Foundations in Coastal Areas

HOME BUILDER'S GUIDE TO COASTAL CONSTRUCTION FEMA 499/August 2005 *Technical Fact Sheet No. 11*

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***.

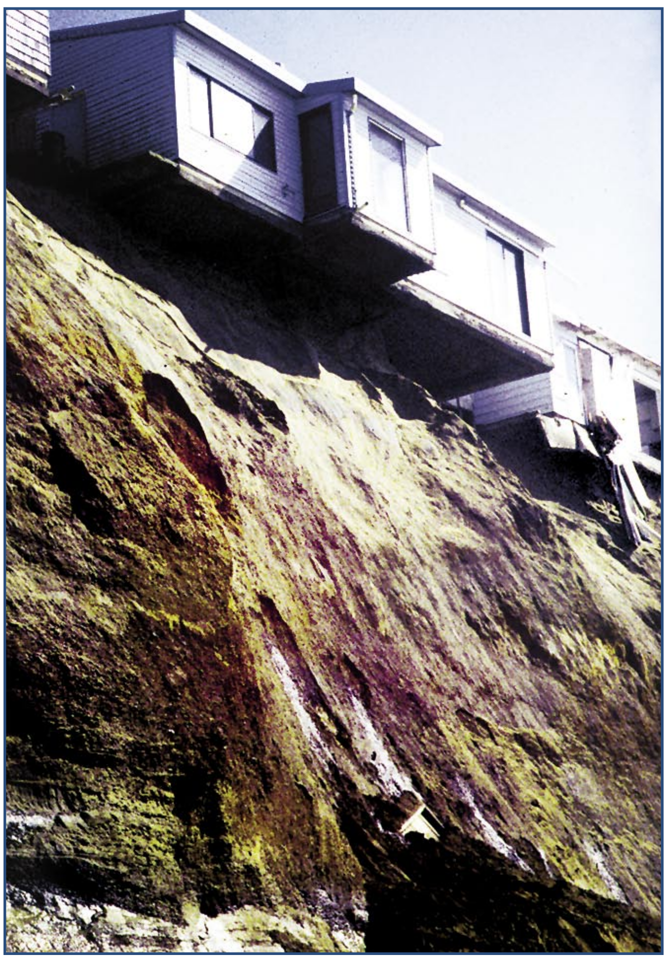
Pile failures led to collapse of floor of elevated building.

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

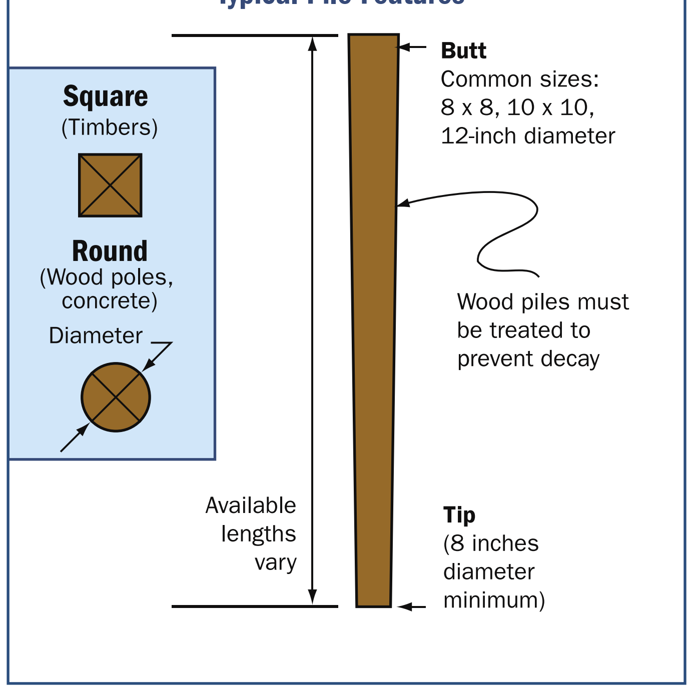
HOME BUILDER'S GUIDE TO COASTAL CONSTRUCTION FEMA 499/August 2005 *Technical Fact Sheet No. 12*

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.)

