3. **Lowest Floor Elevation –** Elevate above the DFE the bottom of the lowest horizontal structural member supporting the lowest floor. Add "freeboard" to reduce damage and lower flood insurance premiums.

4. **Free of Obstructions –** Use an open foundation. Do not obstruct the area below the elevated portion of the building. Avoid or minimize the use of breakaway walls. Do not install utilities or finish enclosed areas below the DFE (owners tend to convert these areas to habitable uses, which is prohibited under the National Flood Insurance Program and will lead to additional flood damage and economic loss).

5. **Foundation –** Make sure the foundation is deep enough to resist the effects of scour and erosion; strong enough to resist wave, current, flood, and debris forces; and capable of transferring wind and seismic forces on upper stories to the ground.

*The DFE is the locally mandated flood elevation, which will be equal to or higher than the Base Flood Elevation (BFE). The BFE is the expected elevation of flood waters and wave effects during the 100-year flood (also known as the Base Flood).

6. **Connections –** Key connections include roof sheathing, roof-to-wall, wall-to-wall, and walls-to-foundation. Be sure these connections are constructed according to the design. Bolts, screws, and ring-shanked nails are common requirements. Standard connection details and nailing should be identified on the plans.

7. **Exterior Walls –** Use structural sheathing in high-wind areas for increased wall strength. Use tighter nailing schedules for attaching sheathing. Care should be taken not to over-drive pneumatically driven nails. This can result in loss of shear capacity in shearwalls.

8. **Windows and Glass Doors –** In high-wind areas, use windows and doors capable of withstanding increased wind pressures. In windborne debris areas, use impact-resistant glazing or shutters.

9. **Flashing and Weather Barriers –** Use stronger connections and improved flashing for roofs, walls, doors, and windows and other openings. Properly installed secondary moisture barriers, such as housewrap or building paper, can reduce water intrusion from wind-driven rain.

10. **Roof –** In high-wind areas, select appropriate roof coverings and pay close attention to detailing. Avoid roof tiles in hurricane-prone areas.

11. **Porch Roofs and Roof Overhangs –** Design and tie down porch roofs and roof overhangs to resist uplift forces.

12. **Building Materials –** Use flood-resistant materials below the DFE. All exposed materials should be moisture- and decay-resistant. Metals should have enhanced corrosion protection.

13. **Mechanical and Utilities –** Electrical boxes, HVAC equipment, and other equipment should be elevated to avoid flood damage and strategically located to avoid wind damage. Utility lines and runs should be installed to minimize potential flood damage.

14. **Quality Control –** Construction inspections and quality control are essential for building success. Even "minor" construction errors and defects can lead to major damage during high-wind or flood events. Keep this in mind when inspecting construction or assessing yearly maintenance needs.

Recommended practice and guidance concerning the topics listed above can be found in the documents referenced in these fact sheets and in many trade publications (e.g., the *Journal of Light Construction,* http://www.jlconline.com).

Will the Likelihood of Success (Building Performance) Be Improved by Exceeding Minimum Requirements?

States and communities enforce regulatory requirements that determine where and how buildings may be sited, designed, and constructed. There are often economic benefits to exceeding the enforced requirements (see box). Designers and home builders can help owners evaluate their options and make informed decisions about whether to exceed these requirements.

Benefits of Exceeding Minimum Requirements

- Reduced building damage during coastal storm events
- Reduced building maintenance
- Longer building lifetime
- Reduced insurance premiums*
- Increased reputation of builder

*Note: Flood insurance premiums can be reduced up to 60 percent by exceeding minimum siting, design, and construction practices. See the V-Zone Risk Factor Rating Form in FEMA's *Flood Insurance Manual* (http://www.fema.gov/nfip/manual.shtm).

Summary of Coastal Construction Requirements and Recommendations

HOME BUILDER'S GUIDE TO COASTAL CONSTRUCTION FEMA 499/August 2005 *Technical Fact Sheet No. 2*

Purpose: To summarize National Flood Insurance Program (NFIP) regulatory requirements concerning coastal construction and provide recommendations for exceeding those requirements in some instances.

Key Issues

- ***New construction**** in coastal flood hazard areas (V zones and A zones) must meet minimum NFIP and community requirements. ***Repairs, remodeling, and additions*** must meet community requirements and may also be subject to NFIP requirements.
- NFIP design and construction requirements are more ***stringent in V zones than in A zones***, in keeping with the increased flood, wave, floodborne debris and erosion hazards in V zones.
- Some coastal areas mapped as A zones may be subject to damaging waves and erosion (these areas are often referred to as Coastal A Zones). Buildings in these areas 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 to V-zone standards.***
- Buildings constructed to minimum NFIP A-zone standards and subject solely to shallow flooding without the threat from breaking waves and erosion will generally sustain only minor damage during the Base Flood.
- Following the recommendations in the table below will result in lower damage to the building and reduced flood insurance premiums (see the V-Zone Risk Factor Rating Form in FEMA's *Flood Insurance Manual* (http://www.fema.gov/nfip/manual.shtm).

* For floodplain management purposes, new construction means structures for which the start of construction began on or after the effective date of a 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.

The following tables summarize NFIP regulatory requirements and recommendations for exceeding those requirements for both (1) new construction and (2) repairs, remodeling, and additions.

Requirements and Recommendations for New Construction[a]

See page 8 for notes.	V Zone	A Zones in Coastal Areas: Coastal A — Areas With Potential for Breaking Waves and Erosion During Base Flood[b]	A Zones in Coastal Areas: A — Areas With Shallow Flooding Only, Where Potential for Breaking Waves and Erosion Is Low[c]
General Requirements			
Design (Also see Certification)	**Requirement:** building and its foundation must be designed, constructed, and anchored to prevent flotation, collapse, and lateral movement due to **simultaneous wind and water loads** [see Fact Sheet No. 5]	**Requirement:** building must be designed, constructed, and anchored to prevent flotation, collapse, and lateral movement resulting from hydrodynamic and hydrostatic loads, including the effects of buoyancy **Recommendation:** follow V-zone requirement	**Requirement:** building must be designed, constructed, and anchored to prevent flotation, collapse, and lateral movement resulting from hydrodynamic and hydrostatic loads, including the effects of buoyancy

See page 8 for notes.	V Zone	A Zones in Coastal Areas: Coastal A — Areas With Potential for Breaking Waves and Erosion During Base Flood[b]	A Zones in Coastal Areas: A — Areas With Shallow Flooding Only, Where Potential for Breaking Waves and Erosion Is Low[c]
General Requirements (cont.)			
Free of Obstructions	**Requirement:** the space below the lowest floor must be free of obstructions (e.g., free of any building element, equipment, or other fixed objects that can transfer flood loads to the foundation, or that can cause floodwaters or waves to be deflected into the building), or must be constructed with non-supporting breakaway walls, open lattice, or insect screening. [see Fact Sheet Nos. 5, 27]	**Requirement:** none **Recommendation:** follow V-zone requirement	**Requirement:** none
Materials [see Fact Sheet Nos. 1, 8]	**Requirement:** structural and nonstructural building materials at or below Base Flood Elevation (BFE) must be flood-resistant	**Requirement:** structural and nonstructural building materials at or below BFE must be flood-resistant	**Requirement:** structural and nonstructural building materials at or below BFE must be flood-resistant
Construction [see Fact Sheet No. 1] **(Also see Certification)**	**Requirement:** building must be constructed with methods and practices that minimize flood damage	**Requirement:** building must be constructed with methods and practices that minimize flood damage	**Requirement:** building must be constructed with methods and practices that minimize flood damage
Siting [see Fact Sheet Nos. 6, 7]	**Requirement:** all new construction shall be landward of mean high tide; alteration of sand dunes and mangrove stands that increases potential flood damage is prohibited **Recommendation:** site new construction landward of long-term erosion setback and landward of area subject to erosion during 100-year coastal flood event	**Requirement:** encroachments into floodways designated along rivers and streams are prohibited unless they will cause no increase in flood stage; where floodways have not been designated, encroachments into the Special Flood Hazard Area cannot increase the BFE by more than 1 foot **Recommendation:** follow V-zone requirement	**Requirement:** encroachments into floodways designated along rivers and streams are prohibited unless they will cause no increase in flood stage; where floodways have not been designated, encroachments into the Special Flood Hazard Area cannot increase the BFE by more than 1 foot
Foundation			
Structural Fill	**Prohibited** [see Fact Sheet No. 11]	Allowed, but **not recommended;** compaction required where used; protect against scour and erosion[d] [see Fact Sheet No. 11]	**Allowed;** compaction required where used; protect against scour and erosion[d]
Solid Foundation [see Fact Sheet Nos. 11, 15]	**Prohibited**	Allowed, but **not recommended**[d]	**Allowed**[d]
Open Foundation [see Fact Sheet No. 11]	**Required**	**Recommended**[d]	**Allowed**[d]
Lowest Floor Elevation [see Fact Sheet No. 4] **(Also see Certification)**	See **Bottom of Lowest Horizontal Structural Member** (below) [see Fact Sheet No. 5]	**Requirement:** top of floor must be at or above BFE[e] **Recommendation:** elevate bottom of lowest horizontal structural member to or above BFE[e]	**Requirement:** top of floor must be at or above BFE[e] **Recommendation:** elevate bottom of lowest horizontal structural member to or above BFE[e]

See page 8 for notes.	V Zone	A Zones in Coastal Areas: Coastal A – Areas With Potential for Breaking Waves and Erosion During Base Flood[b]	A Zones in Coastal Areas: A – Areas With Shallow Flooding Only, Where Potential for Breaking Waves and Erosion Is Low[c]
Foundation (cont.)			
Bottom of Lowest Horizontal Structural Member [see Fact Sheet No. 4]	must be at or above BFE[e] [see Fact Sheet No. 5]	Allowed below BFE[e], but **not recommnded**[d] **Recommendation:** follow V-zone requirement	Allowed below BFE[e], but **not recommended**[d] **Recommendation:** follow V-zone requirement
Orientation of Lowest Horizontal Structural Member	**Requirement:** none **Recommendation:** orient perpendicular to wave crest	**Requirement:** none **Recommendation:** follow V-zone requirement	**Requirement:** none
Freeboard [see Fact Sheet Nos. 1, 4]	Not required[e], but **recommended**	Not required[e], but **recommended**	Not required[e], but **recommended**
Enclosures Below BFE			
(Also see Certification) [see Fact Sheet No. 27]	**Prohibited,** except for breakaway walls, open lattice, and screening[f] **Recommendation:** if constructed, use open lattice or screening instead of breakaway walls	Allowed, but **not recommended** **Requirement:** if area is fully enclosed, enclosure walls must be equipped with openings to equalize hydrostatic pressure; size, location, and covering of openings governed by regulatory requirements **Recommendation:** elevate on open foundation; if enclosure is constructed, use breakaway walls (with flood openings), open lattice, or screening, as required in V zone[f,g]	**Allowed** **Requirement:** if area is fully enclosed, enclosure walls must be equipped with openings to equalize hydrostatic pressure; size, location, and covering of openings governed by regulatory requirements[f,g]
Nonstructural Fill			
	Allowed for minor landscaping and site drainage as long as fill does not interfere with free passage of flood waters and debris beneath building, or cause changes in flow direction during coastal storms that could result in damage to buildings	**Allowed**[h] **Recommendation:** follow V-zone requirement	**Allowed** **Recommendation:** follow V-zone requirement
Use of Space Below BFE[i] (see Fact Sheet No. 27)			
	Allowed only for parking, building access, and storage	**Allowed only** for parking, building access, and storage	**Allowed only** for parking, building access, and storage
Utilities[i]			
	Requirement: utilities, including ductwork and equipment, must be designed, located, and elevated to prevent flood waters from entering and accumulating in components during flooding; utility lines must not be installed or stubbed out in enclosures below BFE	**Requirement:** utilities, including ductwork and equipment, must be designed, located, and elevated to prevent flood waters from entering and accumulating in components during flooding; utility lines must not be installed or stubbed out in enclosures below BFE	**Requirement:** utilities, including ductwork and equipment, must be designed, located, and elevated to prevent flood waters from entering and accumulating in components during flooding; utility lines must not be installed or stubbed out in enclosures below BFE

See page 8 for notes.

	V Zone	A Zones in Coastal Areas: Coastal A — Areas With Potential for Breaking Waves and Erosion During Base Flood[b]	A Zones in Coastal Areas: A — Areas With Shallow Flooding Only, Where Potential for Breaking Waves and Erosion Is Low[c]
Certification			
Elevation	**Requirement:** bottom of lowest horizontal structural member must be at or above BFE[e]; electrical, heating, ventilation, plumbing, and air conditioning equipment and other service facilities (including ductwork) must be designed and/or located so as to prevent water from entering or accumulating within the components during flooding [see Fact Sheet Nos. 4, 5, 29]	**Requirement:** top of lowest floor must be at or above BFE[e]; electrical, heating, ventilation, plumbing, and air conditioning equipment and other service facilities (including ductwork) must be designed and/or located so as to prevent water from entering or accumulating within the components during flooding [see Fact Sheet Nos. 4, 29] **Recommendation:** follow V zone requirement	**Requirement:** top of lowest floor must be at or above BFE[e]; electrical, heating, ventilation, plumbing, and air conditioning equipment and other service facilities (including ductwork) must be designed and/or located so as to prevent water from entering or accumulating within the components during flooding [see Fact Sheet Nos. 4, 29] **Recommendation:** follow V zone requirement
Structure	**Requirement:** registered engineer or architect must certify that design and methods of construction are in accordance with accepted standards of practice for meeting design requirements described under **General Requirements** [see Fact Sheet No. 5]	**Requirement:** none **Recommendation:** follow V zone requirement	**Requirement:** none **Recommendation:** follow V zone requirement
Breakaway Walls [see Fact Sheet Nos. 5, 27] **(Also see Enclosures Below BFE)**	**Requirement:** walls must be designed to break free under larger of (1) design wind load, (2) design seismic load, or (3) 10 psf, acting perpendicular to the plane of the wall; if loading at which breakaway wall is intended to collapse exceeds 20 psf, breakaway wall design shall be certified; when certification is required, registered engineer or architect must certify that walls will collapse under a water load associated with the Base Flood and that elevated portion of building and its foundation will not be subject to collapse, displacement, or lateral movement under simultaneous wind and water loads[f]	Not required, but **recommended**[f,g] with open foundation in lieu of solid walls; if breakaway walls are used and enclose an area, flood openings are required. [see Fact Sheet Nos. 11, 15]	**Requirement:** none[f,g]
Openings in Below-BFE Walls [see Fact Sheet Nos. 11, 15] **(Also see Enclosures Below BFE)**	Not Applicable[j]	**Requirement:** unless number and size of openings meet regulatory requirements, registered engineer or architect must certify that openings are designed to automatically equalize hydrostatic forces on walls by allowing automatic entry and exit of flood waters	**Requirement:** unless number and size of openings meet regulatory requirements, registered engineer or architect must certify that openings are designed to automatically equalize hydrostatic forces on walls by allowing automatic entry and exit of flood waters

Requirements and Recommendations for Repairs, Remodeling, and Additions

See page 8 for notes.	V Zone	A Zones in Coastal Areas: Coastal A — Areas With Potential for Breaking Waves and Erosion During Base Flood[b]	A Zones in Coastal Areas: A — Areas With Shallow Flooding Only, Where Potential for Breaking Waves and Erosion Is Low[c]
Repairs, Remodeling, and Additions (see Fact Sheet No. 30 and consult AHJ[k] for building code requirements)			
Substantial Improvements and Repairs of Substantial Damage	**Requirement:** must meet current NFIP requirements concerning new construction in V zones[k,l] except for siting landward of mean high tide **[see Fact Sheet Nos. 4, 5, 7, 11, 15, 27, 29]**	**Requirement:** must meet current NFIP requirements concerning new construction in A zones[k,m] **[see Fact Sheet Nos. 4, 11, 15, 27, 29]** **Recommendation:** follow V-zone requirement	**Requirement:** must meet current NFIP requirements concerning new construction in A zones[k,m] **[see Fact Sheet Nos. 4, 11, 15, 27, 29]** **Recommendation:** elevate bottom of lowest horizontal structural member to or above BFE
Lateral Additions That Constitute Substantial Improvement	**Requirement:** both addition and existing building must meet current NFIP requirements concerning new construction in V zones[k,l,n] **[see Fact Sheet Nos. 4, 5, 7, 11, 15, 27, 29]**	**Requirement:** only addition must meet current NFIP requirements concerning new construction in A zones[k,m,o] (**See Fact Sheet Nos. 4, 7, 11, 15, 27, 29**), *provided* existing building is not subject to any work other than cutting entrance in common wall and connecting existing building to addition; if any other work is done to existing building, it too must meet current NFIP requirements for new construction in A zones **Recommendation:** follow V-zone requirement	**Requirement:** only addition must meet current NFIP requirements concerning new construction in A zones[k,m,o] (**See Fact Sheet Nos. 4, 7, 11, 15, 27, 29**), *provided* the existing building is not subject to any work other than cutting an entrance in a common wall and connecting the existing building to the addition; if any other work is done to existing building, it too must meet current NFIP requirements for new construction in A zones **Recommendation:** elevate bottom of lowest horizontal structural member of addition to or above BFE (same for existing building if it is elevated)
Lateral Additions That Do *Not* Constitute Substantial Improvement	**Requirement:** *post-Flood Insurance Rate Map (FIRM)* existing building – addition must meet NFIP requirements in effect at time building was originally constructed [k,l,n] pre-FIRM existing building – NFIP requirements concerning new construction not triggered [k] **[see Fact Sheet Nos. 4, 5, 7, 11, 15, 27, 29]** **Recommendation:** make addition compliant with current NFIP requirements for V-zone construction	**Requirement:** *post-FIRM* existing building – addition must meet NFIP requirements in effect at time building was originally constructed [k,m,o] **[see Fact Sheet Nos. 4, 7, 11, 15, 27, 29]** *pre-FIRM* existing building – NFIP requirements concerning new construction not triggered[k] **Recommendation:** follow V-zone requirement	**Requirement:** *post-FIRM* existing building – addition must meet NFIP requirements in effect at time building was originally constructed [k,m,o] **[see Fact Sheet Nos. 4, 7, 11, 15, 27, 29]** *pre-FIRM* existing building – NFIP requirements concerning new construction not triggered[k] **Recommendation:** elevate bottom of lowest horizontal structural member of addition to or above BFE (same for existing building if it is elevated) **[see Fact Sheet No. 4]**

See page 8 for notes.	V Zone	A Zones in Coastal Areas: Coastal A – Areas With Potential for Breaking Waves and Erosion During Base Flood[b]	A Zones in Coastal Areas: A – Areas With Shallow Flooding Only, Where Potential for Breaking Waves and Erosion Is Low[c]
Repairs, Remodeling, and Additions (cont.)	**(see Fact Sheet No. 30 and consult AHJ[k] for building code requirements)**		
Vertical Additions That Constitute Substantial Improvement	**Requirement:** entire building must meet current NFIP requirements concerning new construction in V zones[k,l,n] **[see Fact Sheet Nos. 4, 5, 7, 11, 15, 27, 29]**	**Requirement:** entire building must meet current NFIP requirements concerning new construction in A zones[k,m,o] **[see Fact Sheet Nos. 4, 7, 11, 15, 27, 29]** **Recommendation**: follow V-zone requirement	**Requirement:** entire building must meet current NFIP requirements concerning new construction in A zones[k,m,o] **[see Fact Sheet Nos. 4, 7, 11, 15, 27, 29]** **Recommendation:** elevate bottom of lowest horizontal structural member to or above BFE **[see Fact Sheet No. 4]**
Vertical Additions That Do *Not* Constitute Substantial Improvement	**Requirement:** *post-FIRM* existing building – addition must meet NFIP requirements in effect at time building was originally constructed [k,l,n] *pre-FIRM* existing building – NFIP requirements concerning new construction not triggered[k] **[see Fact Sheet Nos. 4, 5, 7, 11, 15, 27, 29]** **Recommendation:** make addition compliant with current NFIP requirements for V-zone construction	**Requirement:** *post-FIRM* existing building – addition must meet NFIP requirements in effect at time building was originally constructed[k,m,o] *pre-FIRM* existing building – NFIP requirements concerning new construction not triggered[k] **[see Fact Sheet Nos. 4, 5, 7, 11, 15, 27, 29]** **Recommendation:** follow V-zone requirement	**Requirement:** *post-FIRM* existing building – addition must meet NFIP requirements in effect at time building was originally constructed[k,m,o] ***pre-FIRM*** existing building – NFIP requirements concerning new construction not triggered[k] **[see Fact Sheet Nos. 4, 5, 7, 11, 15, 27, 29]** **Recommendation:** elevate bottom of lowest horizontal structural member to or above BFE **[see Fact Sheet No. 4]**
Elevating on New Foundation	**Requirement:** new foundation must meet current NFIP requirements concerning new construction in V zones[k,l]; building must be properly connected and anchored to new foundation	**Requirement:** new foundation must meet current NFIP requirements concerning new construction in A zones[k,m]; building must be properly connected and anchored to new foundation **Recommendation:** follow V-zone requirement	**Requirement:** new foundation must meet current NFIP requirements concerning new construction in A zones[k,m]; building must be properly connected and anchored to new foundation **Recommendation:** elevate bottom of lowest horizontal structural member to or above BFE **[see Fact Sheet No. 4]**
Enclosures Below Buildings – When enclosure constitutes a **substantial improvement**	**Requirement:** both enclosure and existing building must meet current NFIP requirements for new construction in V zones[k,l,n] **[see Fact Sheet Nos. 4, 5, 7, 11, 27, 29]**	**Requirement:** both enclosure and existing building must meet current NFIP requirements for new construction in A zones[k,m,o] **[see Fact Sheet Nos. 4, 7, 11, 15, 27, 29]** **Recommendation:** follow V-zone requirement	**Requirement:** both enclosure and existing building must meet current NFIP requirements for new construction in A zones[k,m,o] **[see Fact Sheet Nos. 4, 7, 11, 15, 27, 29]** **Recommendation:** elevate bottom of lowest horizontal structural member to or above BFE **[see Fact Sheet No. 4]**

See page 8 for notes.	V Zone	A Zones in Coastal Areas: Coastal A — Areas With Potential for Breaking Waves and Erosion During Base Flood[b]	A Zones in Coastal Areas: A — Areas With Shallow Flooding Only, Where Potential for Breaking Waves and Erosion Is Low[c]
Repairs, Remodeling, and Additions (cont.)	**(see Fact Sheet No. 30 and consult AHJ[k] for building code requirements)**		
Enclosures Below Buildings – When enclosure does ***not*** constitute a substantial improvement	**Requirement:** *post-FIRM* existing building – enclosure must meet NFIP requirements in effect at time building was originally constructed[k,l,n] *pre-FIRM* existing building – NFIP requirements concerning new construction not triggered[k] [see Fact Sheet No. 27] **Recommendation:** make enclosure compliant with current NFIP requirements for new V-zone construction	**Requirement:** *post-FIRM* existing building – enclosure must meet NFIP requirements in effect at time building was originally constructed[k,m,o] *pre-FIRM* existing building – NFIP requirements concerning new construction not triggered[k] [see Fact Sheet Nos. 15, 27] **Recommendation:** construct only breakaway enclosures; install flood openings in enclosure; do not convert enclosed space to habitable use	**Requirement:** *post-FIRM* existing building – enclosure must meet NFIP requirements in effect at time building was originally constructed[k,m,o] *pre-FIRM* existing building – NFIP requirements concerning new construction not triggered[k] [see Fact Sheet Nos. 15, 27] **Recommendation:** install flood openings in enclosure; do not convert enclosed space to habitable use
Reconstruction of Destroyed or Razed Building	**Requirement:** where entire building is destroyed, damaged, or purposefully demolished or razed, replacement building must meet current NFIP requirements concerning new construction in V zones[k,l], even if built on foundation from original building [see Fact Sheet Nos. 4, 5, 30]	**Requirement:** where entire building is destroyed, damaged, or purposefully demolished or razed, replacement building must meet current NFIP requirements concerning new construction in A zones[k,m], even if built on foundation from original building [see Fact Sheet Nos. 4, 30] **Recommendation:** follow V-zone requirement	**Requirement:** where entire building is destroyed, damaged, or purposefully demolished or razed, replacement building must meet current NFIP requirements concerning new construction in A zones[k,m], even if built on foundation from original building [see Fact Sheet Nos. 4, 30]
Moving Existing Building	**Requirement:** where existing building is moved to new location or site, relocated building must meet current NFIP requirements concerning new construction in V zones[k,l] [see Fact Sheet Nos. 4, 5, 30]	**Requirement:** where existing building is moved to new location or site, relocated building must meet current NFIP requirements concerning new construction in A zones[k,m] [see Fact Sheet Nos. 4, 30] **Recommendation:** follow V-zone requirement	**Requirement:** where existing building is moved to new location or site, relocated building must meet current NFIP requirements concerning new construction in A zones[k,m] [see Fact Sheet Nos. 4, 30] **Recommendation:** elevate bottom of lowest horizontal structural member to or above BFE [see Fact Sheet No. 4]

Notes

a “***Prohibited***” and “***Allowed***” refer to the minimum NFIP regulatory requirements; individual states and communities may enforce more stringent requirements that supersede those summarized here. ***Exceeding minimum NFIP requirements will provide increased flood protection and may result in lower flood insurance premiums.***

b In these areas, buildings are subject to flooding conditions similar to, but less severe than, those in V zones. These areas can be subject to breaking waves ≥ 1.5 feet high (which can destroy conventional wood-frame and unreinforced masonry wall construction) and erosion (which can undermine shallow foundations).

c In these areas, buildings are subject to flooding conditions similar to those in riverine A zones.

d Some coastal communities require ***open foundations in A zones.***

e State or community may require ***freeboard*** or regulate to a higher elevation (e.g., Design Flood Elevation (DFE)).

f Some coastal communities ***prohibit breakaway walls*** and allow only open lattice or screening.

g If an area below the BFE in an A-zone building is fully enclosed by breakaway walls, the walls must meet the requirement for ***openings*** that allow equalization of hydrostatic pressure.

h Placement of ***nonstructural fill*** adjacent to buildings in coastal AO zones is not recommended.

i There are some ***differences between*** what is permitted under ***floodplain management regulations*** and what is covered by ***NFIP flood insurance.*** Building designers should be guided by floodplain management requirements, not by flood insurance policy provisions. For more information, see Section 9.3.1.1 in Chapter 9 of FEMA’s Coastal Construction Manual (FEMA 55).

j ***Walls below BFE*** must be designed and constructed as breakaway walls that meet the minimum requirements of the NFIP regulations. For more information, see Section 6.4.3.3 in Chapter 6 of FEMA’s Coastal Construction Manual (FEMA 55).

k Consult with authority having jurisdiction (AHJ) regarding ***more restrictive requirements for repairs, remodeling, and additions.***

l ***NFIP requirements for new construction in V zones*** include those pertaining to Design and Construction, Flood-Resistant Materials, Siting, Foundations, Lowest Floor Elevation, Enclosures Below the BFE, Free of Obstructions, Utilities, and Certifications.

m ***NFIP requirements for new construction in A zones*** include those pertaining to Design and Construction, Flood-Resistant Materials, Siting, Foundations, Foundation Openings, Lowest Floor Elevation, Enclosures Below the BFE, Utilities, and Certifications.

n An addition in the form of an ***attached garage*** would not have to be elevated to or above the BFE, because its use (parking) would be allowed below the BFE; however, it would have to meet other NFIP requirements for new construction in V zones.

o An addition in the form of an ***attached garage*** would not have to be elevated to or above the BFE, because its use (parking) would be allowed below the BFE; however, it would have to meet other NFIP requirements for new construction in A zones.

Lowest Floor Elevation

HOME BUILDER'S GUIDE TO COASTAL CONSTRUCTION FEMA 499/August 2005 *Technical Fact Sheet No. 4*

Purpose: To discuss benefits of exceeding the National Flood Insurance Program (NFIP) minimum elevation requirements, to point out common construction practices that are violations of NFIP regulations and result in significantly higher flood insurance premiums, and to discuss the NFIP Elevation Certificate.

Why Is the Lowest Floor Elevation Important?

In inland areas, experience has shown that floods damage areas of buildings not elevated above the flood level and destroy contents of those areas. In coastal areas, wave action causes even more damage, often ***destroying enclosed building areas below the flood level (and any building areas above the flood level that depend on the lower area for structural support). Once waves rise above the lowest structural member in a V zone or coastal A zone, the elevated portion of the building is likely to be severely damaged or destroyed.***

Recommended Lowest Floor Elevations*

Because of the additional hazard associated with wave action in V zones and in A zones in coastal areas, it is recommended that the minimum elevation requirements of the NFIP be exceeded in these areas:

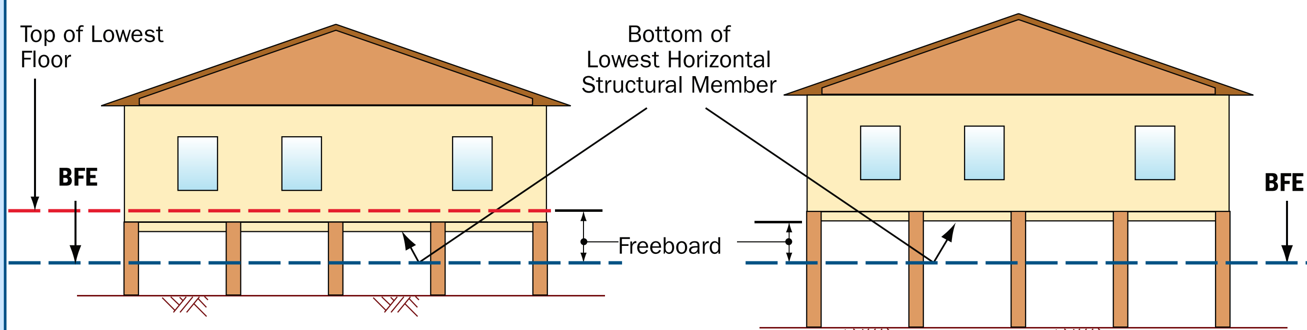
- It is recommended that ***the bottom of the lowest horizontal structural member of V-zone buildings be elevated 1 foot or more above the Base Flood Elevation (BFE),*** i.e., add freeboard.
- It is recommended that ***the lowest horizontal structural member of A-zone buildings in coastal areas be elevated 1 foot or more above the BFE*** (i.e., add freeboard).

*NFIP minimum elevation requirements: A zone – elevate top of lowest floor to or above BFE; V zone – elevate bottom of lowest horizontal structural member to or above BFE. **In both V and A zones, many people have decided to elevate a full story for below-building parking, far exceeding the elevation requirement.** See Fact Sheet No. 2 for more information about NFIP minimum requirements in A and V zones.

Recommended Practice:

A Zones in Coastal Areas:
Subject to Breaking Waves and Erosion During the Base Flood
Lowest Horizontal Structural Member Above BFE (Freeboard)

V Zones:
Bottom of Lowest Horizontal Structural Member Above BFE (Freeboard)



A-Zone Building (Open Foundation)

V-Zone Building (Open Foundation)

What Does FEMA Consider the Lowest Floor?

- The "lowest floor" means **the lowest floor of the lowest enclosed area, except for unfinished or flood-resistant enclosures used solely for parking of vehicles, building access, or storage**.
- If the lowest enclosed area is used for anything other than ***parking of vehicles, building access, or storage***, the floor of that area is considered the lowest floor. This will violate NFIP requirements and drastically increase flood insurance premiums.
- Note that ***any below-BFE finished areas***, including foyers, will violate NFIP requirements, sustain unreimbursable flood damage, and increase flood insurance premiums.
- The floor of a basement (where "basement" means the floor is below grade on all sides) will ***always*** be the lowest floor, regardless of how the space is used.
- Walls of enclosed areas below the BFE must meet special requirements in coastal areas (see Fact Sheet No. 27).

Construction Practices and the Lowest Floor

Setting the lowest floor at the correct elevation is critical. Failure to do so can result in a building being constructed below the BFE. As a result, work can be stopped, certificates of occupancy can be withheld, and correcting the problem can be expensive and time-consuming.

- After piles have been installed, the intended elevation of the lowest floor should be checked before the piles are cut off.
- Alternatively, after piers or columns have been constructed, the intended elevation of the lowest floor should be checked before the lowest horizontal structural supporting members are installed.
- After the lowest horizontal structural supporting members have been installed, the elevation should be checked again, before any further vertical construction is carried out.

Do not modify building plans to create habitable space below the intended lowest floor. Doing so will put the building in violation of flood regulations and building codes.

FEMA Elevation Certificate

The NFIP requires participating communities to adopt a floodplain management ordinance that specifies minimum requirements for reducing flood losses. One such requirement is that communities ***obtain, and maintain a record of, the lowest floor elevations for all new and substantially improved buildings***.
The Elevation Certificate (see following pages) provides a way for a community to comply with this requirement and for insurers to determine flood insurance premiums.

Most communities require permit applicants to retain a surveyor, engineer, or architect to complete and submit the elevation certificate. Note that ***multiple elevation certificates may need to be submitted for the same building***: a certificate *may* be required when the ***lowest floor level is set*** (and before additional vertical construction is carried out); a certificate *will* be required ***upon completion of all construction***.

The Elevation Certificate requires that the following information be ***certified and signed by the surveyor/engineer/architect*** and ***signed by the building owner***:

- elevations of certain floors in the building
- lowest elevation of utility equipment/machinery
- floor slab elevation for attached garage
- adjacent grade elevations
- flood opening information (A zones)

The Elevation Certificate is available on FEMA's web site: http://www.fema.gov/nfip/elvinst.shtm

FEDERAL EMERGENCY MANAGEMENT AGENCY
NATIONAL FLOOD INSURANCE PROGRAM

O.M.B. No. 3067-0077
Expires December 31, 2005

ELEVATION CERTIFICATE

Important: Read the instructions on pages 1 - 7.

SECTION A - PROPERTY OWNER INFORMATION			For Insurance Company Use:
BUILDING OWNER'S NAME			Policy Number
BUILDING STREET ADDRESS (Including Apt., Unit, Suite, and/or Bldg. No.) OR P.O. ROUTE AND BOX NO.			Company NAIC Number
CITY	STATE	ZIP CODE	
PROPERTY DESCRIPTION (Lot and Block Numbers, Tax Parcel Number, Legal Description, etc.)			
BUILDING USE (e.g., Residential, Non-residential, Addition, Accessory, etc. Use a Comments area, if necessary.)			
LATITUDE/LONGITUDE (OPTIONAL) (##° - ##' - ##.##" or ##.#####°)	HORIZONTAL DATUM: |__| NAD 1927 |__| NAD 1983	SOURCE: |__| GPS (Type): ____ |__| USGS Quad Map |__| Other ____	

SECTION B - FLOOD INSURANCE RATE MAP (FIRM) INFORMATION

B1. NFIP COMMUNITY NAME & COMMUNITY NUMBER	B2. COUNTY NAME	B3. STATE

B4. MAP AND PANEL NUMBER	B5. SUFFIX	B6. FIRM INDEX DATE	B7. FIRM PANEL EFFECTIVE/REVISED DATE	B8. FLOOD ZONE(S)	B9. BASE FLOOD ELEVATION(S) (Zone AO, use depth of flooding)

B10. Indicate the source of the Base Flood Elevation (BFE) data or base flood depth entered in B9.
|__| FIS Profile |__| FIRM |__| Community Determined |__| Other (Describe): ____________________

B11. Indicate the elevation datum used for the BFE in B9: |__| NGVD 1929 |__| NAVD 1988 |__| Other (Describe): ____________

B12. Is the building located in a Coastal Barrier Resources System (CBRS) area or Otherwise Protected Area (OPA)? |__| Yes |__| No
Designation Date:______________

SECTION C - BUILDING ELEVATION INFORMATION (SURVEY REQUIRED)

C1. Building elevations are based on: |__|Construction Drawings* |__|Building Under Construction* |__|Finished Construction
*A new Elevation Certificate will be required when construction of the building is complete.

C2. Building Diagram Number _____ (Select the building diagram most similar to the building for which this certificate is being completed - see pages 6 and 7. If no diagram accurately represents the building, provide a sketch or photograph.)

C3. Elevations – Zones A1-A30, AE, AH, A (with BFE), VE, V1-V30, V (with BFE), AR, AR/A, AR/AE, AR/A1-A30, AR/AH, AR/AO
Complete Items C3.a-i below according to the building diagram specified in Item C2. State the datum used. If the datum is different from the datum used for the BFE in Section B, convert the datum to that used for the BFE. Show field measurements and datum conversion calculation. Use the space provided or the Comments area of Section D or Section G, as appropriate, to document the datum conversion.
Datum ___________ Conversion/Comments ______________________________
Elevation reference mark used____________ Does the elevation reference mark used appear on the FIRM? |__| Yes |__| No

- ❏ a) Top of bottom floor (including basement or enclosure) ____________ . ___ ft.(m)
- ❏ b) Top of next higher floor ____________ . ___ ft.(m)
- ❏ c) Bottom of lowest horizontal structural member (V zones only) ____________ . ___ ft.(m)
- ❏ d) Attached garage (top of slab) ____________ . ___ ft.(m)
- ❏ e) Lowest elevation of machinery and/or equipment servicing the building (Describe in a Comments area.) ____________ . ___ ft.(m)
- ❏ f) Lowest adjacent (finished) grade (LAG) ____________ . ___ ft.(m)
- ❏ g) Highest adjacent (finished) grade (HAG) ____________ . ___ ft.(m)
- ❏ h) No. of permanent openings (flood vents) within 1 ft. above adjacent grade ________
- ❏ i) Total area of all permanent openings (flood vents) in C3.h ________ sq. in. (sq. cm)

License Number, Embossed Seal, Signature, and Date

SECTION D - SURVEYOR, ENGINEER, OR ARCHITECT CERTIFICATION

This certification is to be signed and sealed by a land surveyor, engineer, or architect authorized by law to certify elevation information.
I certify that the information in Sections A, B, and C on this certificate represents my best efforts to interpret the data available.
I understand that any false statement may be punishable by fine or imprisonment under 18 U.S. Code, Section 1001.

CERTIFIER'S NAME		LICENSE NUMBER	
TITLE	COMPANY NAME		
ADDRESS	CITY	STATE	ZIP CODE
SIGNATURE	DATE	TELEPHONE	

IMPORTANT: In these spaces, copy the corresponding information from Section A.			For Insurance Company Use:
BUILDING STREET ADDRESS (Including Apt., Unit, Suite, and/or Bldg. No.) OR P.O. ROUTE AND BOX NO.			Policy Number
CITY	STATE	ZIP CODE	Company NAIC Number

SECTION D - SURVEYOR, ENGINEER, OR ARCHITECT CERTIFICATION (CONTINUED)

Copy both sides of this Elevation Certificate for (1) community official, (2) insurance agent/company, and (3) building owner.

COMMENTS

|__| Check here if attachments

SECTION E - BUILDING ELEVATION INFORMATION (SURVEY NOT REQUIRED) FOR ZONE AO AND ZONE A (WITHOUT BFE)

For Zone AO and Zone A (without BFE), complete Items E1. through E5. If the Elevation Certificate is intended for use as supporting information for a LOMA or LOMR-F, Section C must be completed.

E1. Building Diagram Number _____ (Select the building diagram most similar to the building for which this certificate is being completed – see pages 6 and 7. If no diagram accurately represents the building, provide a sketch or photograph.)

E2. The top of the bottom floor (including basement or enclosure) of the building is |__|__| ft. (m) |__|__| in. (cm) |__| above or |__| below (check one) the highest adjacent grade. (Use natural grade, if available.)

E3. For Building Diagrams 6-8 with openings (see page 7), the next higher floor or elevated floor (elevation b) of the building is |__|__| ft. (m) |__|__|in. (cm) above the highest adjacent grade. Complete Items C3.h and C3.i on front of form.

E4. The top of the platform of machinery and/or equipment servicing the building is |__|__| ft. (m) |__|__| in. (cm) |__| above or |__| below (check one) the highest adjacent grade. (Use natural grade, if available.)

E5. For Zone AO only: If no flood depth number is available, is the top of the bottom floor elevated in accordance with the community's floodplain management ordinance? |__| Yes |__| No |__| Unknown. The local official must certify this information in Section G.

SECTION F - PROPERTY OWNER (OR OWNER'S REPRESENTATIVE) CERTIFICATION

The property owner or owner's authorized representative who completes Sections A, B, C (Items C3.h and C3.i only), and E for Zone A (without a FEMA-issued or community-issued BFE) or Zone AO must sign here. *The statements in Sections A, B, C, and E are correct to the best of my knowledge.*

PROPERTY OWNER'S OR OWNER'S AUTHORIZED REPRESENTATIVE'S NAME

ADDRESS	CITY	STATE	ZIP CODE
SIGNATURE	DATE	TELEPHONE	

COMMENTS

|__| Check here if attachments

SECTION G - COMMUNITY INFORMATION (OPTIONAL)

The local official who is authorized by law or ordinance to administer the community's floodplain management ordinance can complete Sections A, B, C (or E), and G of this Elevation Certificate. Complete the applicable item(s) and sign below.

G1. |__| The information in Section C was taken from other documentation that has been signed and embossed by a licensed surveyor, engineer, or architect who is authorized by state or local law to certify elevation information. (Indicate the source and date of the elevation data in the Comments area below.)

G2. |__| A community official completed Section E for a building located in Zone A (without a FEMA-issued or community-issued BFE) or Zone AO.

G3. |__| The following information (Items G4-G9) is provided for community floodplain management purposes.

G4. PERMIT NUMBER	G5. DATE PERMIT ISSUED	G6. DATE CERTIFICATE OF COMPLIANCE/OCCUPANCY ISSUED

G7. This permit has been issued for: |__| New Construction |__| Substantial Improvement

G8. Elevation of as-built lowest floor (including basement) of the building is: _____________ . ___ ft. (m) Datum:_______________

G9. BFE or (in Zone AO) depth of flooding at the building site is: _____________ . ___ ft. (m) Datum:_______________

LOCAL OFFICIAL'S NAME	TITLE
COMMUNITY NAME	TELEPHONE
SIGNATURE	DATE

COMMENTS

|__| Check here if attachments

V-Zone Design and Construction Certification

Purpose: To explain the certification requirements for structural design and construction in V zones.

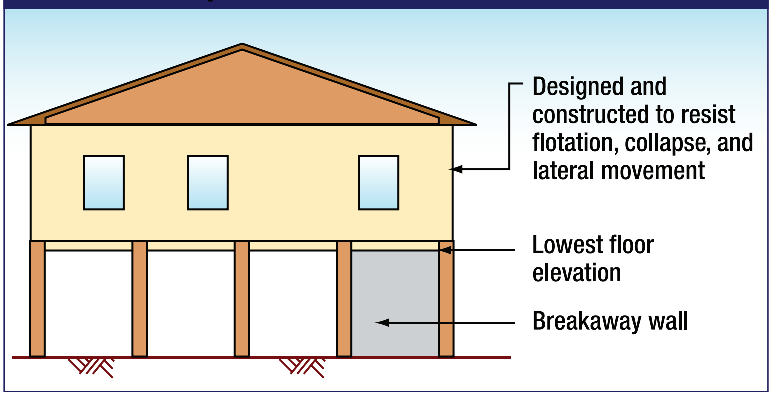
Structural Design and Methods of Construction Certification

As part of the agreement for making flood insurance available in a community, the National Flood Insurance Program (NFIP) requires the community to adopt a floodplain management ordinance that specifies minimum design and construction requirements. Those requirements include a ***certification of the structural design and the methods of construction.***

Specifically, NFIP regulations and local floodplain management ordinances require that:

1. a ***registered professional engineer or architect*** shall ***develop or review*** the ***structural design, specifications, and plans*** for the construction, and
2. a ***registered professional engineer or architect*** shall ***certify that the design and methods of construction*** to be used are in accordance with accepted standards of practice for meeting the following criteria:
   - the ***bottom of the lowest horizontal structural member of the lowest floor*** (excluding the pilings or columns) is elevated to or above the Base Flood Elevation (BFE); and
   - the pile or column foundation and structure attached thereto is ***anchored to resist flotation, collapse, and lateral movement due to the effects of wind and water loads acting simultaneously*** on all building components. Water loading values used shall be those associated with the Base Flood. Wind loading values used shall be those required by applicable state or local building standards.

Required Certifications in V Zones



The community, through its inspection procedures, will verify that the building is built in accordance with the certified design.

Other Certifications Required in V Zones

- Lowest Floor Elevation, by a surveyor, engineer, or architect (see Fact Sheet No. 4)
- Breakaway Wall Collapse, by a registered professional engineer or architect (see Fact Sheet No. 27)

Completing the V-Zone Certification

There is no single V-zone certificate used on a nationwide basis. Instead, local communities and/or states have developed their own certification procedures and documents.

Registered engineers and architects involved in V-zone construction projects should ***check with the authority having jurisdiction regarding the exact nature and timing of required certifications***.

Page 2 shows a sample certification form developed by one state. It is intended to show one of many possible ways by which a jurisdiction may require that the certification and supporting information be provided. In this instance, three certifications are included on the form (Lowest Floor Elevation, Design and Methods of Construction, Breakaway Wall Collapse).

The Design and Methods of Construction certification should take into consideration the NFIP Free-of-Obstruction requirement for V zones: *the space below the lowest floor must be free of obstructions (e.g., free of any building element, equipment, or other fixed objects that can transfer flood loads to the foundation, or that can cause floodwaters or waves to be deflected into the building), or must be constructed with non-supporting breakaway walls, open lattice, or insect screening.* **(See NFIP Technical Bulletin 5-93 and Fact Sheet No. 27.)**

Note: The V-zone certificate is not a substitute for and cannot be used without the NFIP Elevation Certificate (see Fact Sheet No. 4), which is required for flood insurance rating.

V-ZONE CERTIFICATE

Name____________________________________ Policy Number *(Insurance Co. Use)* ____________
Building Address or
Other Description ____
City _____________________________________ State ______________ Zip Code __________

SECTION I: Flood Insurance Rate Map (FIRM) Information

Community Number________ Panel Number ________ Suffix ____ Date of FIRM Index ____ FIRM Zone____

SECTION II: Elevation Information

NOTE: This Certificate does not substitute for an Elevation Certificate

1. Elevation of the Bottom of Lowest Horizontal Structural Member........................_____ feet (NGVD)
2. Base Flood Elevation (BFE)..._____ feet (NGVD)
3. Elevation of Lowest Adjacent Grade..._____ feet (NGVD)
4. Approximate Depth of Anticipated Scour/Erosion used for Foundation Design..........._____ feet (NGVD)
5. Embedment Depth of Pilings or Foundation Below Lowest Adjacent Grade.............._____ feet (NGVD)

SECTION III: V-Zone Certification Statement

NOTE: This section must be certified by a registered engineer or architect

I certify that I have developed or reviewed the structural design, plans, and specifications for construction and that the design and methods of construction to be used are in accordance with accepted standards of practice for meeting the following provisions:

- The bottom of the lowest horizontal structural member of the lowest floor (excluding piles and columns) is elevated to or above the BFE; and
- The pile and column foundation and structure attached thereto is anchored to resist flotation, collapse, and lateral movement due to the effects of the wind and water loads acting simultaneously on all building components. Water loading values used are those associated with the base flood. Wind loading values used are those required by the applicable State or local building code. The potential for scour and erosion at the foundation has been anticipated for conditions associated with the base flood, including wave action.

SECTION IV: Breakaway Wall Certification Statement

NOTE: This section must be certified by a registered engineer or architect when breakaway walls exceed a design safe loading resistance of 20 pounds per square foot

I certify that I have developed or reviewed the structural design, plans, and specifications for construction and that the design and methods of construction to be used for the breakaway walls are in accordance with accepted standards of practice for meeting the following provisions:

- Breakaway wall collapse shall result from a water load less than that which would occur during the base flood; and
- **The elevated portion of the building and supporting foundation system shall not be subject to collapse, displacement, or other structural damage due to the effects of wind and water loads acting simultaneously on all building components (wind and water loading val ues to be used are defined in Section III).**

SECTION V: Certification

Signature below certifies: ____ Section III; ____ Section IV

Certifier's Name _______________________________ Company Name______________________________
Title ______________________________________ License Number _____________________________
Street Address ____
City __________________________________ State _________________________ Zip Code ____________

Signature _______________________________ Date ___________________ Telephone Number ___________

How Do Siting and Design Decisions Affect the Owner's Costs?

FEMA

Purpose: To show the effects of planning, siting, and design decisions on coastal home costs.

Key Issues

- When building a coastal home, initial, operating, and long-term costs (i.e., life cycle costs) must be considered.
- Coastal (especially oceanfront) homes cost more to design, construct, maintain, repair, and insure than inland homes.
- Determining the risks associated with a particular building site or design is important.
- Siting, designing, and constructing to minimum regulatory requirements do not necessarily result in the lowest cost to the owner over a long period of time. Exceeding minimum design requirements costs slightly more initially, but can save the owner money in the long run.

Costs

A variety of costs should be considered when planning a coastal home, not just the construction cost. Owners should be aware of each of the following, and consider how siting and design decisions will affect these costs:

Initial costs include property evaluation and acquisition costs and the costs of permitting, design, and construction.

Operating costs include costs associated with the use of the building, such as the costs of utilities and insurance*.

Long-term costs include costs for preventive maintenance and for repair and replacement of deteriorated or damaged building components.

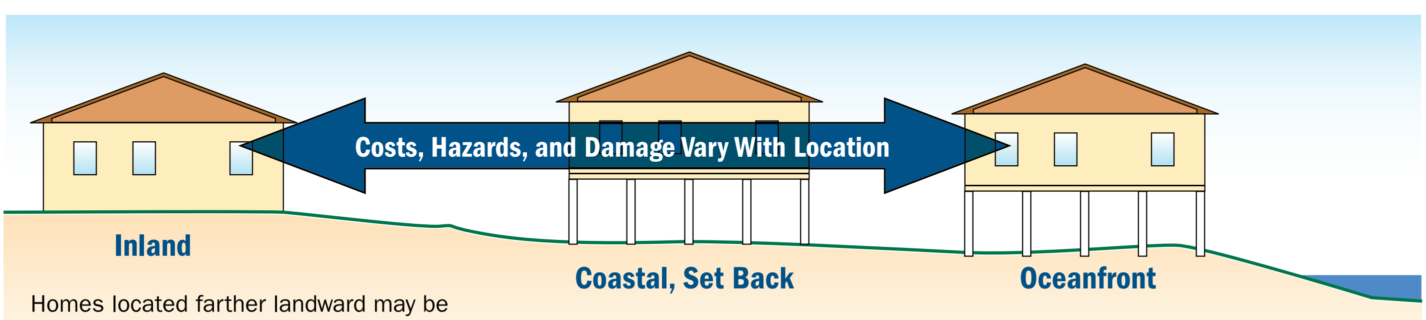
*Note: Flood insurance premiums can be reduced up to 60 percent by exceeding minimum siting, design, and construction practices. See the V-Zone Risk Factor Rating Form in FEMA's *Flood Insurance Manual* (http://www.fema.gov/nfip/manual.shtm).

Risk

One of the most important building costs to be considered is that resulting from storm and/or erosion damage. But how can an owner decide what level of risk is associated with a particular building site or design? One way is to consider the probability of a storm or erosion occurring and the potential building damage that results (see matrix).

Probability of Occurrence

Potential $ Loss	Low	Medium	High
Low	Low Risk	Low Risk	Medium Risk
Medium	Low Risk	Medium Risk	High Risk
High	Medium Risk	High Risk	Extreme Risk



Homes located farther landward may be less appealing to some owners, but will be less prone to damage and will cost less to build, insure, and maintain.

Homes located close to the shore may have spectacular views, but are subject to greater risks, more frequent and more severe damage, and higher construction, maintenance, and insurance costs.

Building sites or designs resulting in extreme or high risk should be avoided — the likelihood of building loss is great, and the long-term costs to the owner will be very high. Building sites or designs resulting in medium or low risk should be given preference.

Siting

Note that over a long period, poor siting decisions are rarely overcome by building design.

Design

- How much more expensive is it to build near the coast as opposed to inland areas? The table below suggests approximately 10 - 30 percent more.
- What about exceeding minimum design requirements in coastal areas? The table suggests that the added construction costs for meeting the practices recommended in the *Home Builder's Guide to Coastal Construction* (beyond typical minimum requirements) are nominal.

Design Item (Items in bold are required by National Flood Insurance Program (NFIP) and/or local building code.)	**Cross-Reference to Fact Sheets**	**Added Initial Costs** (when compared to typical *inland* construction) **Required by Code or NFIP**	**Added Initial Costs** (to exceed Code/NFIP minimum requirements) **for Home Builder's Guide to Coastal Construction Recommended Practices**	**Effect of Design Item on Cost:** Reduce wind/storm damage	Reduce flood damage	Longer material life	Reduce maintenance	Lower insurance	Lower utility bills
A zone, pile/column foundation	1, 4, 11	High	High	✓	✓			✓	
V zone, pile/column foundation	1, 4, 5, 11	High			✓			✓	
Joists sheathed on underside		Low	Low		✓	✓			✓
Structurally sheathed walls		Medium		✓					
Corrosion protection	1, 8	Low		✓	✓	✓	✓		
Decay protection	1, 8	Medium		✓	✓	✓	✓		
Hip roof shape	1	Low	Low	✓					
Enhanced roof sheathing connection	1, 18	Low	Low	✓					
Enhanced roof underlayment	19	Low	Low	✓					
Upgraded roofing materials	1, 20	Medium		✓		✓	✓		
Enhanced flashing	1, 22, 24	Low		✓		✓	✓		
Housewrap	1, 22, 23	Low		✓					✓
Superior siding and connection	25	Medium	Medium	✓			✓		
Protected or impact-resistant glazing	1, 26	High	Medium	✓				✓	
Connection hardware	1, 8, 17	Low		✓	✓				
Flood-resistant materials	1, 8	Low			✓	✓		✓	
Protected utilities and mechanicals	1, 29	Low		✓	✓	✓	✓		✓
Estimated Total Additional Cost (% of building cost)		**15 - 30**	**±5**	✓	✓	✓	✓	✓	✓

Low	<0.5% of base building cost
Medium	0.5% - 2.0% of base building cost
High	>2.0% of base building cost

Estimates are based on a 3,000-square-foot home with a moderate number of windows and special features. Many of the upgraded design features are ***required*** by local codes, but the level of protection beyond the code minimum can vary, depending on the owner's preference.