Typical Pile Features



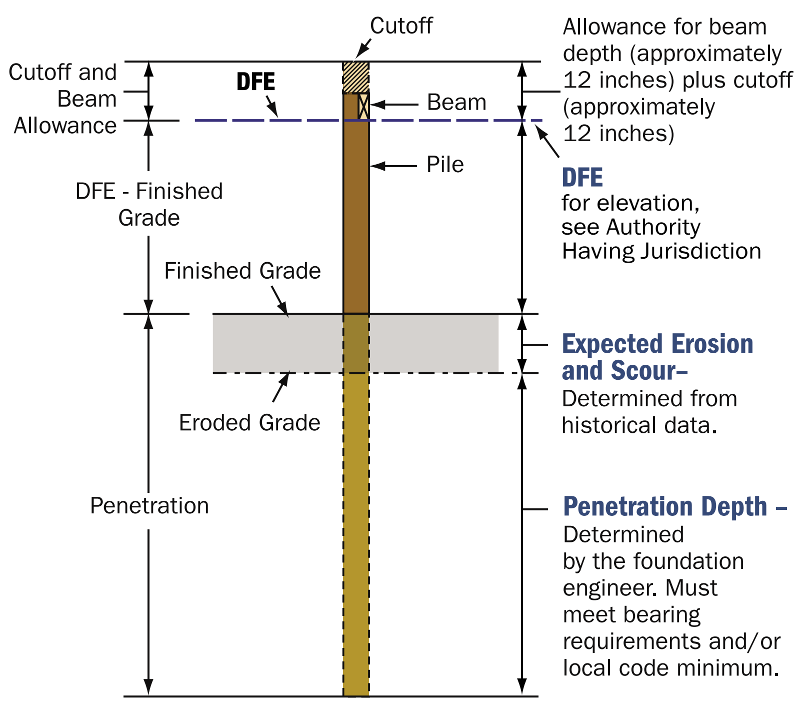
Pile Types

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).

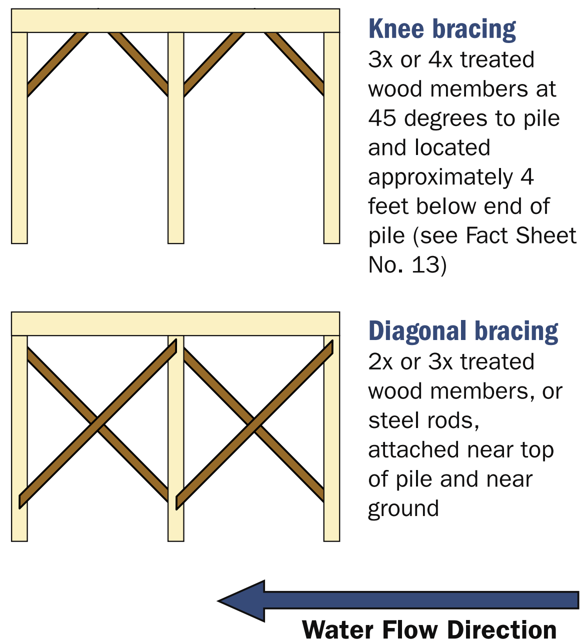
Installation Methods

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.