Selecting a Lot and Siting the Building

HOME BUILDER'S GUIDE TO COASTAL CONSTRUCTION FEMA 499/August 2005 Technical Fact Sheet No. 7

Purpose: To provide guidance on lot selection and siting considerations for coastal residential buildings.

Key Issues

- Purchase and siting decisions should be long-term decisions, not based on present-day shoreline and conditions.
- Parcel characteristics, infrastructure, regulations, environmental factors, and owner desires constrain siting options.
- Conformance with local/state shoreline setback lines does not mean buildings will be "safe."
- Information about site conditions and history is available from several sources.

Siting, design, and construction should be considered together (see Fact Sheet No. 6), but know that poor lot selection and siting decisions can rarely be overcome by improved design and construction. Building failures (see Fact Sheet No. 1) are often the result of poor siting.

The Importance of Property Purchase and Siting Decisions

The single most common and costly siting mistake made by designers, builders, and owners is failing to consider future erosion and slope stability when an existing coastal home is purchased or when land is purchased and a new home is built. Purchase decisions— or siting, design, and construction decisions — based on present-day shoreline conditions often lead to future building failures.

Over a long period of time, owners of poorly sited coastal buildings may spend more money on erosion control and erosion-related building repairs than they spent on the building itself.

What Factors Constrain Siting Decisions?

Many factors affect and limit a home builder's or owner's ability to site coastal residential buildings, but the most influential is probably ***parcel size***, followed by ***topography***, ***location of roads and other infrastructure***, ***regulatory constraints***, and ***environmental constraints***.

Given the cost of coastal property, parcel sizes are often small and owners often build the largest building that will fit within the permissible development footprint. Buyers frequently fail to recognize that siting decisions in these cases have effectively been made at the time the land was platted or subdivided, and that shoreline erosion can render these parcels unsuitable for long-term occupation.

In some instances, however, parcel size may be large enough to allow a hazard-resistant coastal building to be sited and constructed, but an ***owner's desire*** to push the building as close to the shoreline as possible increases the likelihood that the building will be damaged or destroyed in the future.

Coastal Setback Lines – What Protection Do They Provide?

Many states require new buildings to be sited at or landward of coastal construction setback lines, which are usually based on ***long-term, average annual erosion rates***. For example, a typical minimum 50-year setback line with an erosion rate of 2.5 feet/year would require a setback of 125 feet, typically measured from a reference feature such as the dune crest, vegetation line, or high-water line.

Building at the 125-foot setback (in this case) does ***not*** mean that a building will be "safe" from erosion for 50 years.

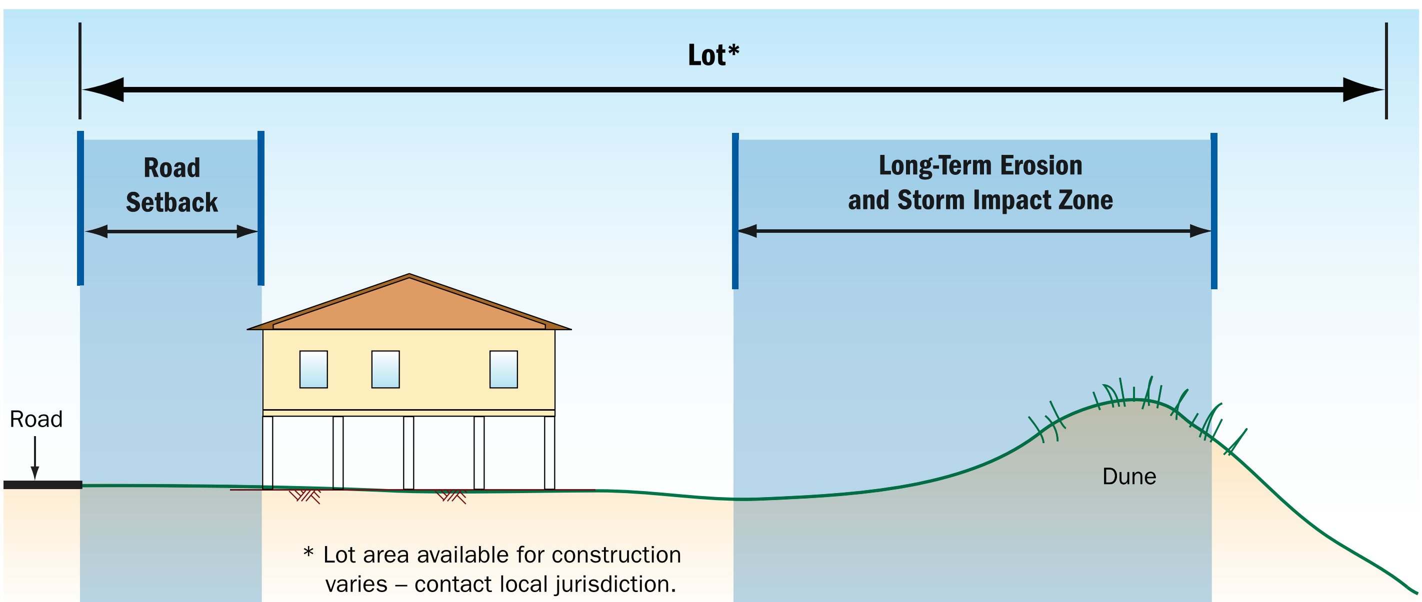
- Storms can cause short-term erosion that far exceeds setbacks based on long-term averages.
- Erosion rates vary over time, and erosion could surpass the setback distance in just a few years' time. The rate variability must also be known to determine the probability of undermining over a given time period.

What Should Builders, Designers, and Owners Do?

- Consult local and state agencies, universities, and consultants for detailed, site-specific erosion and hazard information.
- Look for historical information on erosion and storm effects. How have older buildings in the area fared over time? Use the experience of others to guide siting decisions.
- Determine the owner's risk tolerance, and reject parcels or building siting decisions that exceed the acceptable level of risk.

Common Siting Problems

- Building on a ***small lot between a road and an eroding shoreline*** is a recipe for trouble.
- ***Odd-shaped lots*** that force buildings close to the shoreline increase the vulnerability of the buildings.
- Siting a building near the ***edge of a bluff*** increases the likelihood of building loss, because of both bluff erosion and changes in bluff stability resulting from development activities (e.g., clearing vegetation, building construction, landscaping, changes in surface drainage and groundwater flow patterns).
- Siting near a ***tidal inlet*** with a dynamic shoreline can result in the building being exposed to increasing flood and erosion hazards over time.
- Siting a building ***immediately behind an erosion control structure*** may lead to building damage from wave overtopping and may limit the owner's ability to repair or maintain the erosion control structure.
- Siting a new building ***within the footprint*** of a pre-existing building does not guarantee that the location is a good one.



Recommended building location on a coastal lot.

Siting should consider both long-term erosion and storm impacts.
Siting should consider site-specific experience, wherever available.

Coastal Building Materials

HOME BUILDER'S GUIDE TO COASTAL CONSTRUCTION FEMA 499/August 2005 Technical Fact Sheet No. 8

Purpose: To provide guidance on the selection of building materials used for coastal construction.

Key Issues

- The ***durability*** of a coastal home relies on the types of materials used to construct it. For more details, see the U.S. Department of Housing and Urban Development (HUD) report *Durability by Design, A Guide for Residential Builders and Designers*, available on the HUD User website at http://www.huduser.org/publications/destech/durdesign.html.
- Materials and construction methods should be resistant to ***flood and wind damage, driving rain, corrosion, moisture, and decay***.
- All coastal buildings will require ***maintenance and repairs*** (more so than inland construction) — use proper materials and methods for repairs, additions, and other work following initial construction (see Fact Sheet No. 30).

> Section 60.3(a)(ii) of the National Flood Insurance Program (NFIP) regulations requires that all new construction and substantial improvements in floodprone areas be constructed with materials below the Base Flood Elevation (BFE) that are resistant to flood damage. (See Fact Sheet No. 30 for a definition of "substantial improvement.")

Flood-Resistant Materials

Flooding accounts for a large percentage of the damage caused by a coastal storm. Building materials exposed to flooding must be resilient enough to sustain a certain amount of water exposure in order to avoid the need for complete replacement after the flood.

FEMA defines a flood-resistant material as *any building material capable of withstanding direct and prolonged contact (i.e., at least 72 hours) with floodwaters without sustaining significant damage (i.e., requires more than cosmetic repair).*

The following are examples of flood-resistant materials:

- **Lumber:** pressure-treated or naturally decay-resistant, including redwood, cedar, some oaks, and bald cypress
- **Concrete:** a sound, durable mix, and when exposed to saltwater or salt spray, made with a sulfate-resisting cement, with a 28-day compressive strength of

Select building materials that can endure periodic flooding.

5,000 psi minimum and a water-cement ratio not higher than 0.40 – consult ACI 318-02, *Building Code Requirements for Structural Concrete and Commentary*, by the American Concrete Institute International

- **Masonry:** reinforced and fully grouted
- **Structural Steel:** coated to resist corrosion
- **Insulation:** plastics, synthetics, and closed-cell foam, or other types approved by local building officials

This table lists examples of flood-resistant materials used in coastal homes.

Location of Material Use	Name of Material
Piles and posts	Round, tapered wood piles preservative-treated for ground contact, at a minimum; square-section piles or wood posts preservative-treated for marine use
Piers	Reinforced concrete or concrete masonry units (CMU) (see “Flood-Resistant Materials” above and Fact Sheet No. 14)
Foundation walls	Reinforced concrete or CMU, or wood that is preservative-treated for foundation or marine use (see Fact Sheet No. 15)
Beams	Solid sawn timbers and glue-laminated products, either naturally decay-resistant or preservative-treated for aboveground exposure; built-up members preservative-treated for ground contact
Decking	Preservative-treated or naturally decay-resistant wood, or composite wood members (e.g., manufactured of recycled sawdust and plastic)
Framing	Sawn wood or manufactured lumber (preservative-treated or naturally resistant to decay if in close proximity to the ground)
Exterior sheathing	High-capacity shearwall sheathing rated “Exterior”
Subflooring	Plywood or oriented strand board (OSB) rated “Exposure 1,” or rated “Exterior” if left permanently exposed (e.g., exposed underside of elevated house on open foundation)
Siding	Vinyl or naturally decay-resistant wood (see Fact Sheet No. 25)
Flooring	Latex or bituminous cement formed-in-place, clay, concrete tile, pre-cast concrete, epoxy formed-in-place, mastic flooring, polyurethane formed-in-place, rubber sheets, rubber tiles with chemical-set adhesives, silicone floor formed-in-place, terrazzo, vinyl sheet-goods, vinyl tile with chemical-set adhesives, pressure-treated lumber or naturally decay-resistant lumber
Walls and ceilings	Cement board, brick, metal, cast stone in waterproof mortar, slate, porcelain, glass, glass block, clay tile, concrete, CMU, pressure-treated wood, naturally decay-resistant wood, marine grade plywood or pressure-treated plywood
Doors	Hollow metal
Insulation	Foam or closed-cell
Trim	Natural or artificial stone, steel, or rubber

Many coastal jurisdictions make available a list of approved materials that can be used in coastal environments. Check for locally approved flood-resistant materials. Include all proposed construction and materials in approved plans. For guidance on testing specific materials, refer to *NES Evaluation Protocol for Determination of Flood-Resistant Properties of Building Elements* (NES, Inc. – http://www.nateval.org).

Wind-Resistant Materials

Homes in many coastal areas are often exposed to winds in excess of 90 mph (3-second peak gust). Choose building materials (e.g., roof shingles, siding, windows, doors, fasteners, and framing members) that are designed for use in high-wind areas.

Examples:

- shingles rated for high winds (see Fact Sheet No. 20)
- double-hemmed vinyl siding (see Fact Sheet No. 25)
- deformed-shank nails for sheathing attachments (see Fact Sheet No. 18)
- wind-resistant glazing (see Fact Sheet No. 22)
- reinforced garage doors
- tie-down connectors used throughout structure (from roof framing to foundation — see Fact Sheet Nos. 10 and 17)
- wider framing members (2x6 instead of 2x4)

Remember: A wind-resistant material is only as good as its connection. Always use recommended fasteners and connection methods.

Select building materials that are suitable for the expected wind forces.

Corrosion and Decay Resistance

Coastal environments are conducive to metal corrosion and moisture- and termite-related decay of other building materials. Metal corrosion is most pronounced on coastal homes (within 3,000 feet of the ocean), but moisture- and termite-related decay are prevalent throughout coastal areas.

Corrosion-Resistant Metals

Most jurisdictions require metal building hardware to be hot-dipped galvanized or stainless steel. Some local codes require protective coatings that are thicker than “off-the-shelf” products typically have. For example, a G90 zinc coating (0.75 mil on each face) may be required, which is thicker than the common G60 (0.5 mil on each face) coating.

Recommendations

- Use hot-dipped galvanized or stainless steel hardware. Reinforcing steel should be protected from corrosion by sound materials (masonry, mortar, grout, concrete) and good workmanship (see Fact Sheet No. 16). Use

The term "corrosion-resistant" is widely used but, by itself, is of little help to those specifying or evaluating materials for use in a coastal home. Every material resists corrosion to some extent, or conversely, every material corrodes.

The real issue is *how long will a given material serve its intended purpose at a given home?* The answer depends on the following:

- the material
- where it is used in the home
- whether installation techniques (e.g., drilling, cutting, bending) will compromise its resistance
- its degree of exposure to salt air, moisture, and corrosive agents
- whether maintenance required of the homeowner is performed

The bottom line: **do not blindly specify or accept a product just because it is labeled *corrosion-resistant***. Evaluate the nature of the material, its coating type and thickness (if applicable), and its performance in similar environments before determining whether it is suitable for a particular application.

For guidance on the selection of metal hardware for use in coastal environments, consult an engineer with experience in corrosion protection. For more information about corrosion in coastal environments, see FEMA Technical Bulletin 8-96, *Corrosion Protection for Metal Connectors in Coastal Areas for Structures Located in Special Flood Hazard Areas* (see the Additional Resources section of this fact sheet).

galvanized or epoxy-coated reinforcing steel in situations where the potential for corrosion is high (see Fact Sheet No. 14).

- Avoid joining dissimilar metals, especially those with high galvanic potential (e.g., copper and steel).
- Some wood preservatives should not be used in direct contact with galvanized metal. Verify that wood treatment is suitable for use with galvanized metal, or use stainless steel.
- Metal-plate-connected trusses should not be exposed to the elements. Truss joints near vent openings are more susceptible to corrosion and may require increased corrosion protection.

Metals corrode at a much faster rate near the ocean. Always use well-protected hardware, such as this connector with thick galvanizing. (For information about pile-to-beam connections, see Fact Sheet No. 13).

Moisture Resistance

Materials resistant to moisture can greatly reduce maintenance and extend the life of a coastal home (however, by themselves, such materials cannot prevent all moisture damage. Proper design and installation of moisture barriers (see Fact Sheet No. 9) is also required).

Recommendations

- Control wood decay by separating wood from moisture, using preservative-treated wood, using naturally decay-resistant wood, and applying protective wood finishes.
- Use proper detailing of wood joints and construction to eliminate standing water and reduce moisture absorption by the wood (e.g., avoid exposure of end grain cuts, which absorb moisture up to 30 times faster than the sides of a wood member).
- Do not use untreated wood in ground contact or high-moisture situations. Do not use untreated wood in direct contact with concrete.
- Field-treat any cuts or drill holes that offer paths for moisture to enter wood members.
- For structural uses, employ concrete that is sound, dense, and durable; control cracks with welded wire fabric and/or reinforcing, as appropriate.
- Use masonry, mortar, and grout that conform with the latest building codes.

Termite Resistance

Termite damage to wood construction occurs in many coastal areas (attack is most frequent and severe along the southeastern Atlantic and Gulf of Mexico shorelines, in California, and in Hawaii and other tropical areas). Termites can be controlled by soil treatment, termite shields, and the use of termite-resistant materials.

Wood decay at the base of a wood post supported by concrete.

Recommendations

- Incorporate termite control methods into design in conformance with requirements of the authority having jurisdiction.
- Where a masonry foundation is used and anchorage to the foundation is required for uplift resistance, the upper block cores must usually be completely filled with grout, which may eliminate the requirement for termite shields (see Fact Sheet No. 14).
- Use preservative-treated wood for foundations, sills, above-foundation elements, and floor framing.

Additional Resources

FEMA. NFIP Technical Bulletin 2-93, *Flood-Resistant Materials Requirements for Buildings Located in Special Flood Hazard Areas*. (http://www.fema.gov/fima/techbul.shtm)

FEMA. NFIP Technical Bulletin 8-96, *Corrosion Protection for Metal Connectors in Coastal Areas for Structures Located in Special Flood Hazard Areas*. (http://www.fema.gov/fima/techbul.shtm)

American Concrete Institute International. (http://www.aci-int.org/general/home.asp)

American Wood-Preservers' Association. (http://www.awpa.com)

International Code Council Evaluation Service, Inc. Protocol for Testing the Flood Resistance of Materials. (http://www.icc-es.org/index.shtml)

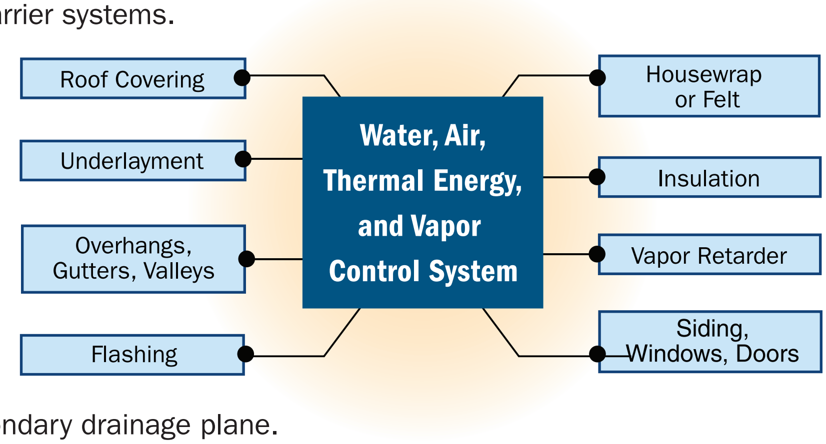
Moisture Barrier Systems

HOME BUILDER'S GUIDE TO COASTAL CONSTRUCTION FEMA 499/August 2005 *Technical Fact Sheet No. 9*

Purpose: To describe the moisture barrier system, explain how typical wall moisture barriers work, and identify common problems associated with moisture barrier systems.

Key Issues

- A successful moisture barrier system will limit water infiltration into unwanted areas and allow drainage and drying of wetted building materials.
- Most moisture barrier systems for walls (e.g., siding and brick veneer) are "redundant" systems, which require at least two drainage planes (see page 2).
- Housewrap or building paper (asphalt-saturated felt) will provide an adequate secondary drainage plane.
- Proper flashing and lapping of housewrap and building paper are critical to a successful moisture barrier system.
- Sealant should never be substituted for proper layering.



The purpose of the building envelope is to control the movement of water, air, thermal energy, and water vapor. The goal is to prevent water infiltration into the interior, limit long-term wetting of the building components, and control air and vapor movement through the envelope.

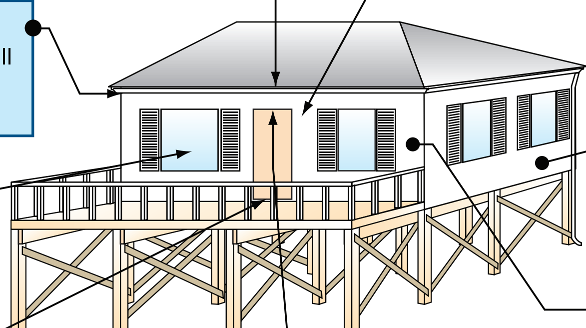
Locations and Causes of Common Water Intrusion Problems

Poor water shedding from roof – Use moderate overhangs of 12-16 inches, drip edges, and a gutter system.

Improper flashing and damaged housewrap or building paper at wall penetrations – Follow window flashing techniques at every wall penetration.

Roof/wall intersection – Install effective kick-out flashing at roof-to-wall intersections, diverter flashing around trapped-valleys, and rake flashing.

Damaged or improperly installed siding – Follow manufacturer's guidelines. Prime all surfaces of wood siding (back-priming) before applying top coats.



Flashing around windows – Proper lapping is key to leak prevention. Do not depend on sealant for sustained protection. Protect flashings with overlapping wrap.

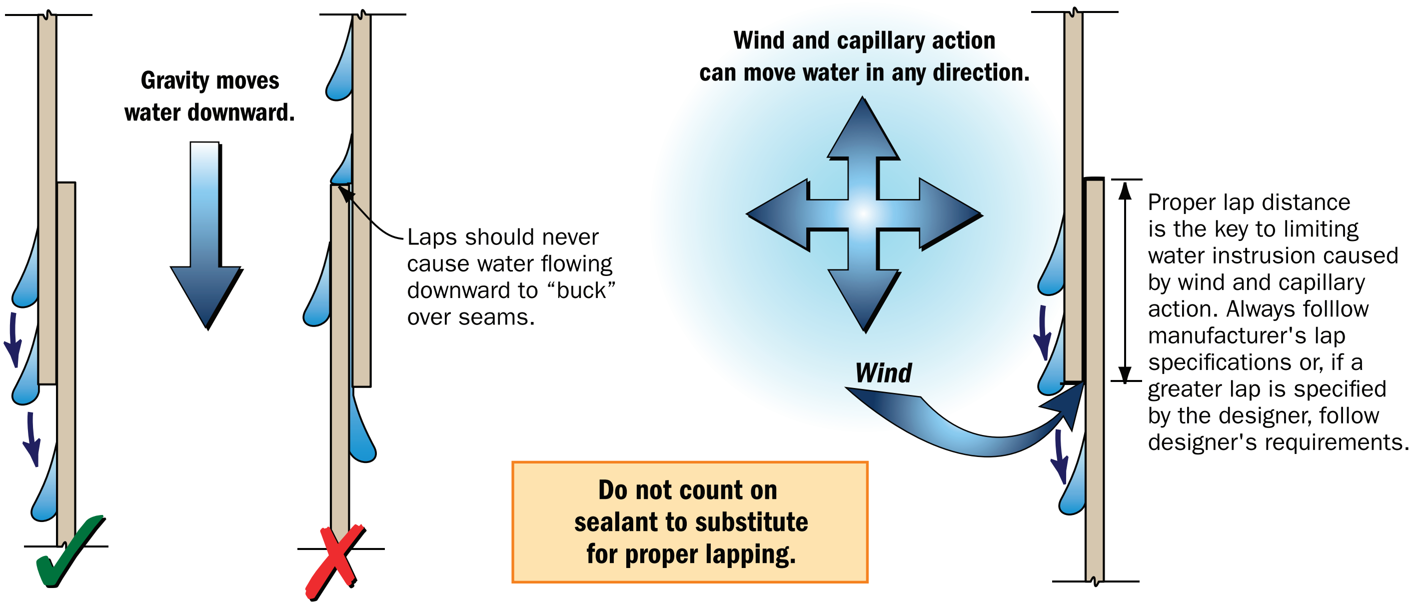
No housewrap or building paper used, or improperly lapped – Virtually all siding leaks. Use housewrap or building paper to shed water. Properly lap material so water flows without bucking seams. Water must be allowed to drain out of walls.

Improper flashing over doors – Proper lapping is key to leak prevention. Do not depend on sealant for sustained protection. Protect flashings with overlapping housewrap or building paper.

Door sills – Use pan flashing to prevent damage to subfloor.

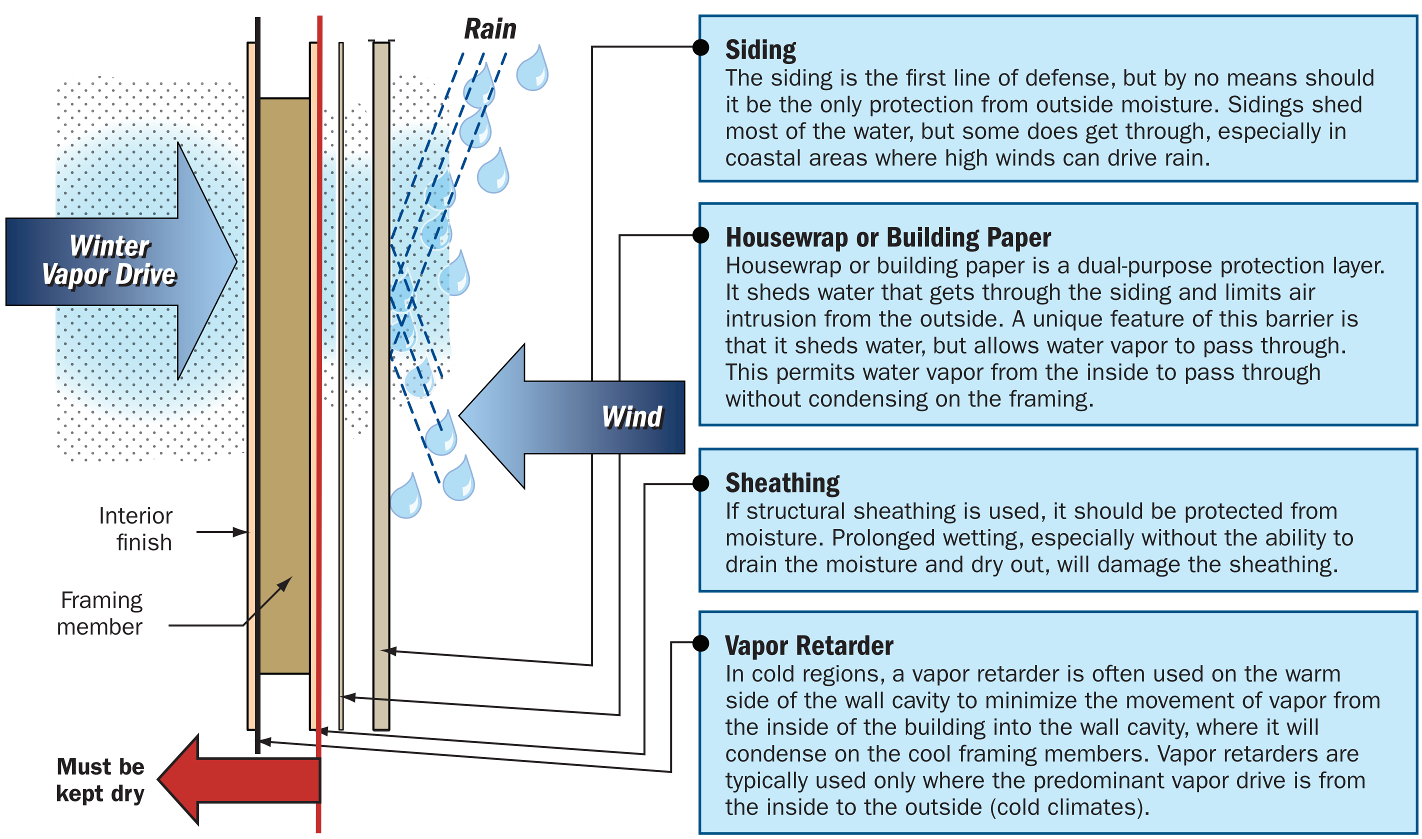
The location of water entry is often difficult to see, and the damage to substrate and structural members behind the exterior wall cladding frequently cannot be detected by visual inspection.

Proper Lapping Is the Key...



Proper lapping of moisture barrier materials is the key to preventing water intrusion. Most water intrusion problems are related to the improper lapping of materials. Usually, flashing details around doors, windows, and penetrations are to blame. If the flashing details are right and the housewrap or building paper is properly installed, most moisture problems will be prevented. Capillary suction is a strong force and will move water in ***any*** direction. Even under conditions of light or no wind pressure, water can be wicked through seams, cracks, and joints upward behind the overlaps of horizontal siding. Proper lap distances and sealant help prevent water intrusion caused by wicking action.

How a Redundant Moisture Barrier Works



Foundations in Coastal Areas

Purpose: To describe foundation types suitable for coastal environments.

Key Issues

- Foundations in coastal areas must elevate buildings above the Base Flood Elevation (BFE), while withstanding flood forces, high winds, scour and erosion, and floating debris.
- Foundations used for inland construction are generally not suitable for coastal construction.
- Deeply embedded pile or column foundations are required for many coastal areas; in other coastal areas, they are recommended – instead of solid wall, crawlspace, slab, or other shallow foundations that can be undermined easily. ("Deeply embedded" means sufficient penetration into the ground to accommodate storm-induced scour and erosion and to resist all design vertical and lateral loads without structural damage.)
- Areas below elevated buildings in V zones must be "free of obstructions" that can transfer flood loads to the foundation and building (see Fact Sheet No. 27).

Storm surge and waves overtopping a barrier island during Hurricane Frederic.

Foundation Design Criteria

All foundations for buildings in flood hazard areas must be constructed with flood-damage-resistant materials (see Fact Sheet No. 8) and must do two things in addition to meeting the requirements for conventional construction: (1) elevate the building above the BFE, and (2) prevent flotation, collapse, and lateral movement of the building, resulting from loads and conditions during the design flood event (in coastal areas, these loads and conditions include inundation by fast-moving water, breaking waves, floating debris, erosion, and high winds).

Because the most hazardous coastal areas are subject to erosion and extreme flood loads, ***the only practical way to perform these two functions is to elevate a building on a deeply embedded and "open" (i.e., pile or column) foundation***. This approach resists storm-induced erosion and scour, and it minimizes the foundation surface area subject to lateral flood loads – it is required by the National Flood Insurance Program (NFIP) in V zones (even when the ground elevation lies above the BFE) and is recommended for coastal A zones. However, even a deeply embedded open pile foundation will not prevent eventual undermining and loss due to long-term erosion (see Fact Sheet No. 7).

Performance of Various Foundation Types in Coastal Areas

There are many ways to elevate buildings above the BFE: fill, slab-on-grade, crawlspace, stemwall, solid wall, pier (column), and pile. Not all of these are suitable for coastal areas. In fact, several of them are prohibited in V zones and are not recommended by the *Home Builder's Guide to Coastal Construction* for A zones in coastal areas.

Fill – Because fill is susceptible to erosion, it is ***prohibited as a means of providing structural support to buildings in V zones*** and must ***not*** be used as a means of elevating buildings in ***any other coastal area subject to erosion, waves, or fast-moving water***.

Slab-on-Grade – Slab-on-grade foundations are also susceptible to erosion and are therefore ***prohibited in V zones***. They also are ***not recommended*** for ***A zones in coastal areas***. (Note that parking slabs are often permitted below elevated buildings, but are themselves susceptible to undermining and collapse.)

Building failure caused by undermining of slab-on-grade foundation during Hurricane Fran.

Crawlspace – Crawlspace foundations are ***prohibited in V zones*** and are ***not recommended for A zones in coastal areas***. They are susceptible to erosion when the footing depth is inadequate to prevent undermining. Crawlspace walls are also vulnerable to wave attack. Where used, crawlspace foundations must be equipped with ***flood openings***; grade elevations should be such that water is not trapped in the crawlspace (see Fact Sheet Nos. 15 and 27).

Failure of crawlspace foundation undermined by scour.

Stemwall – Stemwall foundations are similar to crawlspace foundations in construction, but the interior space that would otherwise form the crawlspace is often backfilled with gravel that supports a floor slab. Stemwall foundations have been observed to perform better during storms than many crawlspace and pier foundations. However, the building code may limit stemwall height to just a few feet. Flood openings are not required in a backfilled stemwall foundation. Stemwall foundations are ***prohibited in V zones*** but are ***recommended in A zones subject to limited wave action***, as long as embedment of the wall is sufficient to resist erosion and scour.

Solid Foundation Walls – Solid foundation walls are ***prohibited by the NFIP in V zones*** and are not recommended for ***A zones subject to breaking waves or other large flood forces*** – the walls act as an obstruction to flood flow. Like crawlspace walls, they are susceptible to erosion when the footing depth is inadequate to prevent undermining. Solid walls have been used in some regions to elevate buildings one story in height. Where used, the walls must allow floodwaters to pass between or through the walls (using flood openings). See Fact Sheet Nos. 15 and 27.

Pier (column) failures: footings undermined and columns separated from footings.

Pier (column) – Pier foundations are ***recommended for A zones where erosion potential and flood forces are small***. This open foundation is commonly constructed with reinforced and grouted masonry units atop a concrete footing. Shallow pier foundations are extremely vulnerable to erosion and overturning if the footing depth and size are inadequate. They are also vulnerable to breakage if materials and workmanship are not first rate. Fact Sheet No. 14 provides guidance on how to determine whether pier foundations are appropriate, and how to design and construct them.

Pile – Pile foundations are ***recommended for V zones and many A zones in coastal areas***. These open foundations are constructed with square or round, wood, concrete, or steel piles, driven or jetted into the ground, or set into augered holes. Critical aspects of a pile foundation include the pile size, installation method and embedment depth, bracing, and the connections to the elevated structure (see Fact Sheet Nos. 12 and 13). Pile foundations with ***inadequate embedment*** will lead to ***building collapse. Inadequately sized*** piles are ***vulnerable to breakage by waves and debris***.

Pile failures led to collapse of floor of elevated building.

Foundations for High-Elevation Coastal Areas

Foundation design is problematic in bluff areas that are vulnerable to coastal erosion but outside mapped flood hazard areas. Although NFIP requirements may not apply, the threat of undermining is not diminished.

Moreover, both shallow and deep foundations will fail in such situations. Long-term solutions to the problem may involve better siting (see Fact Sheet No. 7), moving the building when it is threatened, or (where permitted and economically feasible) controlling erosion through slope stabilization and structural protection.

Insufficient pile embedment and failure of connections at tops of piles allowed elevated building to be floated off its foundation.

House undermined by bluff erosion. Photograph by Lesley Ewing. Courtesy of California Coastal Commission.

Foundations in V Zones With Ground Elevations Above the BFE

In some instances, coastal areas will be mapped on an NFIP Flood Insurance Rate Map (FIRM) as V zones, but will have dunes or bluffs with ground elevations above the BFE shown on the FIRM. ***Deeply embedded pile or column foundations are still required in these areas, and solid or shallow foundations are still prohibited***. The presence of a V-zone designation in these instances indicates that the dune or bluff is expected to erode during the base flood event and that V-zone wave conditions are expected after the erosion occurs. The presence of ground elevations above the BFE in a V zone should not be taken to mean that the area is free from Base Flood and erosion effects.

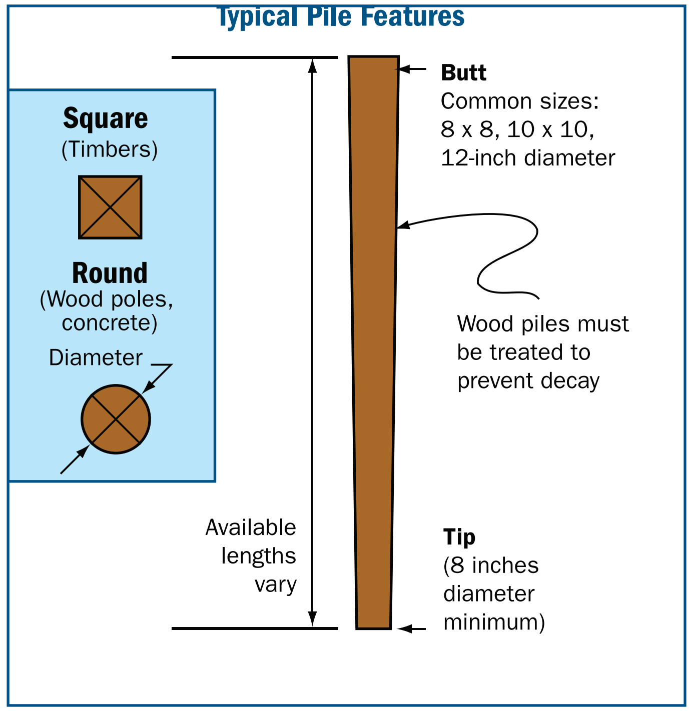
Pile Installation

HOME BUILDER'S GUIDE TO COASTAL CONSTRUCTION FEMA 499/August 2005 *Technical Fact Sheet No. 12*

Purpose: To provide basic information about pile design and installation.

Key Issues

- Use a pile type that is appropriate for local conditions.
- Have piles designed by a foundation engineer for adequate layout, size, and length.
- Use installation methods that are appropriate for the conditions.
- Brace piles properly during construction.
- Make accurate field cuts, and treat all cuts and drilled holes to prevent decay.
- Have all pile-to-beam connections engineered, and use corrosion-resistant hardware. (See Fact Sheet No. 8.)

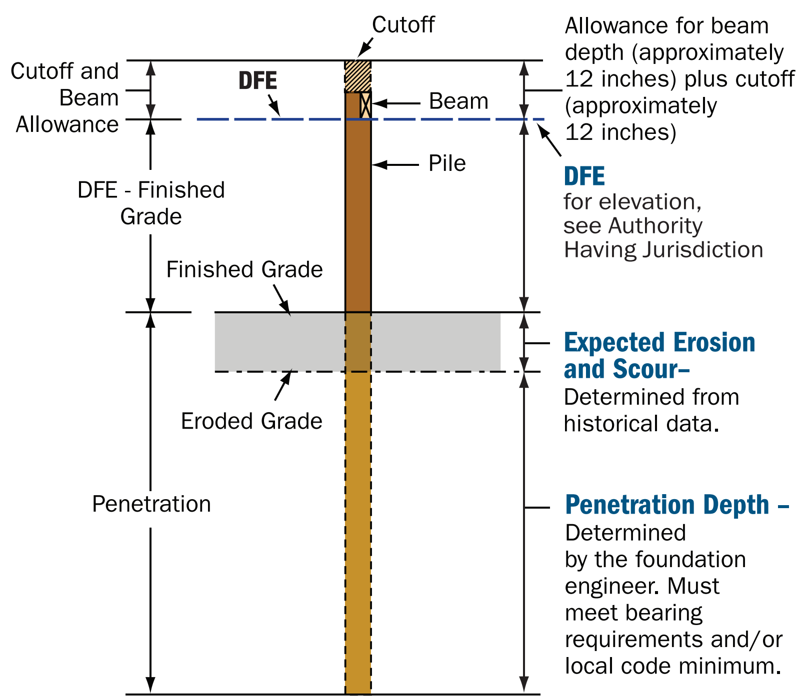


Pile Types

Treated wood piles are the most common type of pile used in coastal construction. They can be square or round in cross section. Wood piles are easily cut and adjusted in the field and are typically the most economical type. Concrete and steel can also be used but are less common. Concrete piles are more expensive, but they are stronger and more durable. Steel piles are rarely used, because of potential corrosion problems.

Pile Size and Length

Pile size and length are determined by the foundation engineer. Specified bearing and penetration requirements must be met. Piles should have no less than an 8-inch tip diameter; minimum timber size should be 8x8. The total length of the pile is based on code requirements, calculated penetration requirements, erosion potential, Design Flood Elevation (DFE), and allowance for cut-off and beam width (see figure at right).



Note: Misaligned piles lead to connection problems. See Fact Sheet No. 13 for information about making connections to misaligned piles.

Pile Layout

The pile layout is determined by the foundation engineer. Accurate placement and correction of misaligned piles is important. Pile placement should not result in more than 50 percent of the pile cross-section being cut for girder or other connections. Verify proper pile locations on drawings before construction and clarify any discrepancies. Layout can be done by a licensed design professional, a construction surveyor, the foundation contractor, or the builder. The layout process must always include establishing an elevation for the finished first floor. Construction of the first-floor platform should not begin until this elevation is established (see Fact Sheet No. 4).

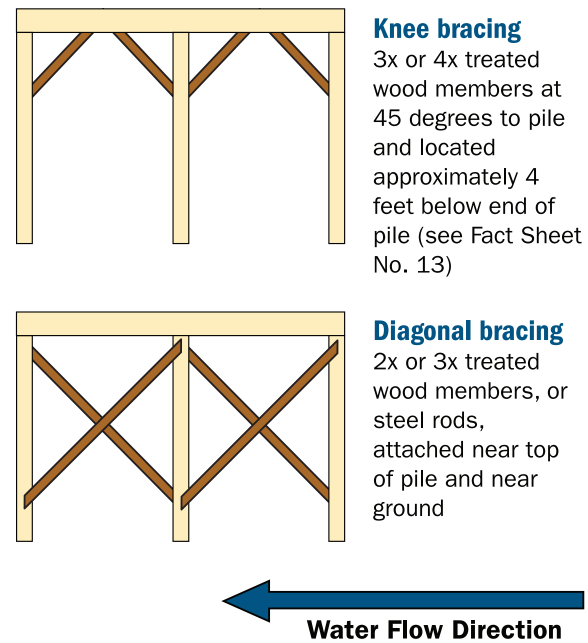
Installation Methods

Piles can be driven, augured, or jetted into place. The installation method will vary with soil conditions, bearing requirements, equipment available, and local practice. One common method is to initially jet the pile to a few feet short of required penetration, then complete the installation by driving with a drop hammer.

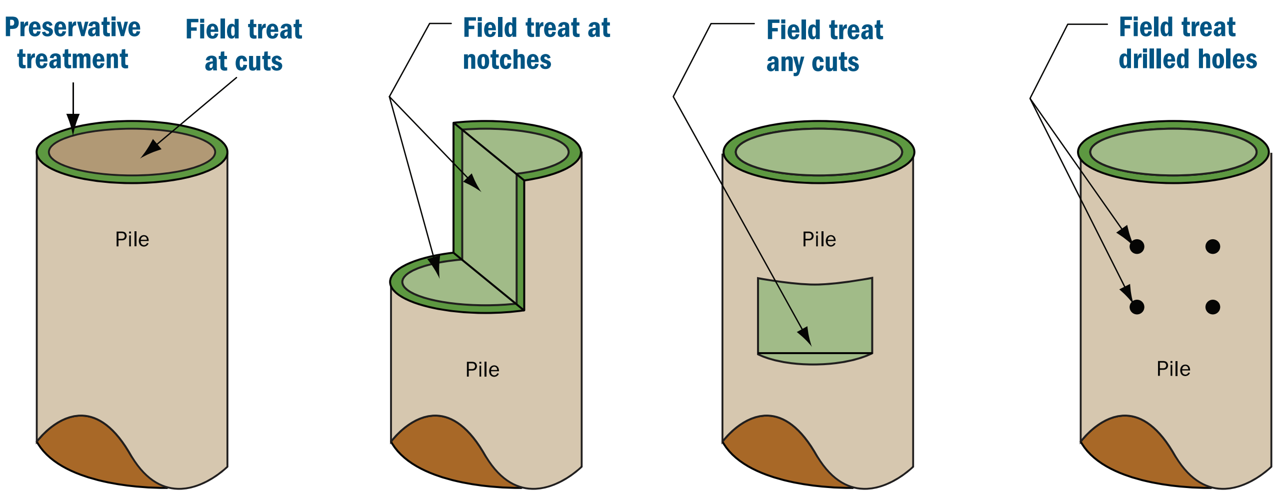
Pile Bracing

Pile bracing is determined by the foundation engineer. Common bracing methods include knee and diagonal bracing. Bracing is often oriented perpendicular to the shoreline so that it is not struck broadside by waves, debris, and velocity flow (see figure at right). Temporary bracing or jacking to align piles and hold true during construction is the responsibility of the contractor.

Pile Bracing Methods



> To avoid costly pile repairs or replacement, measure, locate, and double-check the required pile cutoff elevations before cutting off piles.



Field Cutting and Drilling

A chain saw is the common tool of choice for making cuts and notches in wood piles. After making cuts, exposed areas should be field-treated to prevent decay.

Connections

The connection of the pile to the structural members is one of the most critical connections in the structure. Always follow design specifications and use corrosion-resistant hardware (see Fact Sheet Nos. 8 and 13).

Verification of Pile Capacity

Generally, pile capacity for residential construction is not verified in the field. If a specified minimum pile penetration is provided, bearing is assumed to be acceptable for the local soil conditions. Subsurface soil conditions can vary from the typical assumed conditions, so verification of pile capacity may be prudent, particularly for expensive coastal homes. Various methods are available for predicting pile capacity. Consult a foundation engineer for the most appropriate method for the site.

Additional Resources

American Forest and Paper Association (AF&PA). *National Design Specification for Wood Construction*. (www.afandpa.org)

American Society for Standards and Testing (ASTM). *Standard Specification for Round Timber Piles*, ASTM D25. (www.astm.org)

American Wood-Preservers Association (AWPA). *All Timber Products – Preservative Treatment by Pressure Processes*, AWPA C1-00; *Lumber, Timber, Bridge Ties and Mine Ties – Preservative Treatment by Pressure Processes*, AWPA C2-01; *Piles – Preservative Treatment by Pressure Process*, AWPA C3-99; and others. (www.awpa.com)

Pile Buck, Inc. *Coastal Construction*. (www.pilebuck.com)

Wood-Pile-to-Beam Connections

HOME BUILDER'S GUIDE TO COASTAL CONSTRUCTION FEMA 499/August 2005 *Technical Fact Sheet No. 13*

Purpose: To illustrate typical wood-pile-to-beam connections, provide basic construction guidelines on various connection methods, and show pile bracing connection techniques.

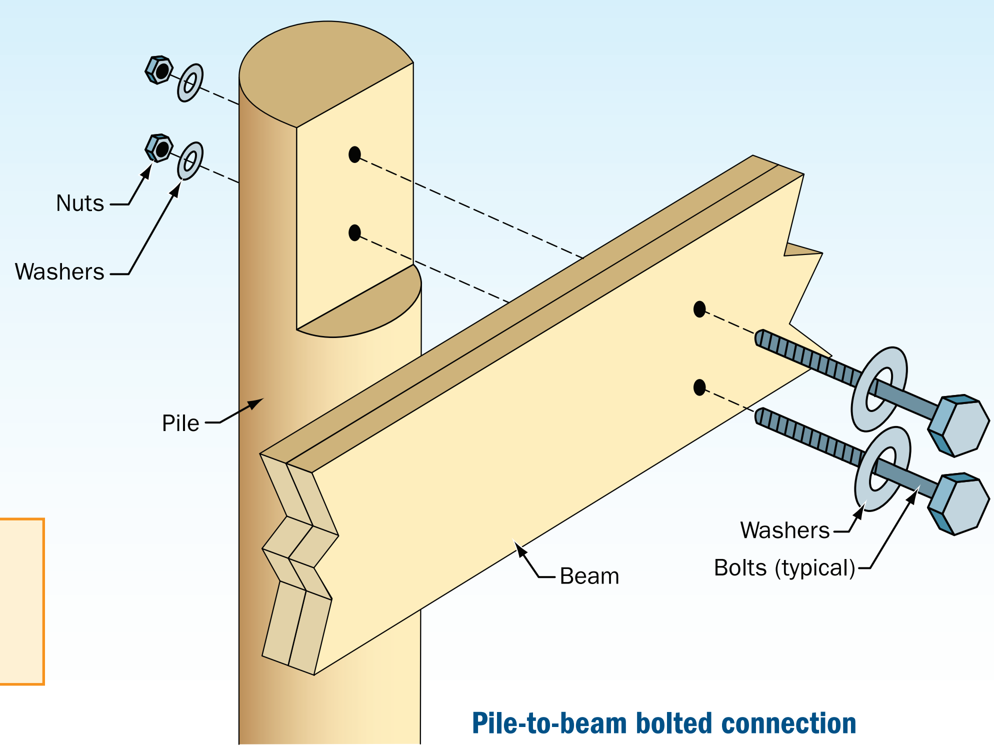
NOTE: The pile-to-beam connection is one of the most critical links in the structure. ***This connection must be designed by an engineer.*** See Fact Sheet No. 10 for "load path" information. The number of bolts and typical bolt placement dimensions shown are for illustrative purposes only. Connection designs are not limited to those shown here, and not all of the information to be considered in the designs is included in these illustrations. ***Final designs are the responsibility of the engineer.***

Key Issues

- Verify pile alignment and correct, if necessary, before making connections.
- Carefully cut piles to ensure required scarf depths.
- Limit cuts to no more than 50 percent of pile cross-section.
- Use corrosion-resistant hardware, such as hot-dipped galvanized or stainless steel (see Fact Sheet No. 8).
- Accurately locate and drill bolt holes.
- Field-treat all cuts and holes to prevent decay.
- Use sufficient pile and beam sizes to allow proper bolt edge distances.

Pile-to-beam connections must:

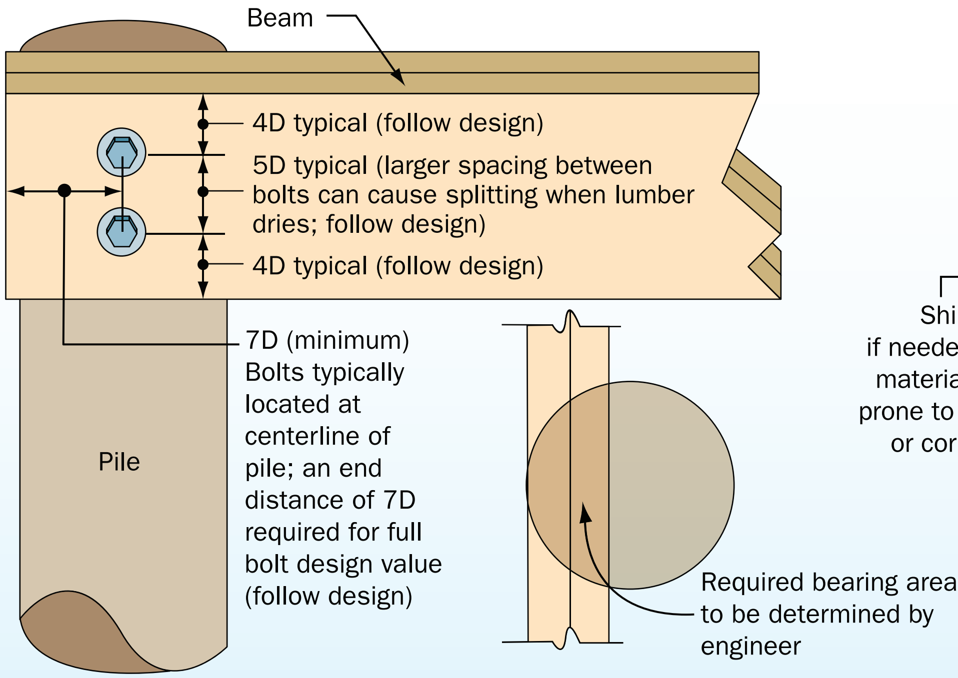
1. provide required ***bearing*** area for beam to rest on pile
2. provide required ***uplift*** (tension) resistance
3. maintain beam in an ***upright*** position
4. be capable of resisting ***lateral*** loads (wind and seismic)
5. be constructed with ***durable*** connectors and fasteners

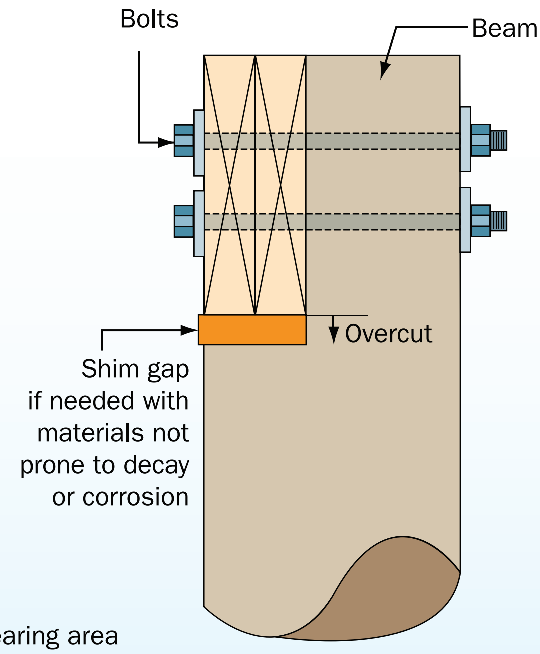


Pile-to-beam bolted connection

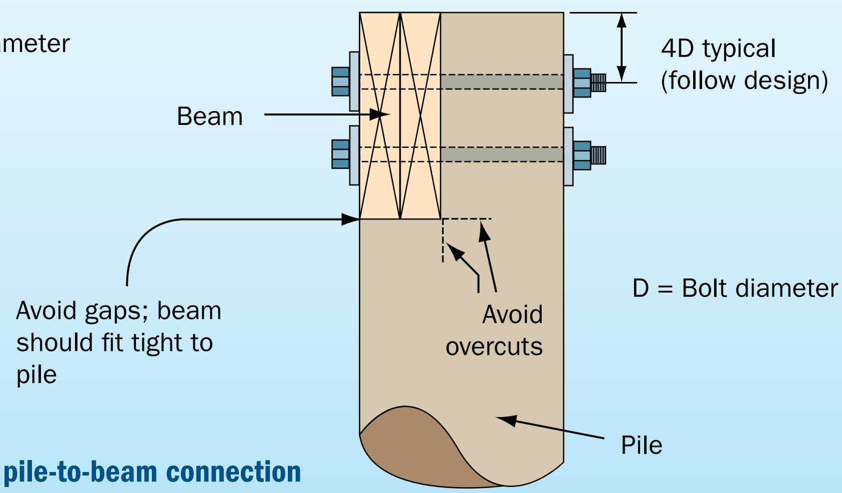
Note: Pile-to-beam connections must be designed by an engineer.