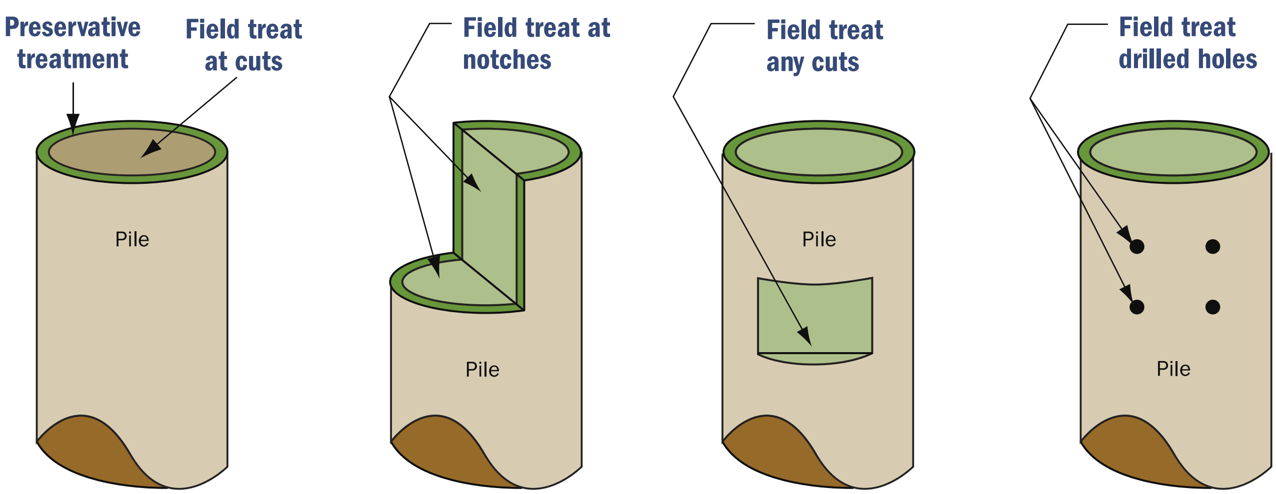
Pile Bracing

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.***

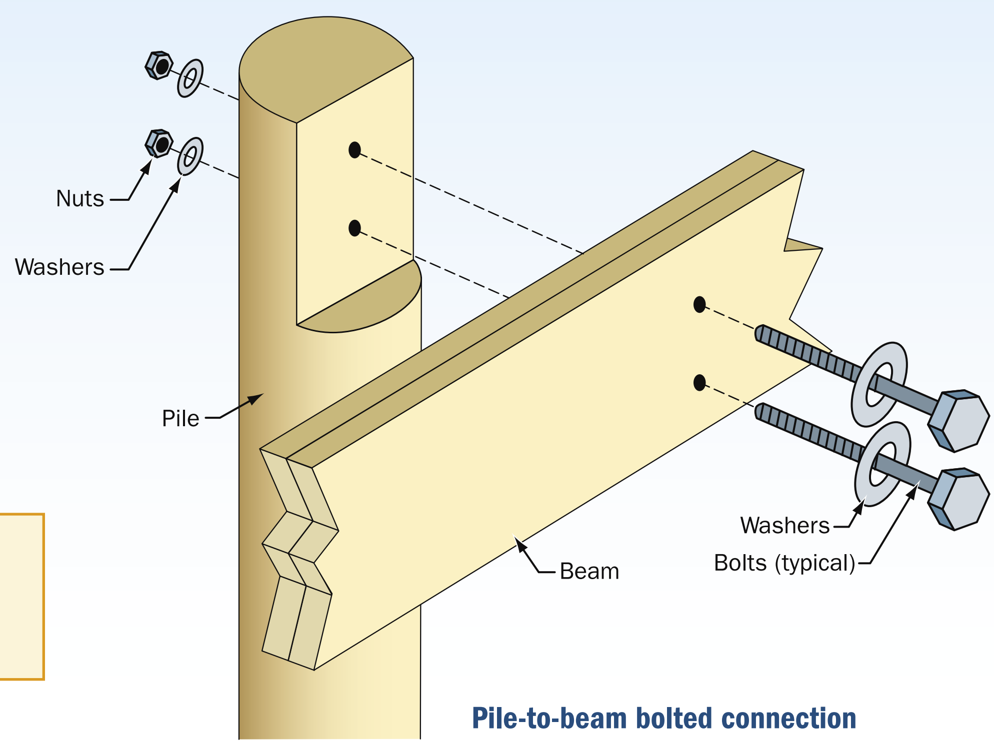
Key Issues

- 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.