Bolt end and edge distance on beam





Connection to overcut pile – shim used to provide adequate bearing



Proper pile-to-beam connection

Note: Pile-to-beam connections must be designed by an engineer.

Problem: Misaligned piles – some piles are shifted in or out from their intended (design) locations.

Possible Solutions (see drawings on page 3 and details on page 4):

Option 1 (see page 3) – beam cannot be shifted

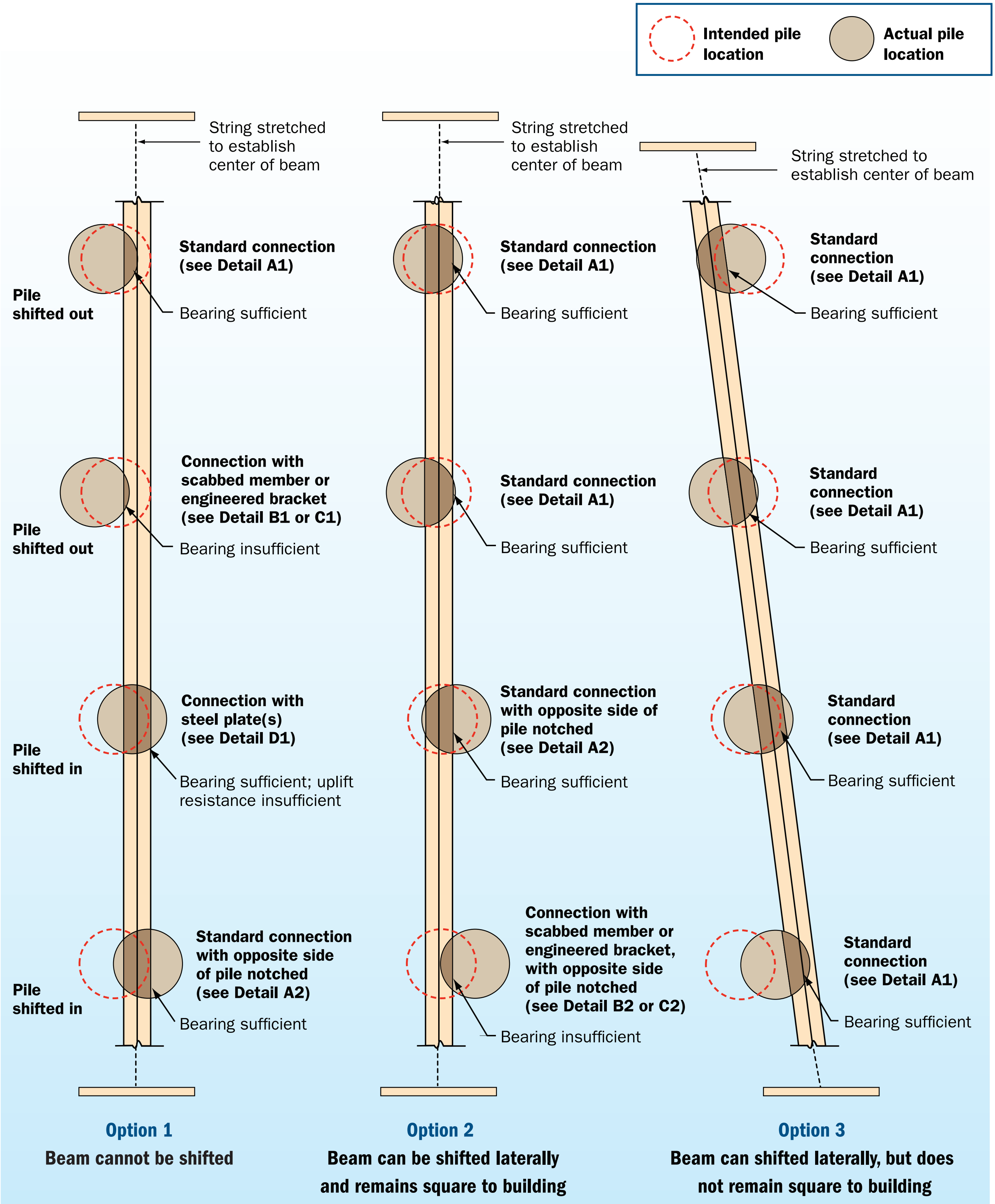
Option 2 (see page 3) – beam can be shifted laterally and remains square to building

Option 3 (see page 3) – beam can be shifted laterally, but does not remain square to building

Option 4 (not shown) – beam cannot be shifted, and connections shown in this fact sheet cannot be made; install and connect sister piles; ***an engineer must be consulted for this option***

Option 5 (not shown) – beam cannot be shifted, and connections shown in this fact sheet cannot be made; remove and reinstall piles, as necessary

Connections to misaligned piles

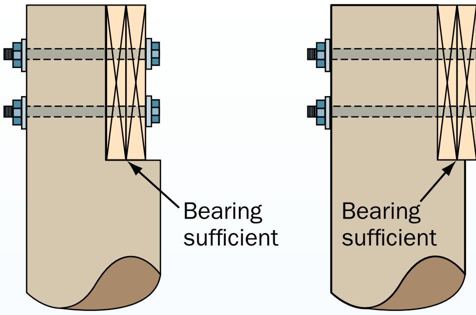


Note: Pile-to-beam connections must be designed by an engineer.

Connections to misaligned piles (see drawings on page 3 and details below)

1. The ability to construct the pile-to-beam connections designed by the engineer is directly dependent on the accuracy of pile installation and alignment.
2. Misaligned piles will require the contractor to modify pile-to-beam connections in the field.
3. Badly misaligned piles will require removal and reinstallation, sister piles, or special connections, all to be determined by the engineer.

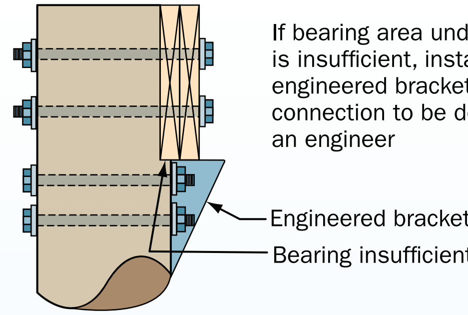
Detail A1 **Standard connection**



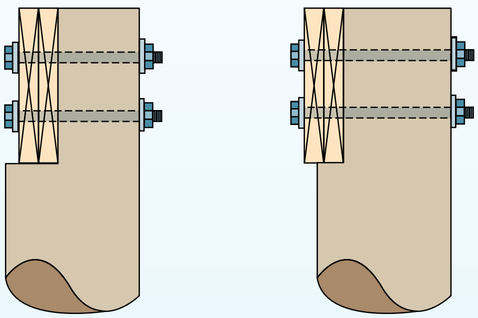
If bearing area under beam is sufficient, a standard bolted connection can be used; if bearing area is insufficient, install scabbed member (Detail B1/B2) or engineered bracket Detail (C1/C2)

Detail C1 **Insufficient bearing – engineered bracket for bearing**

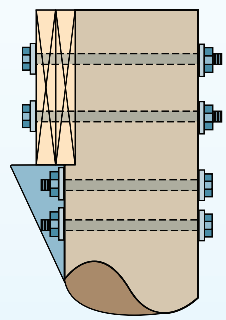
If bearing area under beam is insufficient, install engineered bracket; connection to be designed by an engineer



Detail A2 **Standard connection with pile notched on opposite side to avoid overnotching**

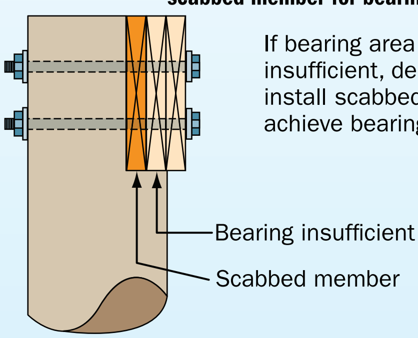


Detail C2 **Engineered bracket with pile notched on opposite side to avoid overnotching**



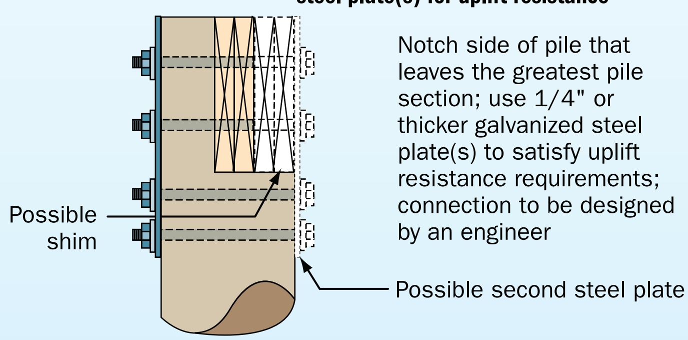
Detail B1 **Insufficient bearing – scabbed member for bearing**

If bearing area under beam is insufficient, deepen notch and install scabbed member to achieve bearing; do not overnotch

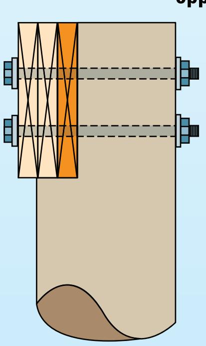


Detail D1 **Insufficient uplift capacity – steel plate(s) for uplift resistance**

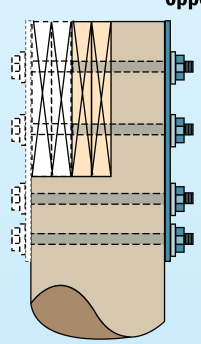
Notch side of pile that leaves the greatest pile section; use 1/4" or thicker galvanized steel plate(s) to satisfy uplift resistance requirements; connection to be designed by an engineer



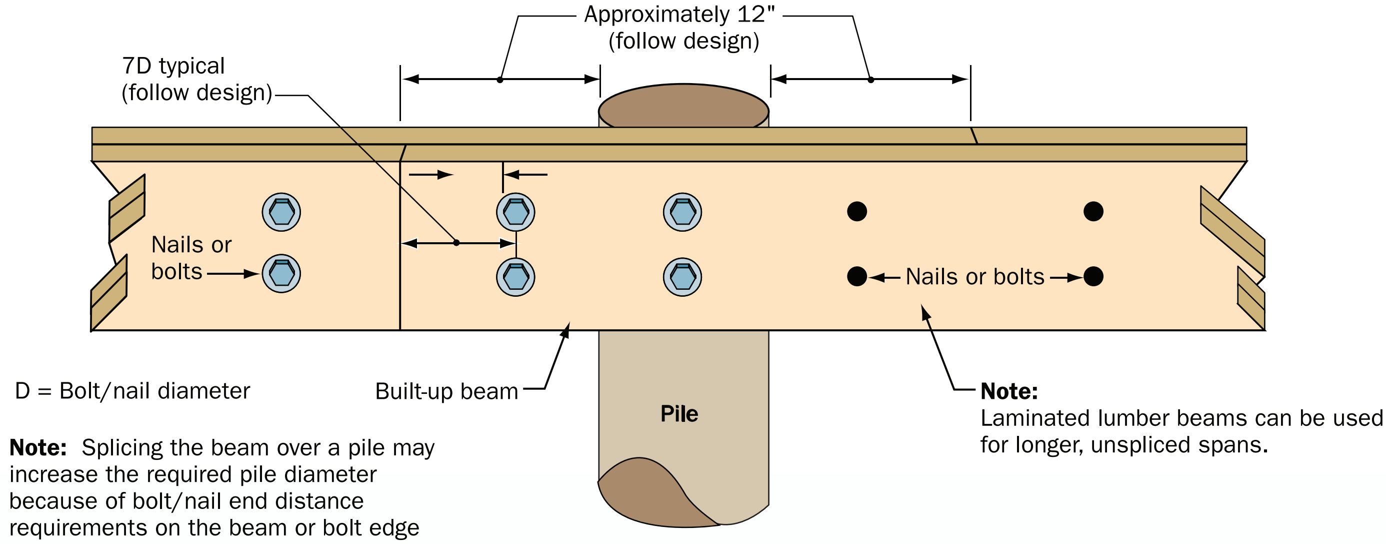
Detail B2 **Scabbed member with pile notched on opposite side to avoid overnotching**



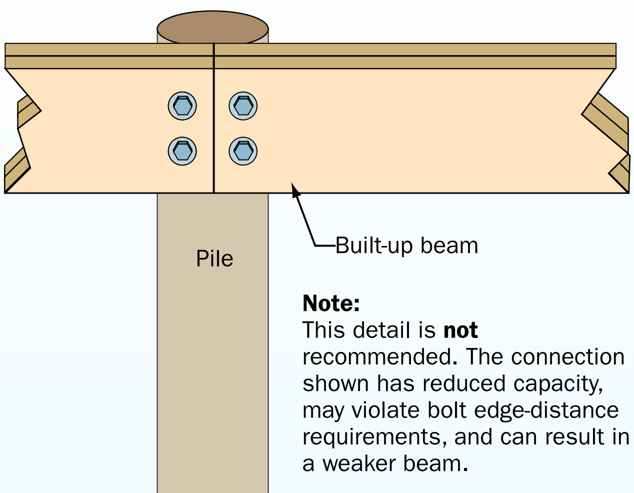
Detail D2 **Steel plate(s) with pile notched on opposite side to avoid overnotching**



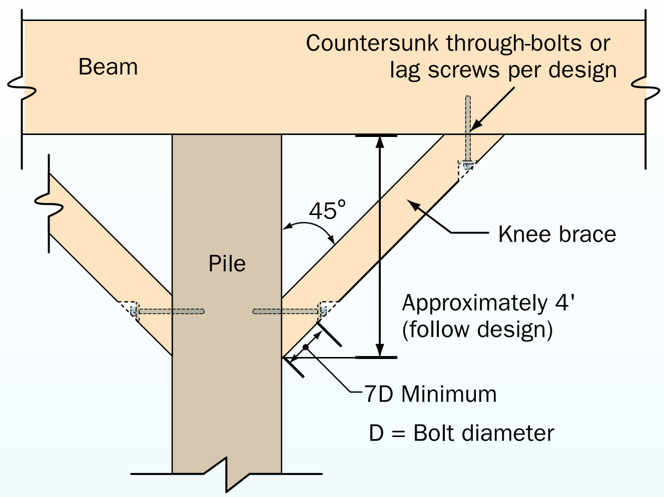
Note: Pile-to-beam connections must be designed by an engineer.



Lapped splice (built-up beam)

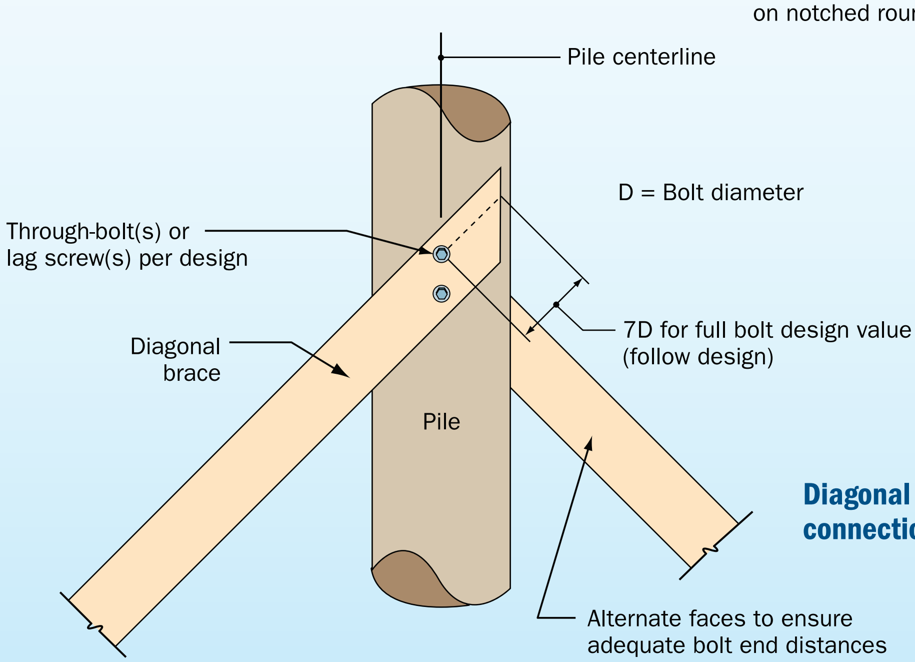


Beam bolted at pile (not recommended)



Knee brace connection on square pile*

*Knee braces of this type can also be used on notched round piles.



Diagonal brace connections on round pile

Note: Pile-to-beam connections must be designed by an engineer.

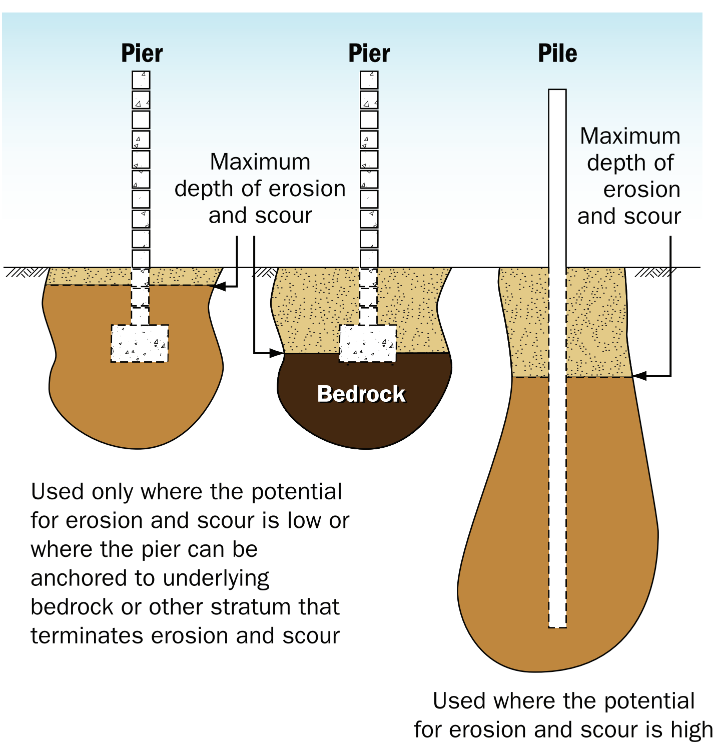
Reinforced Masonry Pier Construction

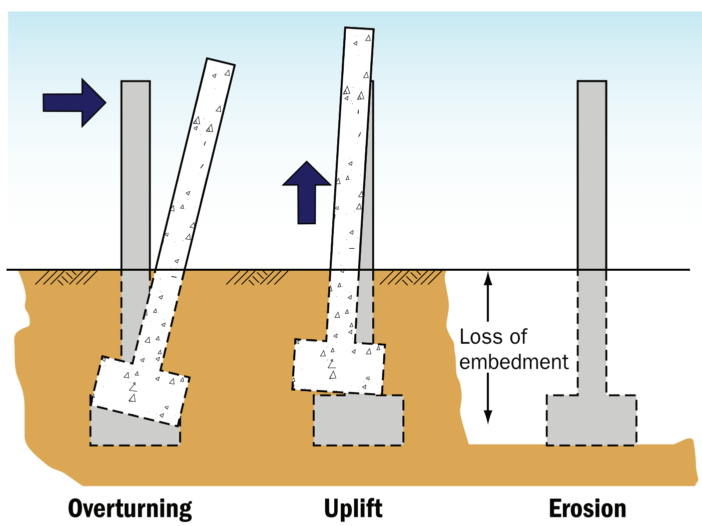
Purpose: To provide an alternative to piles in V zones and A zones in coastal areas where soil properties preclude pile installation, yet the need for an "open foundation system" still exists. Examples of appropriate conditions for the use of piers are where rock is at or near the surface or where the potential for erosion and scour is low.

Key Issues

- The footing must be designed for the soil conditions present. Pier foundations are generally not recommended in V zones or in A zones in coastal areas.
- The connection between the pier and its footing must be properly designed and constructed to resist separation of the pier from the footing and rotation to due to lateral (flood, wind, debris) forces.
- The top of the footing must be below the anticipated erosion and scour depth.
- The piers must be reinforced with steel and fully grouted.
- There must be a positive connection to the floor beam at the top of the pier.
- Special attention must be given to the application of mortar in order to prevent saltwater intrusion into the core, where the steel can be corroded.

Piers vs. Piles





Piers are subject to upward, downward, and horizontal loads. Pier reinforcement and footing size are critical to resisting these loads; therefore, pier and footing design must be verified by an engineer.

In coastal areas, masonry pier foundations are not recommended in V zones with erodible soils, or in A zones subject to waves and erosion — use pile foundations in these areas.

Pier foundations are most appropriate in areas where:

- erosion and scour potential are low,
- flood depths and lateral forces are low, and
- soil can help resist overturning of pier.

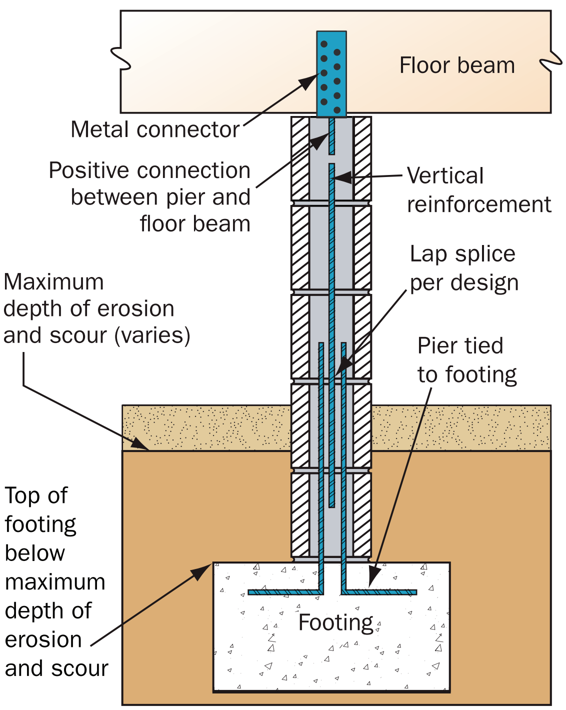
The small footings on the piers in this photograph did not prevent these piers from overturning during Hurricane Iniki.

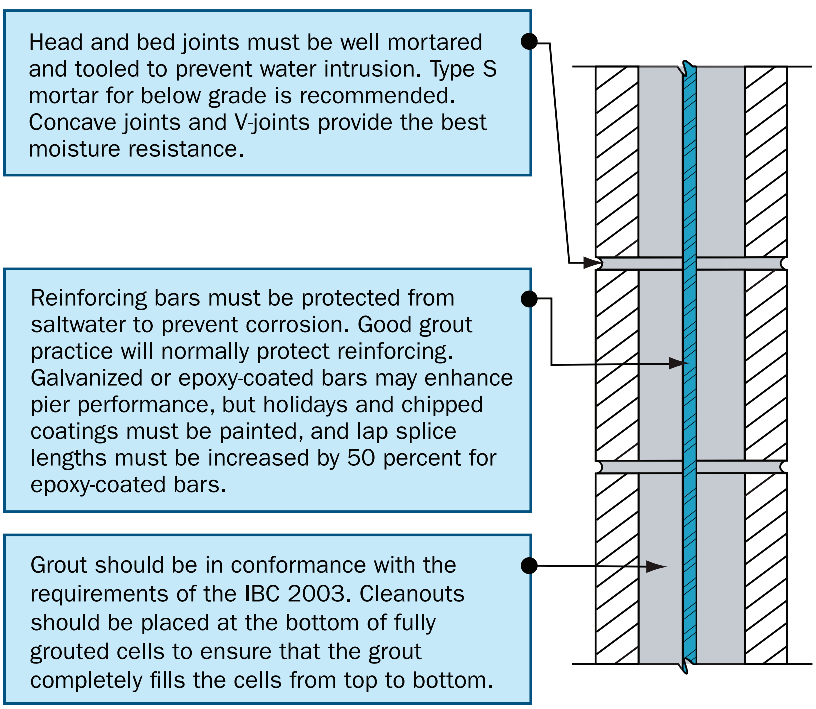
The combination of high winds and moist (sometimes salt-laden) air can have a damaging effect on masonry construction by forcing moisture into even the smallest of cracks or openings in the masonry joints. The entry of moisture into reinforced masonry construction can lead to corrosion of the reinforcement steel and subsequent cracking and spalling of the masonry. Moisture resistance is highly influenced by the quality of the materials and the quality of the masonry construction at the site.

Good Masonry Practice

- Masonry units and packaged mortar and grout materials should be stored off the ground and covered.
- Masonry work in progress must be well protected.
- Mortar and grouts must be carefully batched and mixed. The 2003 International Building Code (IBC 2003) specifies grout proportions by volume for masonry construction.

Recommendations for Masonry Piers in Coastal Regions





Foundation Walls

HOME BUILDER'S GUIDE TO COASTAL CONSTRUCTION FEMA 499/August 2005 *Technical Fact Sheet No. 15*

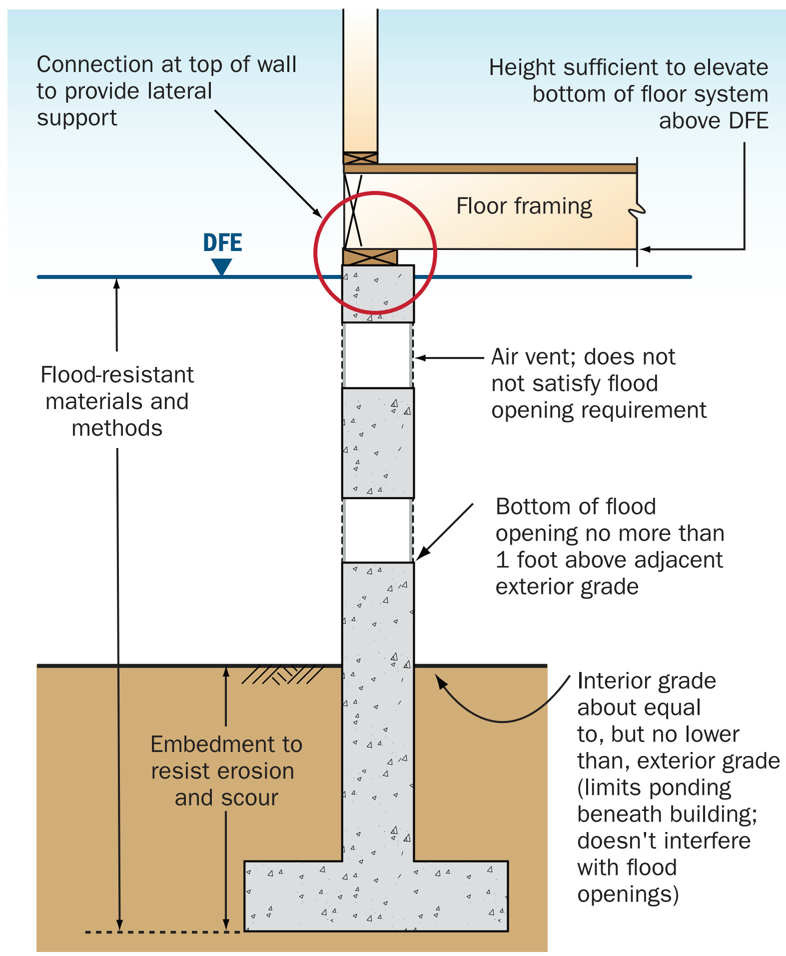
Purpose: To discuss the use of foundation walls in coastal buildings.

Key Issues

- Foundation walls include stemwalls, cripple walls, and other solid walls.
- Foundation walls are prohibited by the National Flood Insurance Program (NFIP) in V zones.*
- Use of foundation walls in A zones in coastal areas should be limited to locations where only shallow flooding occurs, and where the potential for erosion and breaking waves is low.
- Where foundation walls are used, flood-resistant design of foundation walls must consider embedment, height, materials and workmanship, lateral support at the top of the wall, flood openings and ventilation openings, and interior grade elevation.

Foundation Walls – When Are They Appropriate?

Use of foundation walls – such as those in crawlspace and other solid-wall foundations – is potentially troublesome in coastal areas for two reasons: (1) they present an obstruction to breaking waves and fast-moving flood waters, and (2) they are typically constructed on shallow footings, which are vulnerable to erosion. For these reasons, ***their use in coastal areas should be limited to sites subject to shallow flooding, where erosion potential is low and where breaking waves do not occur during the Base Flood***. The NFIP prohibits the use of foundation walls in V zones*. This *Home Builder's Guide to Coastal Construction* recommends against their use in many A zones in coastal areas. ***Deeply embedded pile or column foundations are recommended*** because they present less of an obstruction to floodwaters and are less vulnerable to erosion.



Foundation walls – flood-resistant design considerations

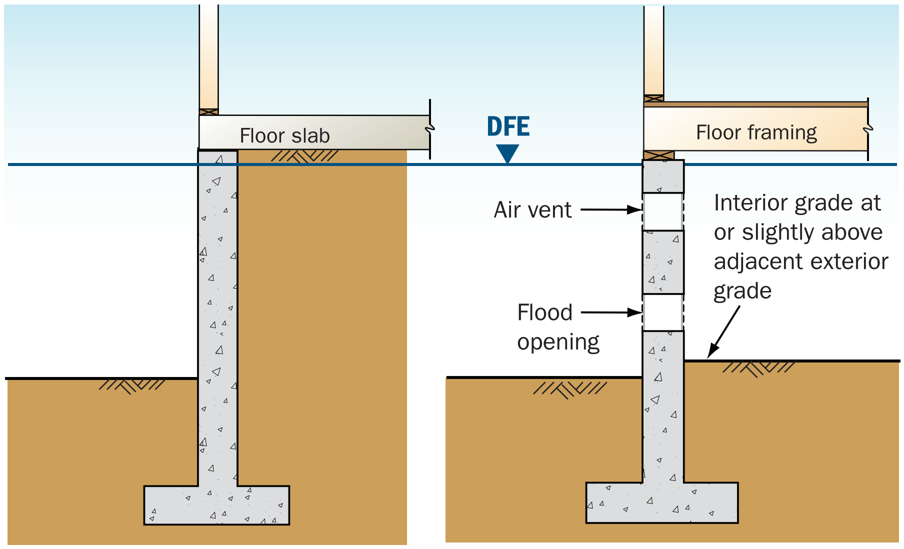
* Note that the use of shearwalls below the Design Flood Elevation (DFE) may be permitted in limited circumstances (e.g., lateral wind/seismic loads cannot be resisted with a braced, open foundation. In such cases, minimize the length of shearwalls and the degree of obstruction to floodwaters and waves, orient shearwalls parallel to the direction of flow/waves, do not form enclosures). Consult the authority having jurisdiction for guidance concerning shearwalls below the DFE.

Design Considerations for Foundation Walls

The design of foundation walls is covered by building codes and standards (e.g., *Standard for Hurricane Resistant Residential Construction*, SSTD 10, by the Southern Building Code Congress International). For flood design purposes, there are six additional design considerations: (1) embedment, (2) height, (3) materials and workmanship, (4) lateral support at the top of the wall, (5) flood openings and ventilation openings, and (6) interior grade elevation.

Embedment – The top of the footing should be no higher than the anticipated depth of erosion and scour (this basic requirement is the same as that for piers; see figure at right and Fact Sheet No. 14). If the required embedment cannot be achieved without extensive excavation, consider a pile foundation instead.

Height – The wall should be high enough to elevate the bottom of the floor system to or above the DFE (see Fact Sheet No. 4).



Floor slab atop backfilled stemwall foundation

Floor joist system and crawlspace

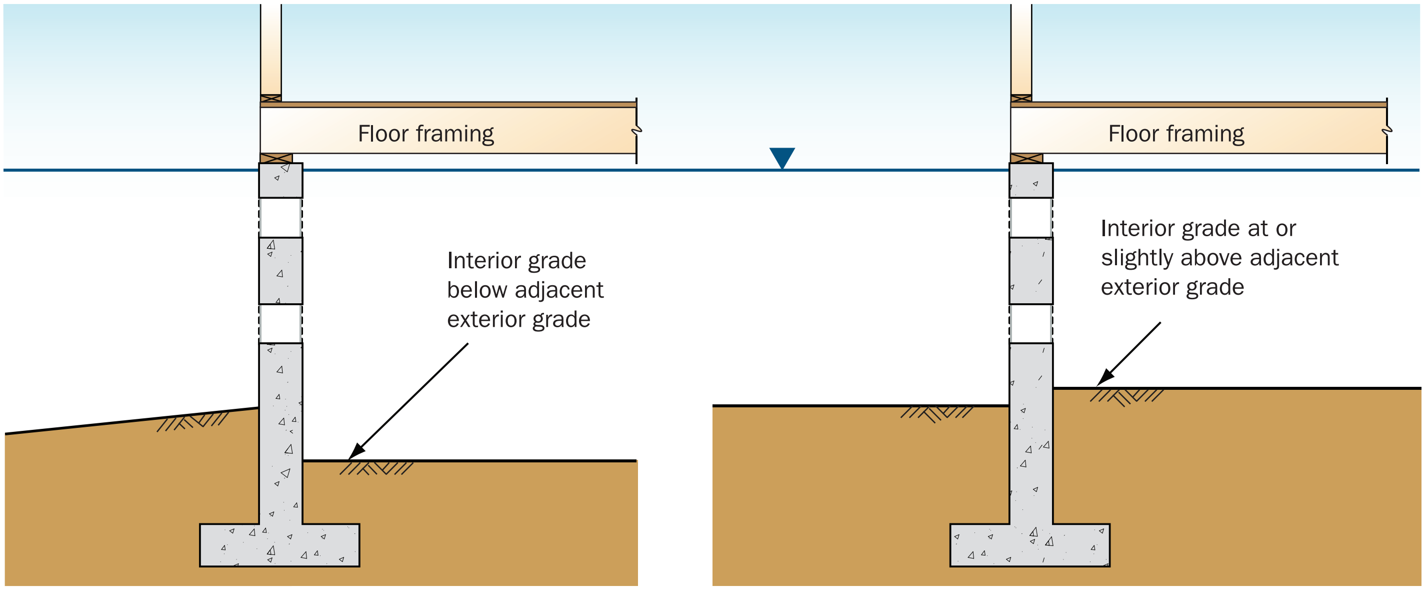
Materials and Workmanship – Foundation walls can be constructed from many materials, but masonry, concrete, and wood are the most common. Each material can be specified and used in a manner to resist damage due to moisture and inundation (see Fact Sheet No. 8). Workmanship for flood-resistant foundations is crucial. Wood should be preservative-treated for foundation or marine use (aboveground or ground-contact treatment will not be sufficient). Cuts and holes should be field-treated. Masonry should be reinforced and fully grouted (see Fact Sheet No. 16 for masonry details). ***Concrete*** should be reinforced and composed of a high-strength, low water-to-cement ratio mix.

Lateral Support at the Top of the Wall – Foundation walls must be designed and constructed to withstand all flood, wind, and seismic forces, as well as any unbalanced soil/hydrostatic loads. The walls will typically require lateral support from the floor system and diaphragm, and connections to the top of the walls must be detailed properly. Cripple walls, where used, should be firmly attached and braced.

Flood Openings and Ventilation Openings – Any area below the DFE enclosed by foundation walls must be equipped with openings capable of automatically equalizing the water levels inside and outside the enclosure. Specific flood opening requirements are included in Fact Sheet No. 27. Flood openings are not required for backfilled stemwall foundations supporting a slab. ***Air ventilation openings required by building codes do not generally satisfy the flood opening requirement***; the air vents are typically installed near the top of the wall, the flood vents must be installed near the bottom, and opening areas for air flow may be insufficient for flood flow.

Interior Grade Elevation – Conventional practice for crawlspace construction calls for excavation of the crawlspace and use of the excavated soil to promote drainage away from the structure (see left-hand figure on page 3). This approach may be acceptable for non-floodplain areas, but in floodplains, this practice can result in increased lateral loads (e.g., from saturated soil) against the foundation walls and ponding in the crawlspace area. If the interior grade of the crawlspace is below the DFE, NFIP requirements can be met by ensuring that the interior grade is at or above the lowest exterior grade adjacent to the building (see right-hand figure on page 3). When floodwaters recede, the flood openings in the foundation walls allow floodwaters to automatically exit the crawlspace. FEMA may accept a crawlspace elevation up to 2 feet below the lowest adjacent exterior grade; however, the community must adopt specific requirements in order for this type of crawlspace to be constructed in a floodplain.

If a stemwall and floor slab system is used, the interior space beneath the slab should be backfilled with compacted gravel (or such materials as required by the building code). As long as the system can act monolithically, it will resist most flood forces. However, if the backfill settles or washes out, the slab will collapse and the wall will lose lateral support.



Conventional practice - not recommended

Recommended practice

Crawlspace construction: interior grade elevation for A zones not subject to breaking waves and erosion

Masonry Details

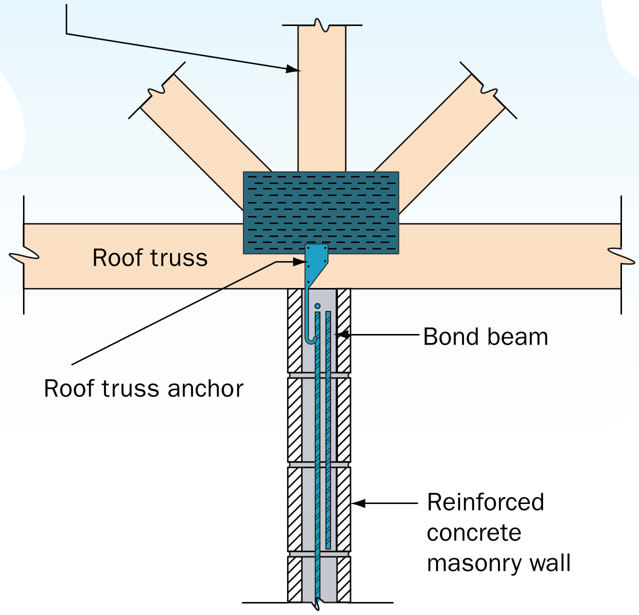
Purpose: To highlight several important details for masonry construction in coastal areas.

Key Issues

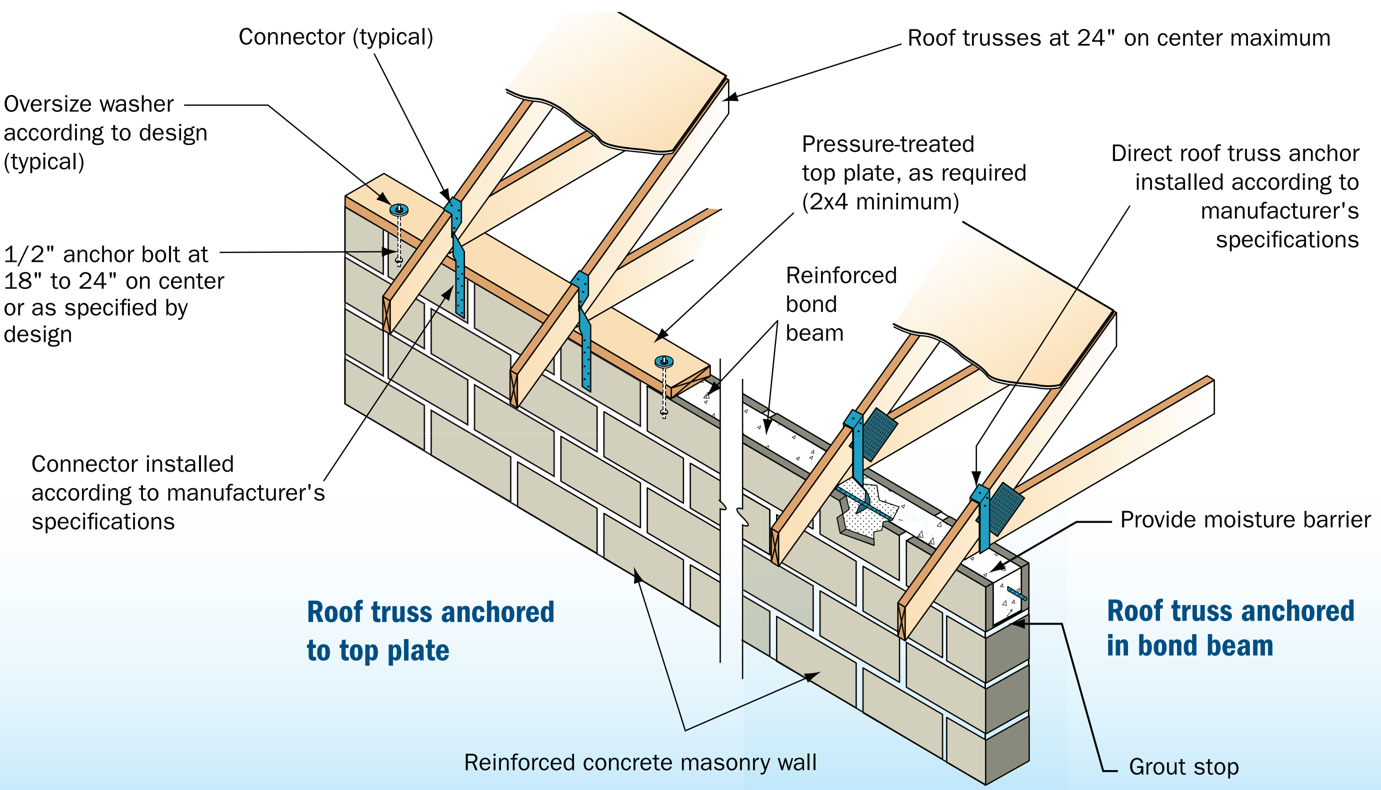
- Continuous, properly connected load paths are essential because of the higher vertical and lateral loads on coastal structures.
- Building materials must be durable enough to withstand the coastal environment.
- Masonry reinforcement requirements are more stringent in coastal areas.

Load Paths

A properly connected load path from roof to foundation is crucial in coastal areas (see Fact Sheets Nos. 10 and 17). The following details show important connections for a typical masonry home.

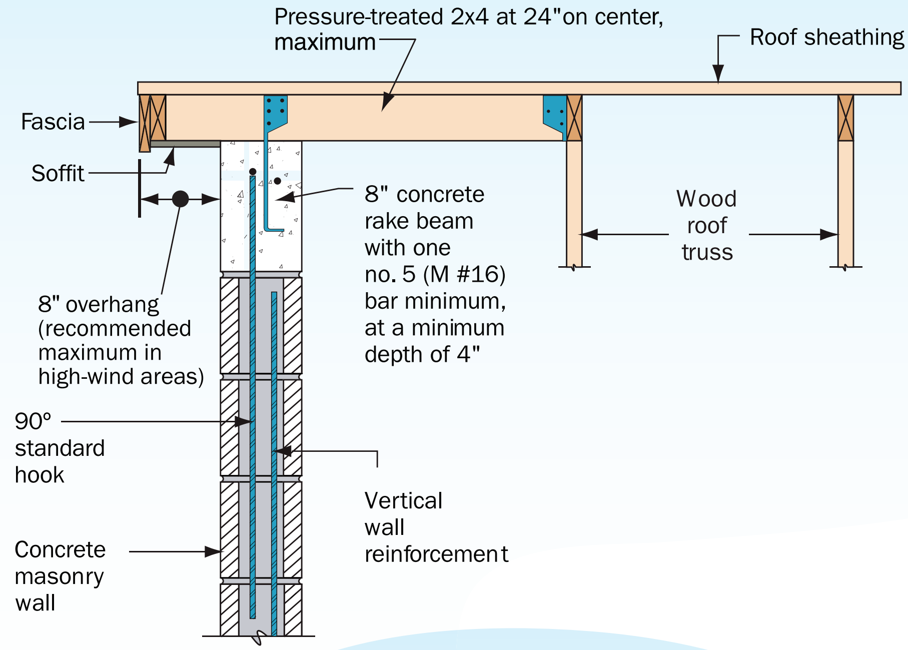


Roof framing to interior masonry wall

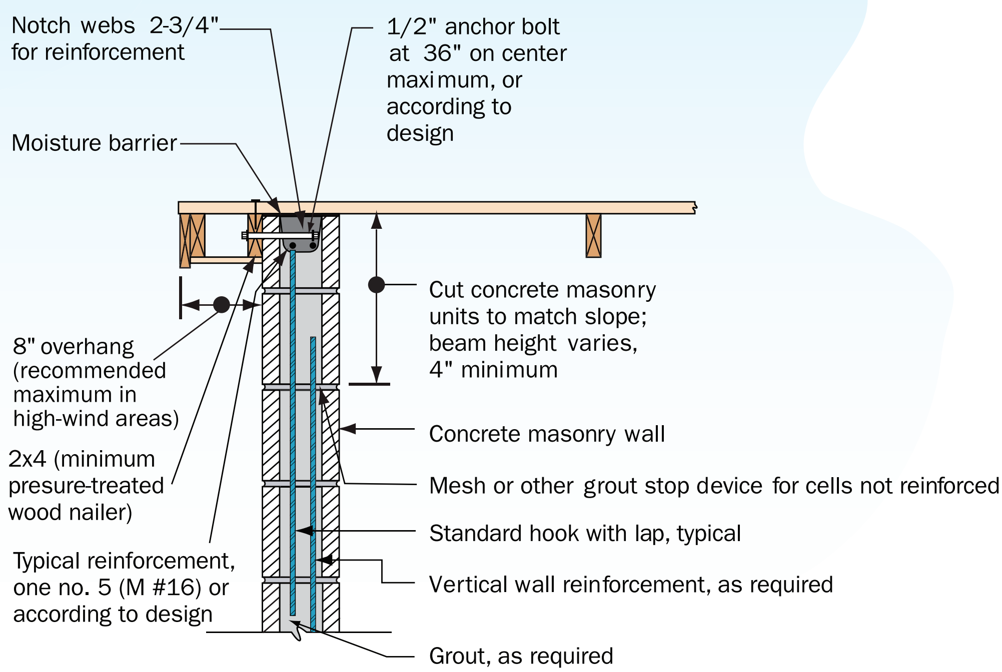


Roof framing to masonry wall.

Gable end wall – cut concrete rake beam with outlooker-type overhang



Gable end wall – cut masonry rake beam with ladder-type overhang

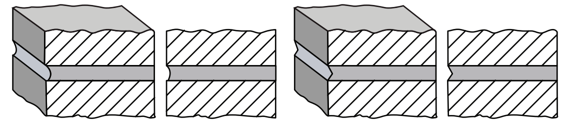


Gable endwall connection.

Durability – High winds and salt-laden air can damage masonry construction. The entry of moisture into large cracks can lead to corrosion of the reinforcement and subsequent cracking and spalling. Moisture resistance is highly dependent on the materials and quality of construction.

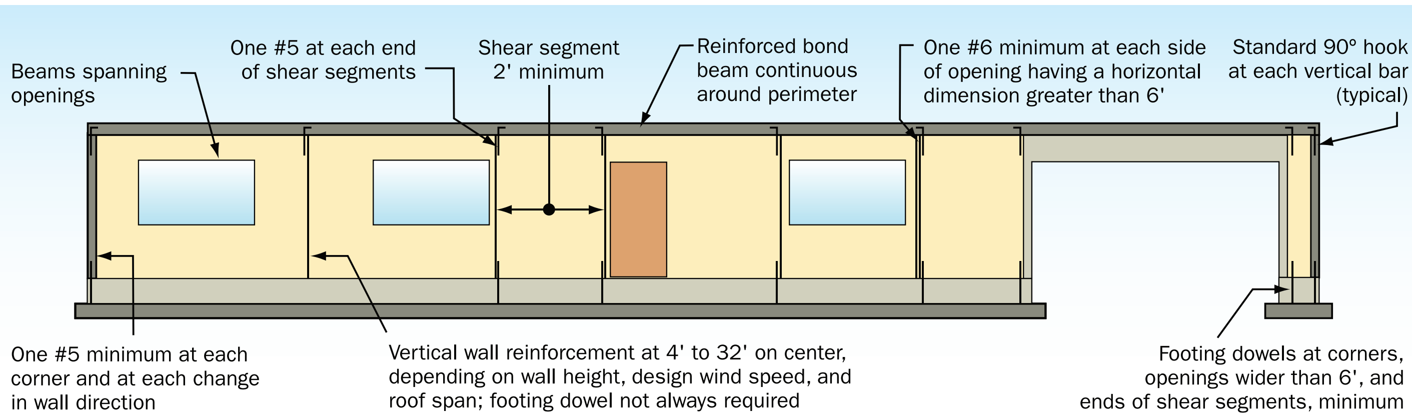
Quality depends on:

- **Proper storage of material –** Keep stored materials covered and off the ground.
- **Proper batching –** Mortar and grout must be properly batched to yield the required strength.



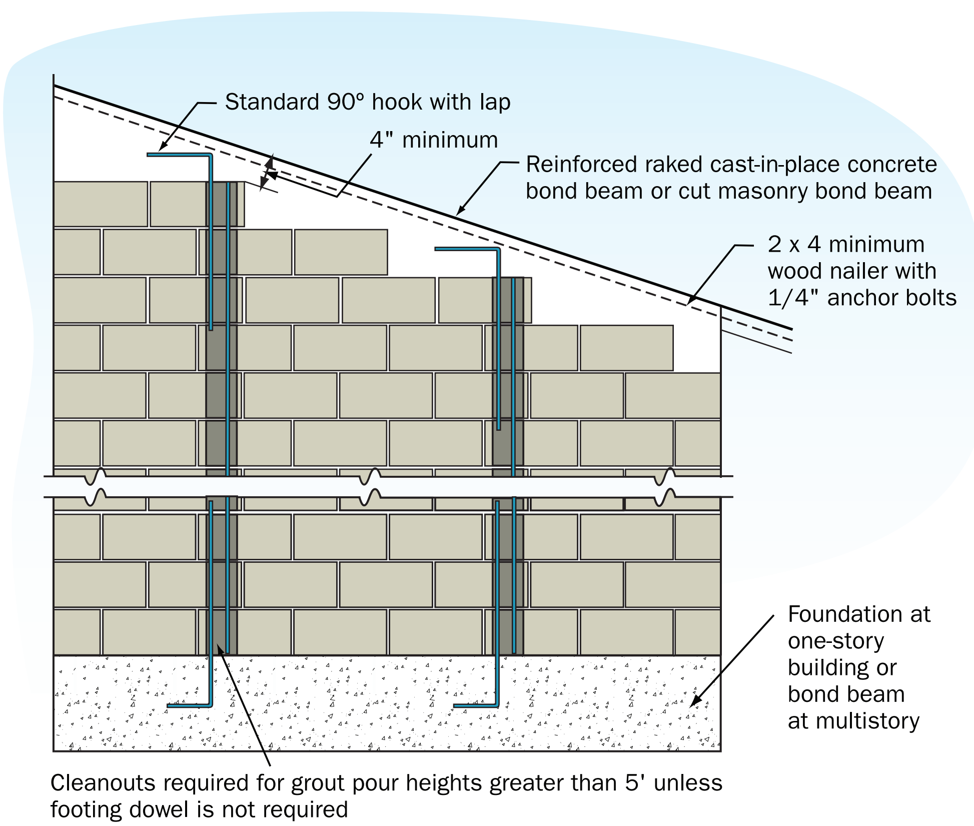
- **Good workmanship –** Head and bed joints must be well mortared and well tooled. Concave joints and V-joints provide the best moisture protection (see detail above). All block walls should be laid with full mortar coverage on horizontal and vertical face shells. Block should be laid using a "double butter" technique for spreading mortar head joints. This practice provides for mortar-to-mortar contact as two blocks are laid together in the wall and prevents hairline cracking in the head joint.
- **Protection of work in progress –** Keep work in progress protected from rain. During inclement weather, the tops of unfinished walls should be covered at the end of the workday. The cover should extend 2 feet down both sides of the masonry and be securely held in place. Immediately after the completion of the walls, the wall cap should be installed to prevent excessive amounts of water from directly entering the masonry.

Reinforcement: Masonry must be reinforced according to the building plans. Coastal homes will typically require more reinforcing than inland homes. The following figure shows typical reinforcement requirements for a coastal home.



Masonry reinforcement.

Gable Ends: Because of their exposure, gable ends are more prone to damage than are hipped roofs unless the joint in conventional construction at the top of the endwall and the bottom of the gable is laterally supported for both inward and outward forces. The figure at right shows a construction method that uses continuous masonry from the floor to the roof diaphragm with a raked cast-in-place concrete bond beam or a cut masonry bond beam.



Continuous gable endwall reinforcement.

Shutter Alternatives

HOME BUILDER'S GUIDE TO COASTAL CONSTRUCTION FEMA 499/August 2005 *Technical Fact Sheet No. 26*

Purpose: To provide general information about the installation and use of storm shutters in coastal areas.