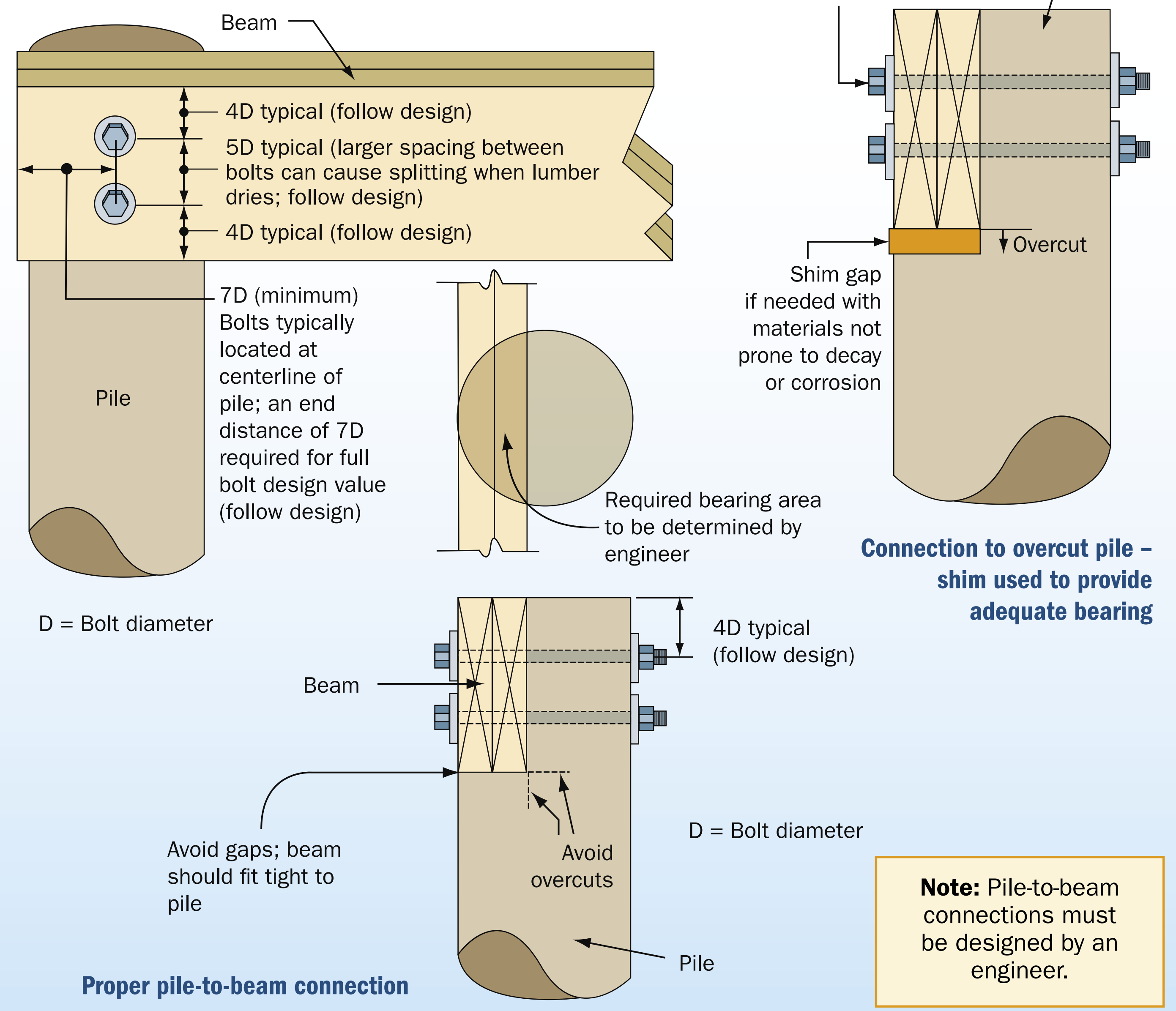
Pile-to-beam connections must:

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

Note: Pile-to-beam connections must be designed by an engineer.