Plywood panels are a cost-effective means of protection.

Why Are Storm Shutters Needed?

Shutters are an important part of a hurricane-resistant or storm-resistant home. They provide protection for glass doors and windows against windborne debris, which is often present in coastal storms. Keeping the building envelope intact (i.e., no window or door breakage) during a major windstorm is vital to the structural integrity of a home. If the envelope is breached, sudden pressurization of the interior can cause major structural damage (e.g., roof loss) and will lead to significant interior and contents damage from wind-driven rain.

Temporary, manufactured metal panel shutter. The shutter is installed in a track permanently mounted above and below the window frame. The shutter is placed in the track and secured with wing nuts to studs mounted on the track. This type of shutter is effective and quickly installed, and the wing nut and stud system provides a secure anchoring method.

Where Are Storm Shutters Required and Recommended?

Model building codes, which incorporate wind provisions from ASCE 7 (1998 edition and later), ***require*** that buildings within the most hazardous portion of the ***hurricane-prone region***, called the ***windborne debris region*** (see page 4 of this fact sheet), either (1) be equipped with shutters or impact-resistant glazing and designed as enclosed structures, or (2) be designed as partially enclosed structures (as if the windows and doors are broken out). Designing a partially enclosed structure typically requires upgrading structural components and connections, but will not provide protection to the interior of the building. Designers and owners should assume that a total loss of the building interior and contents will occur in partially enclosed structures.

Using opening protection (e.g., shutters or laminated glass) is recommended in

Note: Many coastal homes have large and unusually shaped windows, which will require expensive, custom shutters. Alternatively, such windows can be fabricated with laminated (impact-resistant) glass.

windborne debris regions, as opposed to designing a partially enclosed structure. The *Home Builder's Guide to Coastal Construction* also recommends giving strong consideration to the use of opening protection in all hurricane-prone areas where the basic wind speed is 100 mph (3-second peak gust) or greater, even though the model building codes do not require it. Designers should check with the jurisdiction to determine whether state or local requirements for opening protection exceed those of the model code.

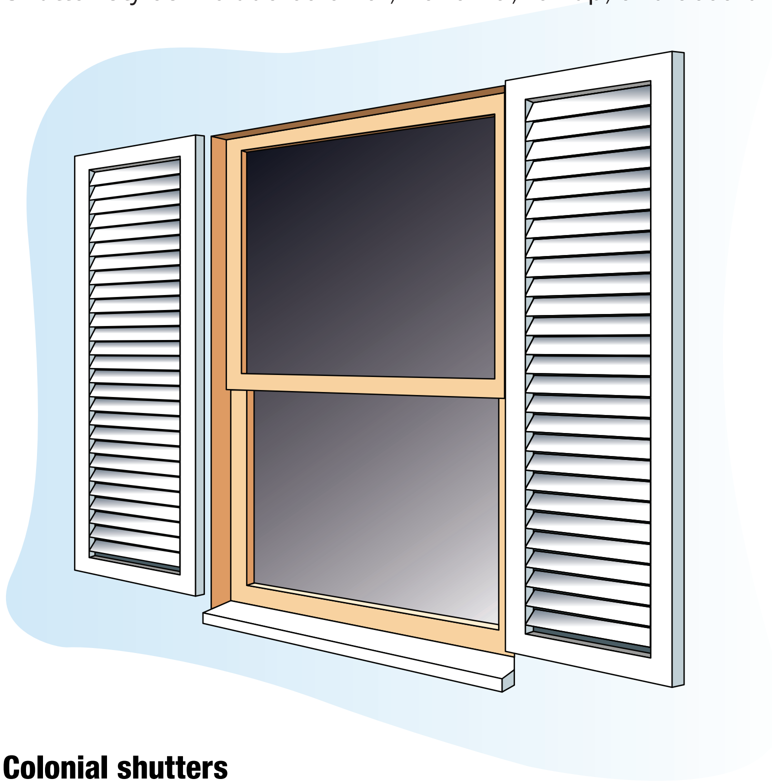
What Types of Shutters Are Available?

A wide variety of shutter types are available, from the very expensive motor-driven, roll-up type, to the less expensive temporary plywood panels (see photograph on page 1 of this fact sheet). Designers can refer to Miami-Dade County, Florida, which has established a product approval mechanism for shutters and other building materials to ensure they are rated for particular wind and windborne debris loads (see Additional Resources on page 5 of this fact sheet).

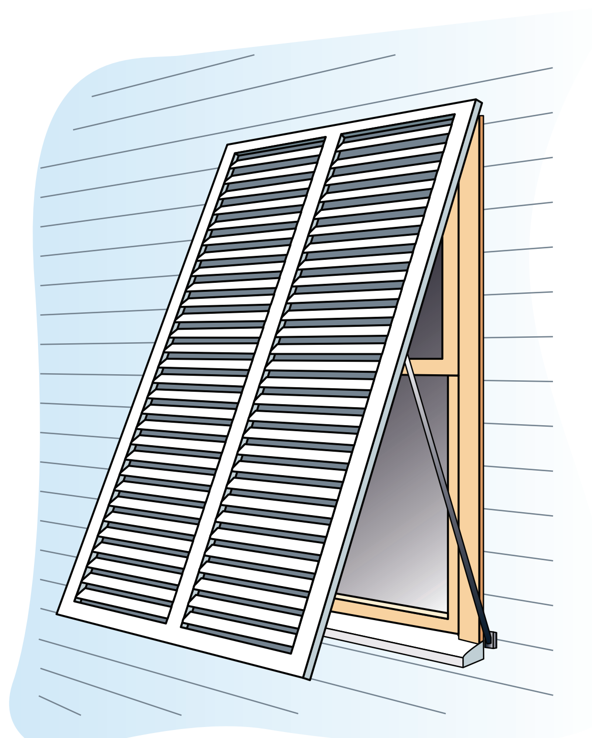
Shutter Type	Cost	Advantages	Disadvantages
Temporary plywood panels	Low	Inexpensive	Must be installed and taken down every time they are needed; must be adequately anchored to prevent blow-off; difficult to install on upper levels
Temporary manufactured panels	Low/Medium	Easily installed on lower levels	Must be installed and taken down every time they are needed; difficult to install on upper levels
Permanent, manual-closing	Medium/High	Always in place Ready to be closed	Must be closed manually from the outside; difficult to access on upper levels
Permanent, motor-driven	High	Easily opened and closed from the inside	Expensive

Shutter Styles

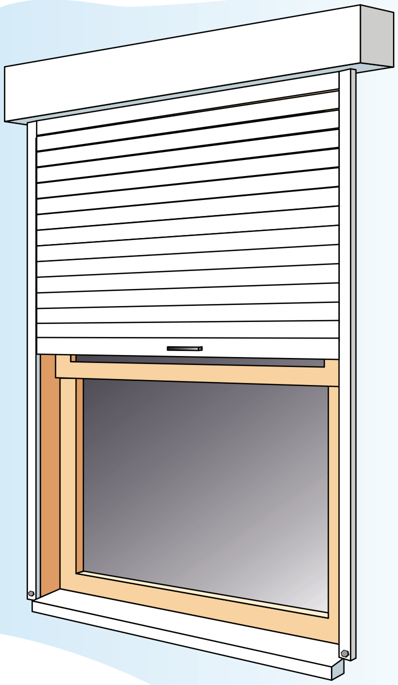
Shutter styles include colonial, Bahama, roll-up, and accordion.



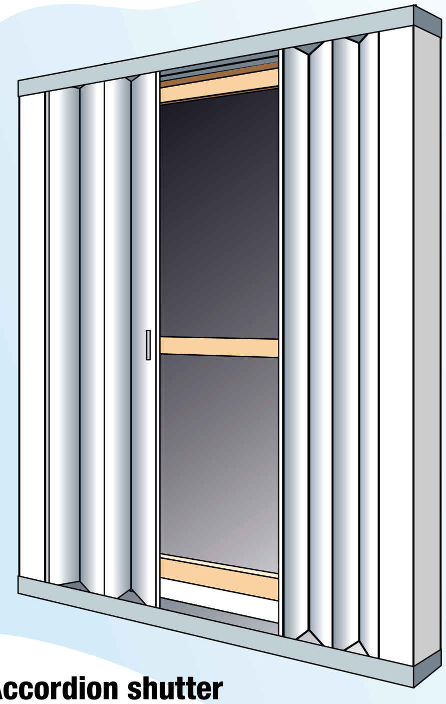
Colonial shutters



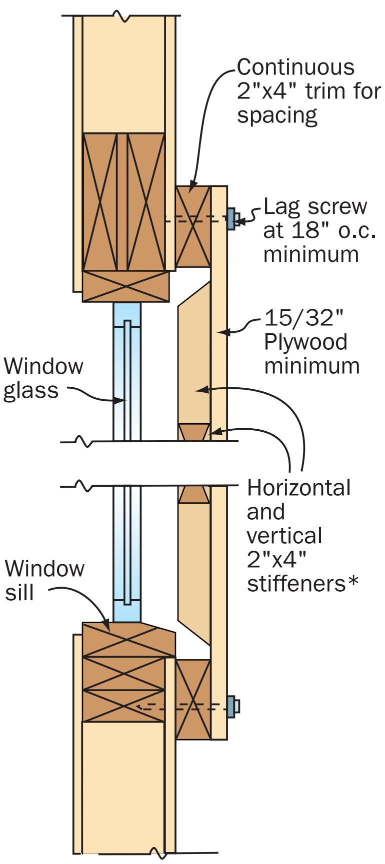
Bahama shutter



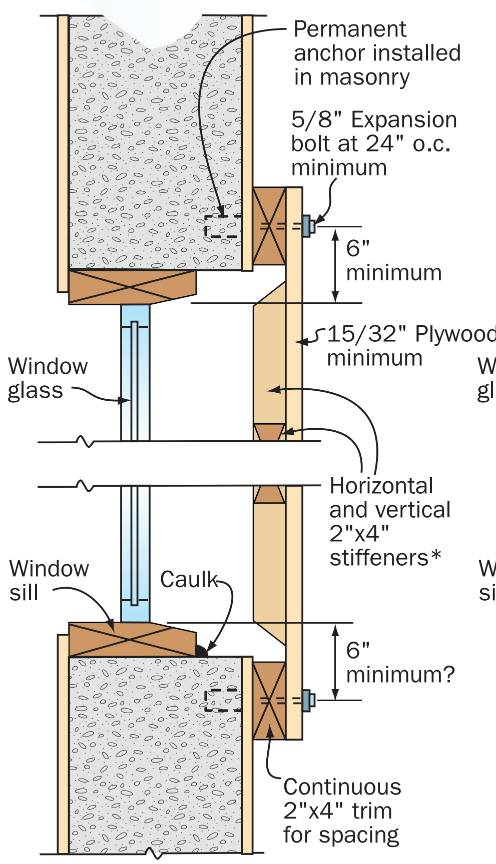
Roll-up shutter



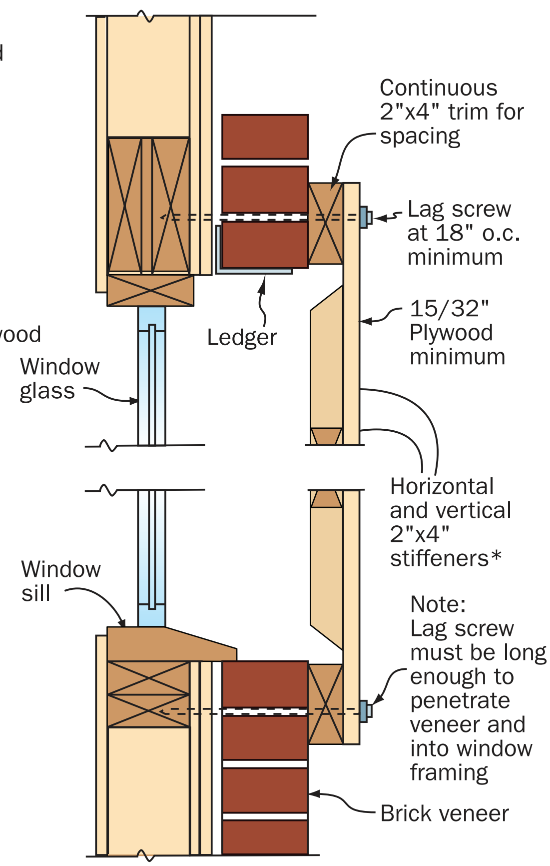
Accordion shutter



Wood Stud Wall



Masonry Wall



Wood Stud Wall With Brick Veneer

*Stiffener can be on either side, although for inside location, adequate space between windowpane and stiffener must be provided.

Common methods for plywood shutter attachment to wood-frame and masonry walls. (For actual shutter design, refer to design drawings or see the Engineered Wood Association guidelines for constructing plywood shutters.)

Are There Special Requirements for Shutters in Coastal Areas?

ASCE 7 and the International Building Code (IBC) state that shutters (or laminated glazing) shall be tested in accordance with the American Society for Testing and Materials (ASTM) standards ASTM E 1886 and ASTM E 1996 (or other approved test methods). E 1886 specifies the test procedure; E 1996 specifies missile loads. The IBC allows the use of wood panels (Table 1609.1.4) and prescribes the type and number of fasteners to be used to attach the panels. A shutter may look like it is capable of withstanding windborne missiles; unless it is tested, however, its missile resistance is unknown.

When installing any type of shutter, carefully follow manufacturer's instructions and guidelines. Be sure to attach shutters to structurally adequate framing members (see shutter details on page 3 of this fact sheet). Avoid attaching shutters to the window frame or brick veneer face. Always use hardware not prone to corrosion when installing shutters.

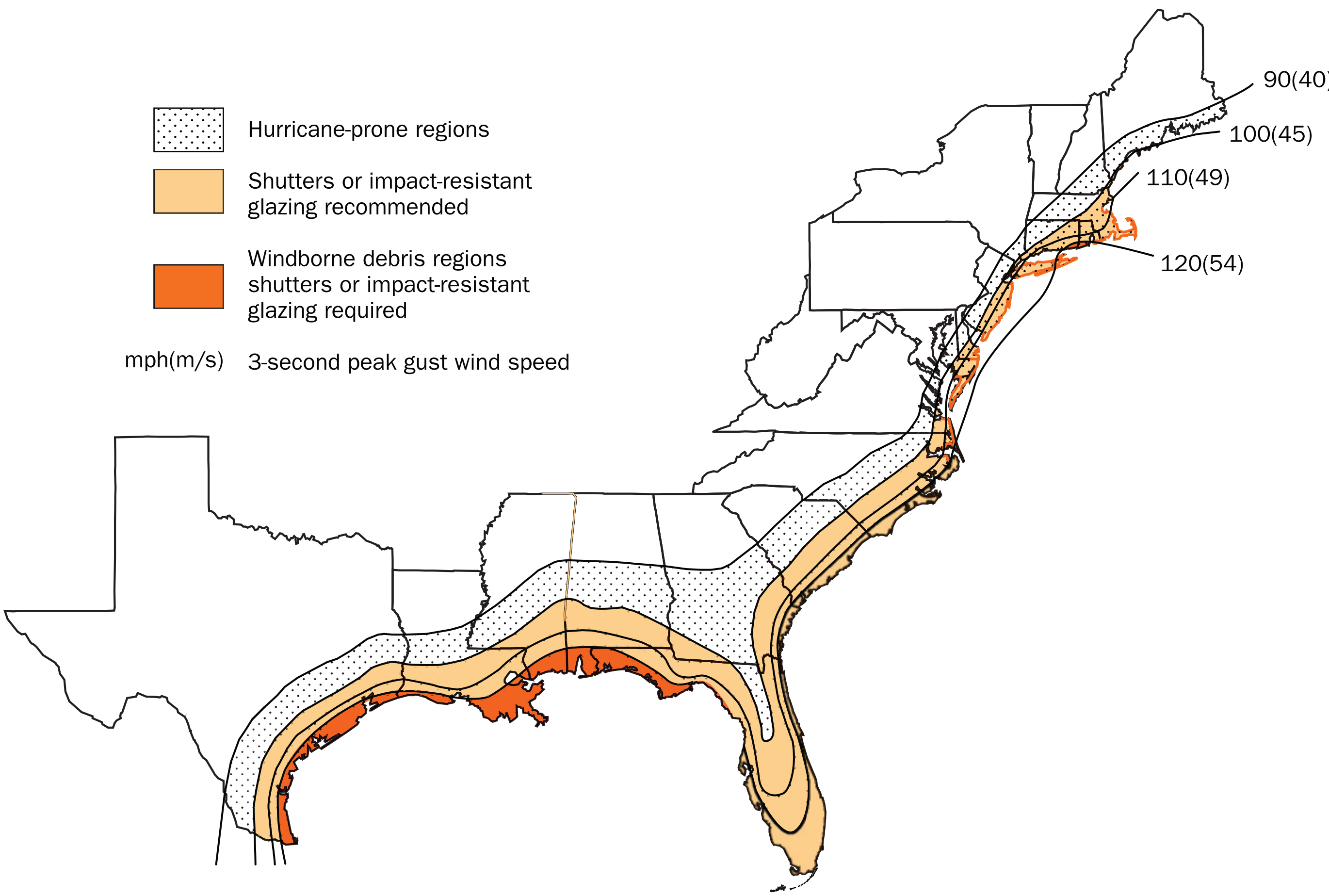
What Are "Hurricane-Prone Regions" "Windborne Debris Regions"?

ASCE 7, the IBC, and the International Residential Code (IRC) define ***hurricane-prone regions*** as:

- the U.S. Atlantic Ocean and Gulf of Mexico coasts where the basic wind speed is greater than 90 mph (3-second peak gust), and
- Hawaii, Guam, Puerto Rico, the U.S. Virgin Islands, and American Samoa.

ASCE 7, the IBC, and the IRC define ***windborne debris regions*** as areas within hurricane-prone regions located:

- within 1 mile of the coast where the basic wind speed is equal to or greater than 110 mph (3-second peak gust) and in Hawaii, or
- in all areas where the basic wind speed is equal to or greater than 120 mph (3-second peak gust), including Guam, Puerto Rico, the U.S. Virgin Islands, and American Samoa.



Additional Resources

American Society of Civil Engineers. *Minimum Design Loads for Buildings and Other Structures*, ASCE 7. (http://www.asce.org)

International Code Council. *International Building Code*. 2003. (http://www.iccsafe.org)

International Code Council. *International Residential Code*. 2003. (http://www.iccsafe.org)

The Engineered Wood Association. *Hurricane Shutter Designs Set 5 of 5. Hurricane shutter designs for wood-frame and masonry buildings*. (http://www.apawood.org)

Miami-Dade County, Florida, product testing and approval process – information available at http://www.miamidade.gov/buildingcode/pc_home.asp

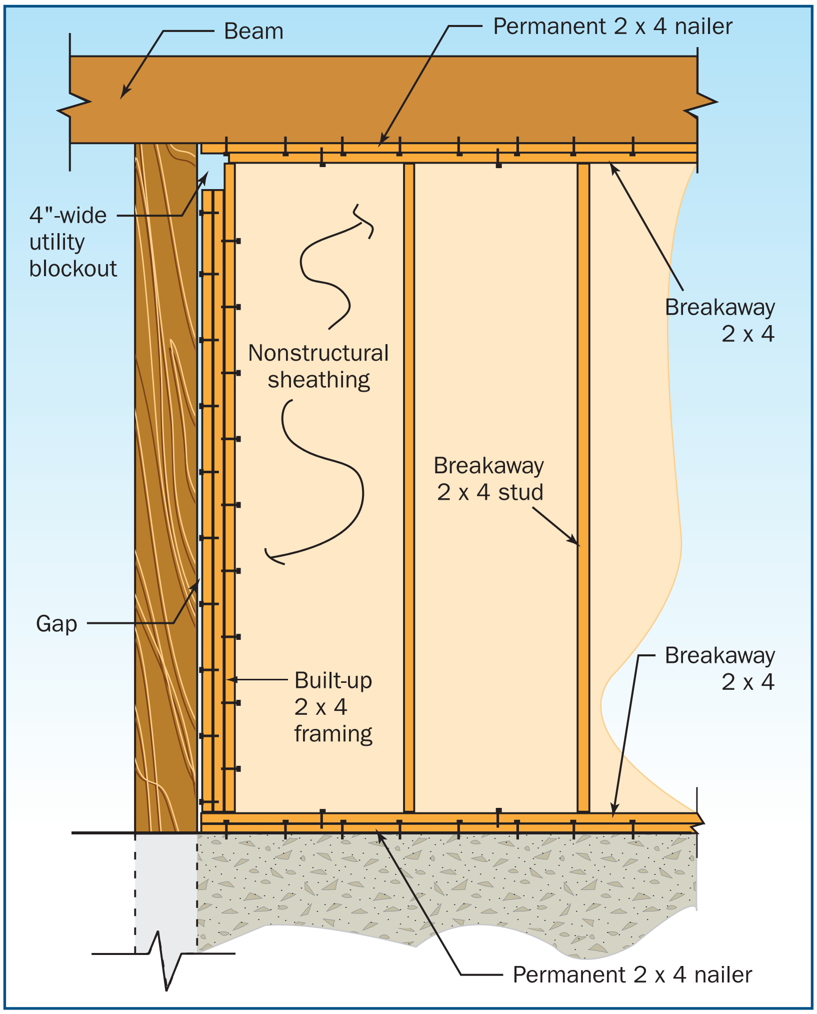
Enclosures can be divided into two types, ***breakaway*** and ***non-breakaway***.

- ***Breakaway*** enclosures are designed to fail under Base Flood conditions without jeopardizing the elevated building – ***any below-BFE enclosure in a V zone must be breakaway***. Breakaway enclosures are permitted in A zones but must be equipped with flood openings.
- ***Non-breakaway*** enclosures, under the NFIP, can be used in an A zone (they may or may not provide structural support to the elevated building), but they must be equipped with flood openings to allow the automatic entry and exit of floodwaters. ***The Home Builder's Guide to Coastal Construction recommends their use only in A zone areas subject to shallow, slow-moving floodwaters without breaking waves.***

Open wood lattice installed beneath an elevated house in a V zone.

Breakaway Walls

Breakaway walls must be designed to break free under the larger of the design wind load, the design seismic load, or 10 psf, acting perpendicular to the plane of the wall. If the loading at which the breakaway wall is intended to collapse exceeds 20 psf, ***the breakaway wall design must be certified.*** When certification is required, a registered engineer or architect must certify that the walls will collapse under a water load associated with the Base Flood and that the elevated portion of the building and its foundation will not be subject to collapse, displacement, or lateral movement under simultaneous wind and water loads. (See the sample certification at the bottom of page 2 of Fact Sheet No. 5.) ***Utilities should not be attached to or pass through breakaway walls.***



Recommended breakaway wall construction.

Flood Openings

Where permitted and used in A zones, foundation walls and enclosures must be equipped with openings that allow the ***automatic entry and exit of floodwaters.***

Note the following:

- Flood openings must be provided ***in at least two of the walls*** forming the enclosure.
- ***The bottom of each flood opening*** must be ***no more than 1 foot above the adjacent grade*** outside the wall.
- ***Louvers, screens, or covers*** may be installed over flood openings as long as they do not interfere with the operation of the openings during a flood.
- Flood openings may be ***sized*** according to either a prescriptive method (1 square inch of flood opening per square foot of enclosed area) or an engineering method (which must be certified by a registered engineer or architect).

Details concerning flood openings can be found in FEMA Technical Bulletin 4-93, *Openings in Foundation Walls*.

Other Considerations

Enclosures are strictly regulated because, if not constructed properly, they ***can transfer flood forces to the main structure*** (possibly leading to structural collapse). There are other considerations, as well:

- Owners may be tempted to convert enclosed areas below the BFE into habitable space, leading to life-safety concerns and uninsured losses. Construction without enclosures should be encouraged. Contractors ***should not stub out utilities in enclosures;*** utility stub-outs make it easier for owners to finish and occupy the space.
- Siding used on non-breakaway portions of a building should not be extended over breakaway walls. Instead, a clean separation should be provided so that any siding installed on breakaway walls is structurally independent of siding elsewhere on the building. Without such a separation, the failure of breakaway walls can result in damage to siding elsewhere on the building.

Siding on the non-breakaway portions of this elevated building was extended over breakaway enclosure walls and was damaged when breakaway walls failed under flood forces.

- Breakaway enclosures in V zones will result in ***substantially higher flood insurance premiums*** (especially where the enclosed area is 300 square feet or greater). Insect screening or lattice is recommended instead.
- If enclosures are constructed in ***A zones with the potential for breaking waves, open foundations with breakaway enclosures are recommended*** in lieu of foundation walls or crawlspaces. If breakaway walls are used, they must be equipped with flood openings that allow flood waters to enter the enclosure during smaller storms. Breakaway enclosures in A zones will ***not*** lead to higher flood insurance premiums.
- Garage doors installed in below-BFE enclosures of V-zone buildings — even reinforced and high-wind-resistant doors — must meet the performance requirement discussed in the **Breakaway Walls** section on page 2 of this fact sheet. Specifically, the doors must be designed to break free under the larger of the design wind load, the design seismic load, or 10 psf, acting perpendicular to the plane of the door. If the loading at which the door is intended to collapse is greater than 20 psf, ***the door must be designed and certified to collapse under Base Flood conditions***. See the **Breakaway Walls** section of this fact sheet for information about certification requirements.

Enclosures and Breakaway Walls

Purpose: To discuss requirements and recommendations for enclosures and breakaway walls below the Base Flood Elevation (BFE).

Key Issues

- Spaces below elevated buildings can be used only for building access, parking, and storage.
- Areas enclosed by solid walls below the BFE ("enclosures") are subject to strict regulation under the National Flood Insurance Program (NFIP). Note that some local jurisdictions enforce stricter regulations for enclosures.
- Non-breakaway enclosures are prohibited in V-zone buildings. Breakaway enclosures in V zones must meet specific requirements and must be certified by a registered design professional
- Enclosures (breakaway and non-breakaway) in A-zone buildings must be built with flood-resistant materials and equipped with flood openings that allow water levels inside and outside to equalize (see Fact Sheet No. 15).
- For V zones, enclosures below the elevated building will result in higher flood insurance premiums.
- Breakaway enclosure walls should be considered expendable, and the building owner will incur substantial costs when the walls are replaced.

Space Below the BFE – What Can it Be Used For?

NFIP regulations state that the area below an elevated building can be used only for ***building access, parking, and storage***. These areas must not be finished or used for recreational or habitable purposes. No mechanical, electrical, or plumbing equipment is to be installed below the BFE.

What Is an Enclosure?

An "***enclosure***" is formed when any space below the BFE is enclosed on all sides by walls or partitions. A V-zone building elevated on an open foundation (see Fact Sheet No. 11), without an enclosure or other obstructions below the BFE, is said to be free-of-obstructions, and enjoys favorable flood insurance premiums (a building is still classified free-of-obstructions if insect screening or open wood lattice is used to surround space below the BFE). See FEMA Technical Bulletin 5-93, *Free of Obstruction Requirements* for more information.