Pile-to-beam bolted connection



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

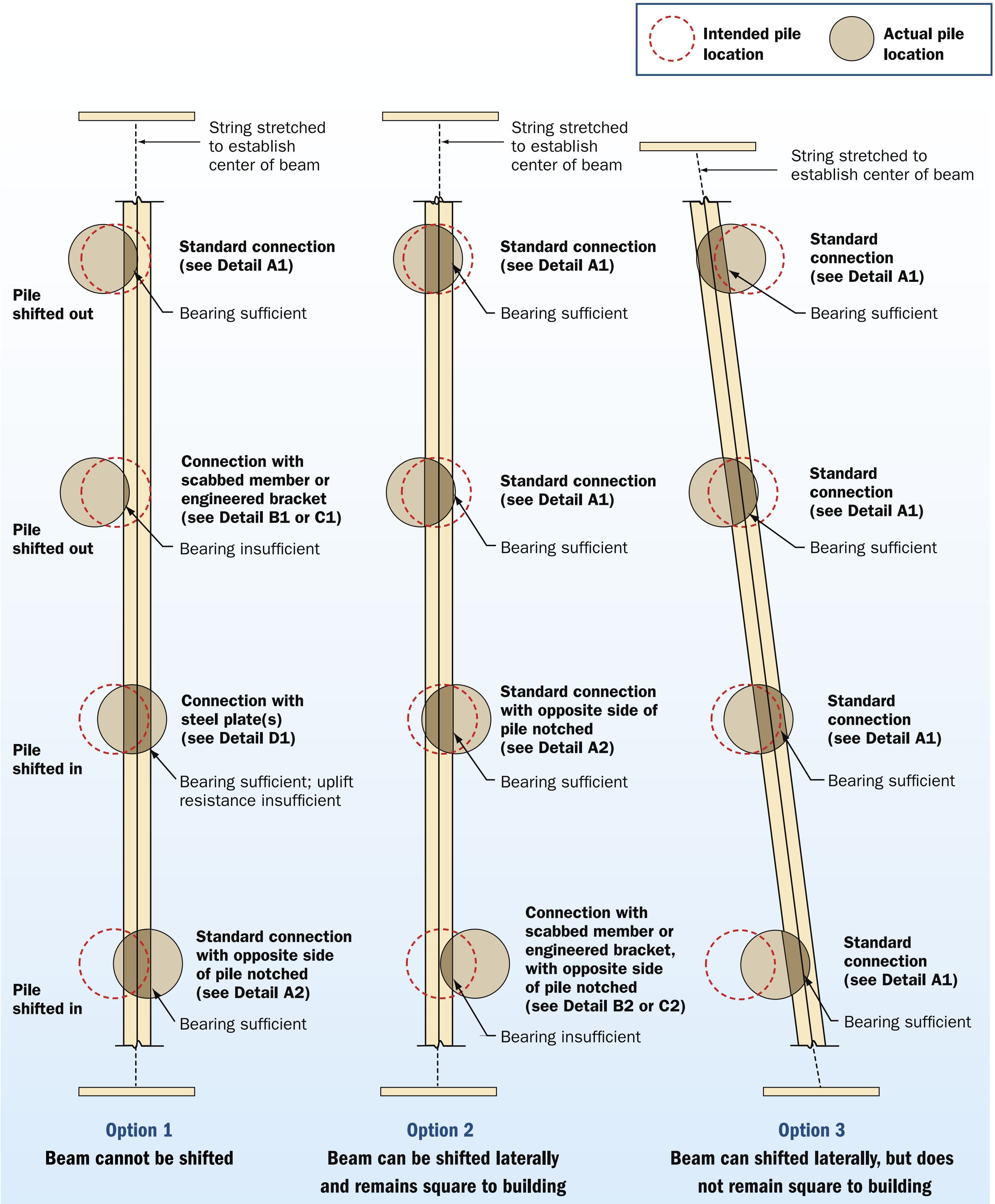
Option 2 (see page 3) – beam can be shifted laterally and remains square to building

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

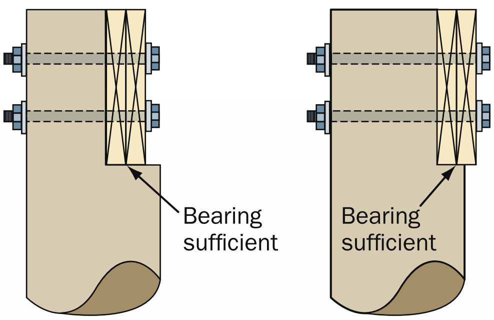


Note: Pile-to-beam connections must be designed by an engineer.