WARNING

Home builders and homeowners should consider the long-term effects of the construction of enclosures below elevated residential buildings and post-construction conversion of enclosed space to habitable use in A zones and V zones. Designers and owners should realize that (1) enclosures and items within them are likely to be destroyed even during minor flood events, (2) enclosures, and most items within them, are not covered by flood insurance and can result in significant costs to the building owner, and (3) even the presence of properly constructed enclosures will increase flood insurance premiums for the entire building (the premium rate will increase as the enclosed area increases). Including enclosures in a building design can have significant cost implications.

This *Home Builder's Guide to Coastal Construction* recommends the use of insect screening or open wood lattice instead of solid enclosures beneath elevated residential buildings.

Breakaway walls that failed under the flood forces of Hurricane Ivan.

Protecting Utilities

HOME BUILDER'S GUIDE TO COASTAL CONSTRUCTION FEMA 499/August 2005 *Technical Fact Sheet No. 29*

Purpose: To identify the special considerations that must be made when installing utility equipment in a coastal home.

Key Issues: Hazards, requirements, and recommendations

Special considerations must be made when installing utility systems in coastal homes. ***Proper placement and connection*** of utilities and mechanical equipment can ***significantly reduce the costs of damage caused by coastal storms*** and will ***enable homeowners to reoccupy their homes*** soon after electricity, sewer, and water are restored to a neighborhood.

Coastal Hazards That Damage Utility Equipment

- Standing or moving floodwaters
- Impact from floating debris in floodwaters
- Erosion and scour from floodwaters
- High winds
- Windborne missiles

Electrical lines and box dislocated by hurricane forces.

Common Utility Damage in Coastal Areas

Floodwaters cause corrosion and contamination, short-circuiting of electronic and electrical equipment, and other physical damage.

Electrical – Floodwaters can corrode and short-circuit electrical system components, possibly leading to electrical shock. In velocity flow areas, electrical panels can be torn from their attachments by the force of breaking waves or the impact of floating debris.

Water/Sewage – Water wells can be exposed by erosion and scour caused by floodwaters with velocity flow. A sewage backup can occur even without the structure flooding.

Fuel – Floodwaters can float and rupture tanks, corrode and short-circuit electronic components, and sever pipe connections. In extreme cases, damage to fuel systems can lead to fires.

Basic Protection Methods

The primary protection methods are ***elevation*** or ***component protection***.

Elevation of utilities and mechanical equipment is the preferred method of protection.

Elevation

Elevation refers to the location of a component and/or utility system above the Design Flood Elevation (DFE).

Component Protection

Component protection refers to the implementation of design techniques that protect a component or group of components from flood damage when they are located below the DFE.

NFIP Utility Protection Requirements

The NFIP regulations [Section 60.3(a)(3)] state that:

All new construction and substantial improvements shall be constructed with electrical, heating, ventilation, plumbing, and air conditioning equipment and other service facilities that are designed and/or located so as to prevent water from entering or accumulating within the components during conditions of flooding.

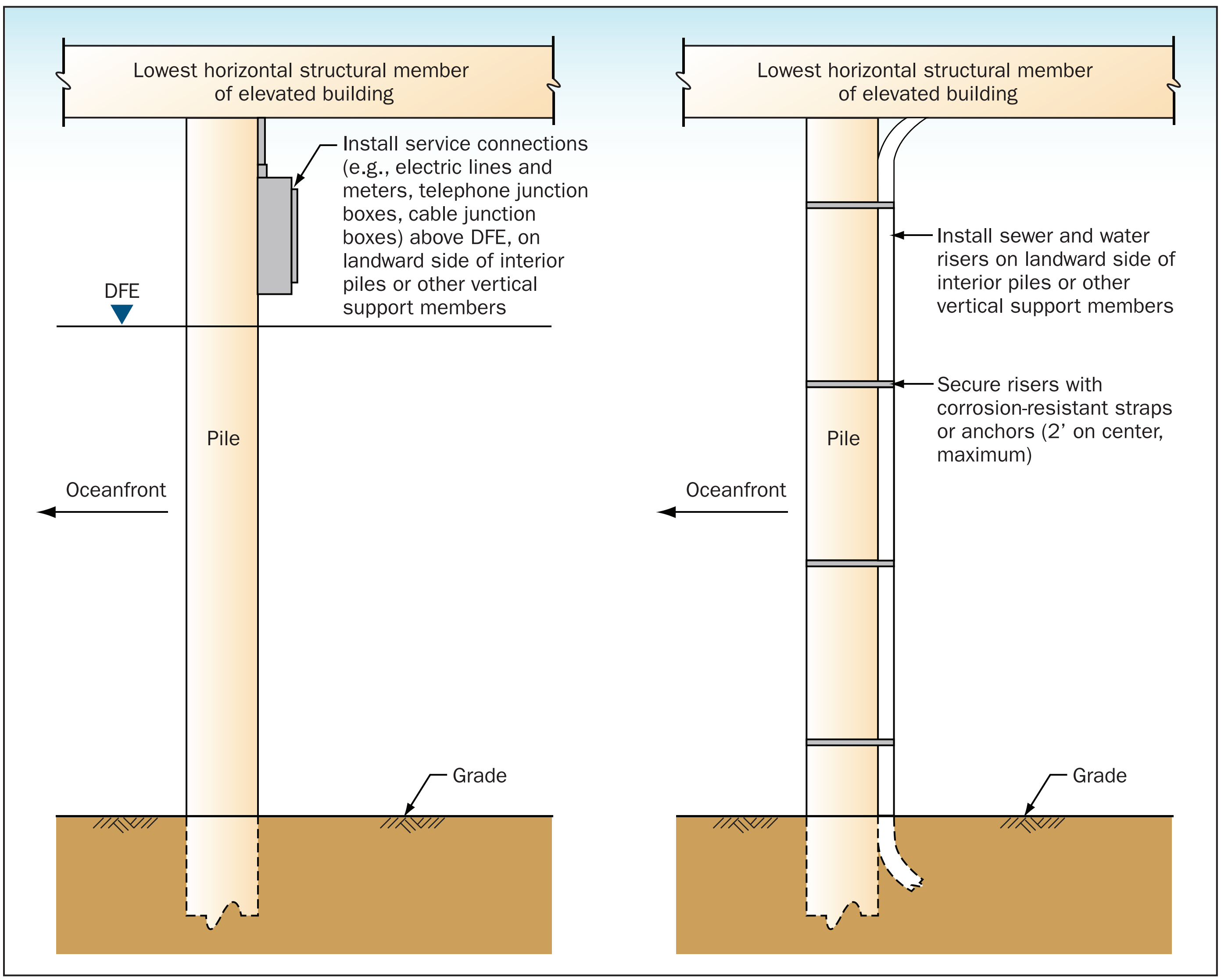
Utility Protection Recommendations

Electrical

- Limit switches, wiring, and receptacles below the DFE to those items required for life safety. Substitute motion detectors above the DFE for below-DFE switches whenever possible. Use only ground-fault-protected electrical outlets below the DFE.
- Install service connections (e.g., electrical lines, panels, and meters; telephone junction boxes; cable junction boxes) above the DFE, on the landward side of interior piles or other vertical support members.
- Use drip loops to minimize water entry at penetrations.
- Never attach electrical components to breakaway walls.

Water/Sewage

- Attach plumbing risers on the landward side of interior piles or other vertical support members.



Recommended installation techniques for electrical and plumbing lines and other utility components.

- When possible, install plumbing runs inside joists for protection.
- Never attach plumbing runs to breakaway walls.

HVAC

- Install HVAC components (e.g., condensers, air handlers, ductwork, electrical components) above the DFE.
- Mount outdoor units on the leeward side of the building.
- Secure the unit so that it cannot move, vibrate, or be blown off its support.
- Protect the unit from damage by windborne debris.

Elevated air conditioning compressors.

Fuel

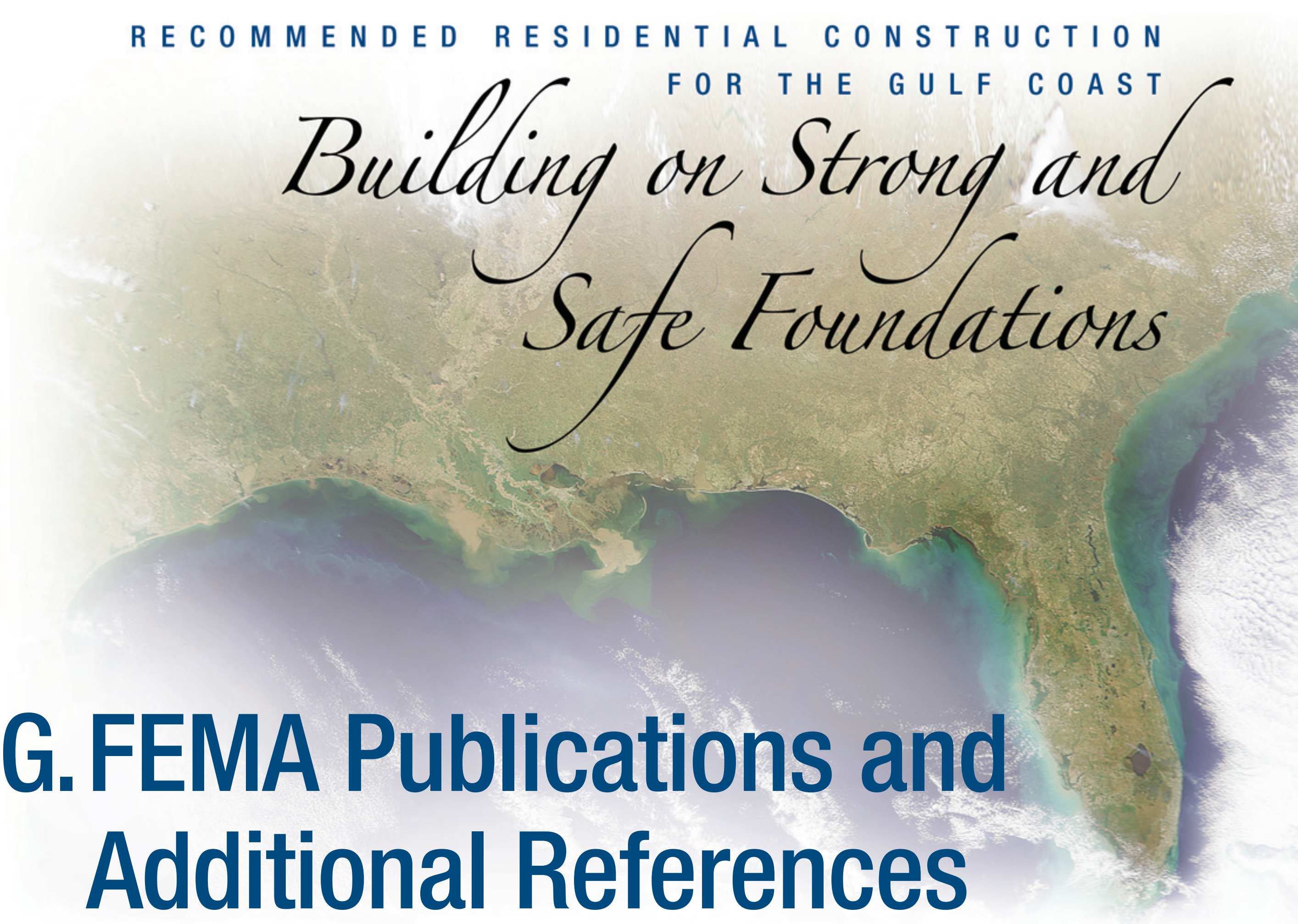
- Fuel tanks should be installed so as to prevent their loss or damage. This will require one of the following techniques: (1) elevation above the DFE and anchoring to prevent blowoff, (2) burial and anchoring to prevent exposure and flotation during erosion and flooding, (3) anchoring at ground level to prevent flotation during flooding and loss during scour and erosion. The first method (elevation) is preferred.
- Any anchoring, strapping, or other attachments must be designed and installed to resist the effects of corrosion and decay.

Additional Resources

American Society of Civil Engineers. *Flood Resistant Design and Construction* (SEI/ASCE 24-98). (http://www.asce.org)

FEMA. NFIP Technical Bulletin 5-93, *Free-Of-Obstruction Requirements for Buildings Located in Coastal High Hazard Areas*. (http://www.fema.gov/fima/techbul.shtm)

FEMA. *Protecting Building Utilities From Flood Damage*. FEMA 348. November 1999. (http://www.fema.gov/hazards/floods/lib06b.shtm)



RECOMMENDED RESIDENTIAL CONSTRUCTION FOR THE GULF COAST

Building on Strong and Safe Foundations

G. FEMA Publications and Additional References

The American Concrete Institute (ACI). 2005. *Building Code Requirements for Structural Concrete and Commentary*, ACI 318. 01-Jan-2005.

American Forest & Paper Association's (AFPM) American Wood Council. 2005. *National Design Specification for Wood Construction.* 2005.

American Society for Testing and Materials (ASTM). 2000. *Standard Test Method for High-Strain Dynamic Testing of Piles*, ASTM D 4945. November 2000.

American Society of Civil Engineers (ASCE) 7-02. 2002. *Minimum Design Loads for Buildings and Other Structures*, ASCE 7-02. ISBN:0-7844-0624-3.

ASCE 24-05. 2006. *Flood Resistant Design and Construction.* ISBN: 0784408181. 01-Jan-2006.

American Wood Preservers' Association (AWPA). 1991. *Care of Pressure-Treated Wood Products.*

FEMA. 1984. *Elevated Residential Structures*, FEMA 54. March 1984.

FEMA. 1995. *Guide to Flood Maps: How to Use a Flood Map to Determine Flood Risk for a Property*, FEMA 258. May 1995.

FEMA. 1996. *Corrosion Protection for Metal Connectors in Coastal Areas for Structures Located in Special Flood Hazard Areas,* FEMA Technical Bulletin 8-96. August 1, 1996.

FEMA. 2000. *Coastal Construction Manual*, FEMA 55. June 2000.

FEMA. 2000. *Design and Construction Guidance for Community Shelters*, FEMA 361. July 2000.

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FEMA. 2004. *Taking Shelter From the Storm: Building a Safe Room Inside Your House*, FEMA 320. March 2004.

FEMA. 2005. *Mitigation Assessment Team Report: Hurricane Charley in Florida,* FEMA 488. April 2005.

FEMA. 2005. *Mitigation Assessment Team Report: Hurricane Ivan in Alabama and Florida,* FEMA 489. August 2005.

FEMA. 2005. *Home Builders' Guide to Coastal Construction Technical Fact Sheets*, FEMA 499. August 2005.

FEMA. 2006. *Mitigation Assessment Team Report: Hurricane Katrina in the Gulf Coast,* FEMA 549. July 2006.

FEMA. 2006. *Flood Insurance Manual*. http://www.fema.gov/business/nfip/manual.shtm. May 2006.

International Building Code (IBC). 2003. 2003 International Building Code. 01-Jan-2005.

International Residential Code (IRC). 2003. *International Residential Code for One- and Two- Family Dwellings*. 01-Mar-2003.

Mississippi Governor's Rebuilding Commission on Recovery, Rebuilding and Renewal. 2005. *A Pattern Book for Gulf Coast Neighborhoods*. November 2005.

National Fire Protection Association (NFPA). 2003. *NFPA 5000®: Building Construction and Safety Code®*, 2003 Edition.

H. Glossary

3-second peak gust – The wind speed averaging time used in ASCE 7 and the IBC.

A Zone – A Zones are the areas not listed as V Zones, but also identified on a Flood Insurance Rate Map (FIRM) as being subject to inundation during a 100-year flood. The associated flood elevation has a 1-percent chance of being equaled or exceeded in any given year. There are several categories of A Zones that may be identified on a FIRM with one of the following designations: AO, AH, A1-30, AE, and unnumbered A Zones.

Allowable Stress Design (ASD) – A method of proportioning structural members such that elastically computed stresses produced in the members by nominal loads do not exceed specified allowable stresses (also called working stress design) (ASCE 7-02).

Base flood - A flooding having a 1 percent chance of being equaled or exceeded in any given year; also known as the 100-year flood.

Base Flood Elevation (BFE) – Elevation of the 1-percent flood. This elevation is the basis of the insurance and floodplain management requirements of the National Flood Insurance Program (NFIP).

Coastal A Zone – The portion of the Special Flood Hazard Area (SFHA) landward of a V Zone or landward of an open coast without mapped V Zones (e.g., the shorelines of the Great Lakes), in which the principal sources of flooding are astronomical tides, storm surges, seiches, or tsunamis, not riverine sources. Like the flood forces in V Zones, those in Coastal A Zones are highly correlated with coastal winds or coastal seismic activity. Coastal A Zones may therefore be subject to wave effects, velocity flows, erosion, scour, or combinations of these forces. During base flood conditions, the potential for breaking wave heights between 1.5 feet and 3.0 feet will exist. Coastal A Zones are not shown on present day FIRMs or mentioned in a community's Flood Insurance Study (FIS) Report.

Crawlspace foundation – Crawlspace foundations are typically low masonry perimeter walls with interior piers supporting a wood floor system. These foundations are usually supported by shallow footings and are prone to failure caused by erosion or scour.

Design flood – The design flood is often, but not always equal to the base flood for areas identified as Special Flood Hazard Areas (SFHAs) on a community's FIRM.

Design Flood Elevation (DFE) – The elevation of the Design Flood, including wave height relative to the datum specified on a community's Flood Hazard Map (American Society of Civil Engineers [ASCE 7-02]).

Design professional – A state licensed architect or engineer.

Erosion – Process by which floodwaters lower the ground surface in an area by removing upper layers of soil.

Exposure Category B – A wind exposure identified in ASCE 7 and the International Building Code (IBC) as urban and suburban areas, wooded areas, or other terrain with numerous closely spaced obstructions having the size of single-family dwellings or larger.

Exposure Category C – A wind exposure identified in ASCE 7 and the IBC as open terrain with scattered obstructions having heights generally less than 30 feet (9.1 meters). This category includes flat open country, grasslands, and all water surfaces in hurricane-prone regions.

Flood Insurance Rate Map (FIRM) – An official map of a community, on which FEMA has delineated both the SFHA and the risk premium zones applicable to the community. The map shows the extent of the base floodplain and may also display the extent of the floodway and BFEs.

Freeboard – The height added to place a structure above the base flood to reduce the potential for flooding. The increased elevation of a building above the minimum design flood level to provide additional protection for flood levels higher than the 1-percent chance flood level and to compensate for inherent inaccuracies in flood hazard mapping.

Hydrodynamic forces – The amount of pressure exerted by moving floodwaters on an object, such as a structure. Among these loads are positive frontal pressure against the structure, drag forces along the sides, and suction forces on the downstream side.

Hydrostatic forces – The amount of lateral pressure exerted by standing or slowly moving floodwaters on a horizontal or vertical surface, such as a wall or a floor slab. The water pressure increases with the square of the water depth.

Leeward – The side away, or sheltered, from the wind.

National Flood Insurance Program (NFIP) – The NFIP is a Federal program enabling property owners in participating communities to purchase insurance as a protection against flood losses in exchange for State and community floodplain management regulations that reduce future flood damages. Participation in the NFIP is based on an agreement between communities and the Federal Government. If a community adopts and enforces floodplain management regulations to reduce future flood risk to new construction in floodplains, the Federal Government will make flood insurance available within the community as a financial protection against flood losses. This insurance is designed to provide an insurance alternative to disaster assistance to reduce the escalating costs of repairing damage to buildings and their contents caused by floods. The program was created by Congress in 1968 with the passage of the National Flood Insurance Act of 1968.

National Geodetic Vertical Datum 1929 (NGVD 1929) – A vertical elevation baseline determined in 1929 as a national standard. Used as the standard for FIRMs until 2000.

North American Vertical Datum 1988 (NAVD 1988) – A vertical elevation baseline determined in 1988 as a more accurate national standard. The current vertical elevation standard for new FIRMs.

Scour – Erosion by moving water in discrete locations, often as a result of water impacting foundation elements.

Shore-normal – Perpendicular to the shoreline.

Slab-on-grade foundation – Type of foundation in which the lowest floor of the house is formed by a concrete slab that sits directly on the ground.

Slug – A unit of mass in the English foot-pound-second system. One slug is the mass accelerated at 1 foot per second (fps) by a force of 1 pound (lb). Since the acceleration of gravity (g) in English units is 32.174 fps, the slug is equal to 32.174 pounds (14.593 kilograms).

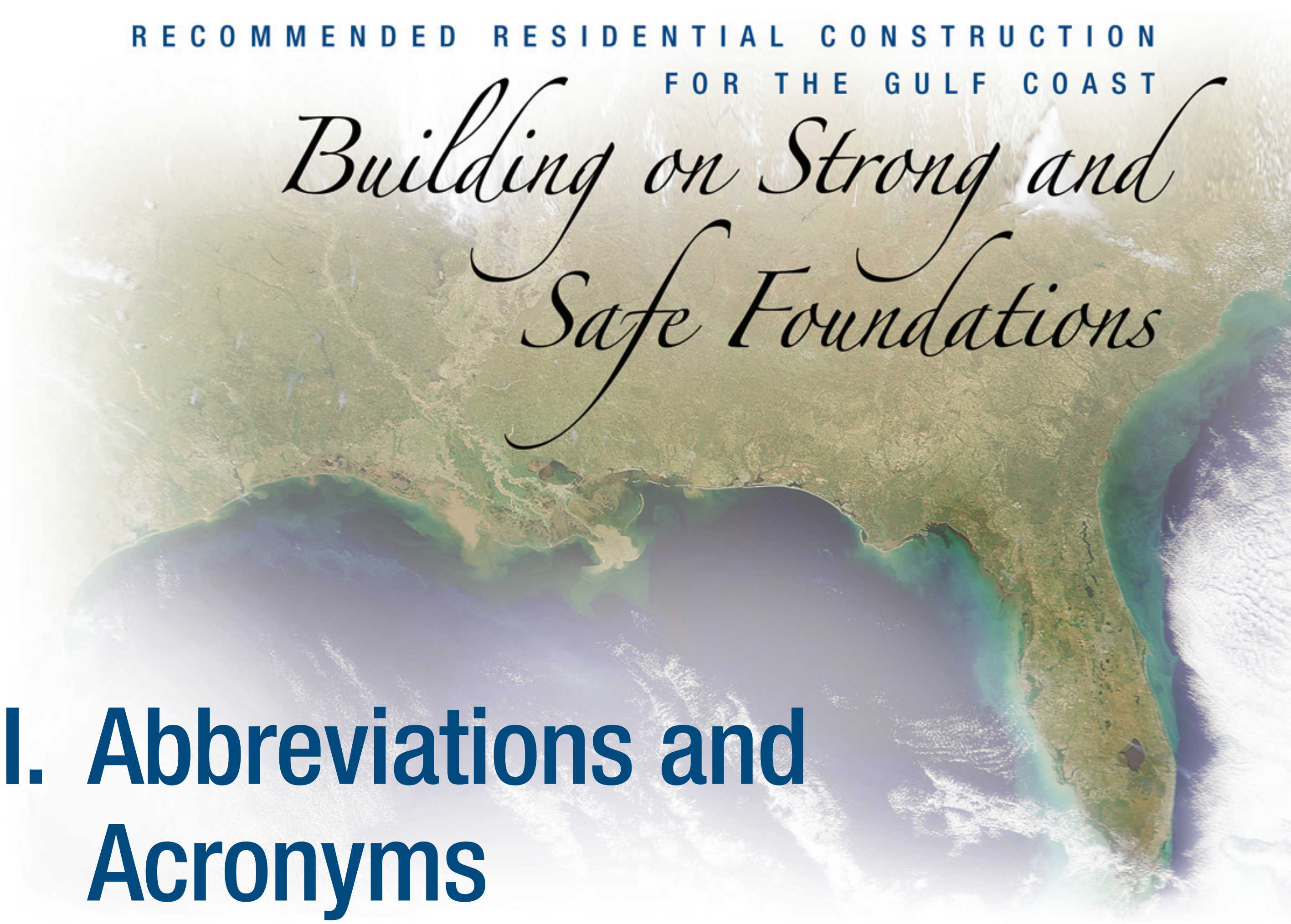
Special Flood Hazard Area (SFHA) – Portion of the floodplain subject to inundation by the base flood.

Stem wall foundation – A type of foundation that uses masonry block and reinforced with steel and concrete. The wall is constructed on a concrete footing, back-filled with dirt, compacted, and the slab is then poured on top.

Strength Design – A method of proportioning structural members such that the computed forces produced in the members by the factored loads do not exceed the member design strength (also called load and resistance factor design) (ASCE 7-02).

V Zones – V Zones are areas identified on FIRMs as zones VE, V1-30, or V. These areas, also known as Coastal High Hazard Areas, are areas along the coast that have a 1 percent or greater annual chance of flooding from storm surge and waves greater than 3 feet in height, as well as being subject to significant wind forces.

Windward – The side facing the wind.



I. Abbreviations and Acronyms

A

ABFE Advisory Base Flood Elevation

ACI American Concrete Institute

AF&PA American Forest & Paper Association

ASCE American Society of Civil Engineers

ASD Allowable Stress Design

ASTM American Society for Testing and Materials

AWPA American Wood Preservers' Association

B

BFE Base Flood Elevation

C

C&C components and cladding

CMU concrete masonry unit

CRSI Concrete Reinforced Steel Institute

cy cubic yard

D

DFE Design Flood Elevation

DL dead load

E

ea each

F

FEMA Federal Emergency Management Agency

FIRM Flood Insurance Rate Map

FIS Flood Insurance Study

fps feet per second

FRP fiber reinforced polyester

ft feet

G

g gravity

I

IBC International Building Code

ICC International Code Council

IRC International Residential Code

K

kip 1,000 pounds

ksi kips per square inch

L

lb pound

lb/sq pounds per square foot

lf linear foot

LL live load

ls lump sum

M

MAT Mitigation Assessment Team

mph miles per hour

MWFRS Main Wind Force Resisting System

N

NAVD North American Vertical Datum of 1988

NDS National Design Specification for Wood

NFIP National Flood Insurance Program

NFPA National Fire Protection Association

NGVD National Geodetic Vertical Datum of 1929

NR Not Recommended

O

o.c. on center

P

pcf pounds per cubic foot

psf pounds per square foot

psi pounds per square inch

R

ROM rough order of magnitude

S

SBC Standard Building Code

SFHA Special Flood Hazard Area

SLOSH Sea, Lake, and Overland Surges from Hurricanes

sq square foot

SWL stillwater elevation

T

TBTO tributylin oxide

TMS The Masonry Society

U

UDA Urban Design Associates

u.n.o. unless noted otherwise

USGS United States Geological Survey

W

WWF welded wire fabrics