Connections to misaligned piles (see drawings on page 3 and details below)

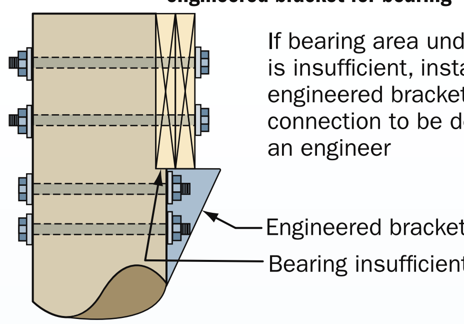
1. The ability to construct the pile-to-beam connections designed by the engineer is directly dependent on the accuracy of pile installation and alignment.
2. Misaligned piles will require the contractor to modify pile-to-beam connections in the field.
3. Badly misaligned piles will require removal and reinstallation, sister piles, or special connections, all to be determined by the engineer.

Detail A1 **Standard connection**



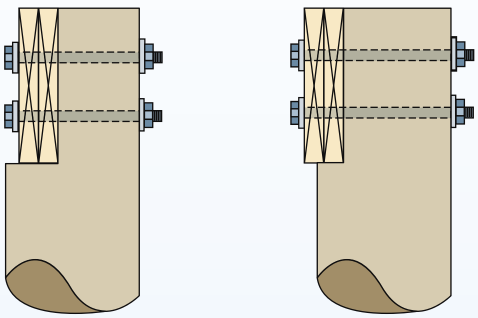
If bearing area under beam is sufficient, a standard bolted connection can be used; if bearing area is insufficient, install scabbed member (Detail B1/B2) or engineered bracket Detail (C1/C2)

Detail C1 **Insufficient bearing – engineered bracket for bearing**

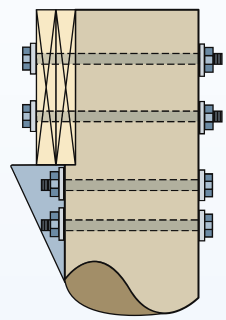


If bearing area under beam is insufficient, install engineered bracket; connection to be designed by an engineer

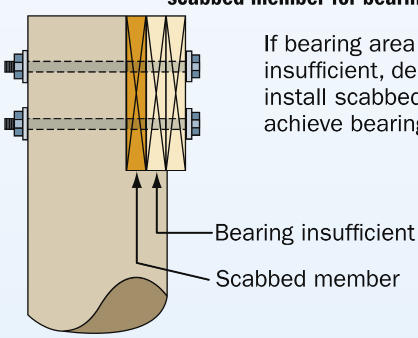
Detail A2 **Standard connection with pile notched on opposite side to avoid overnotching**



Detail C2 **Engineered bracket with pile notched on opposite side to avoid overnotching**

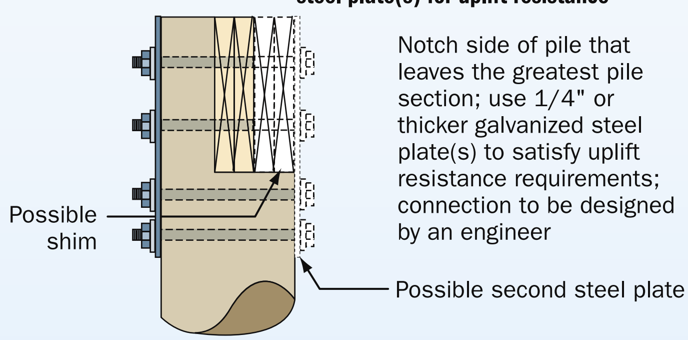


Detail B1 **Insufficient bearing – scabbed member for bearing**



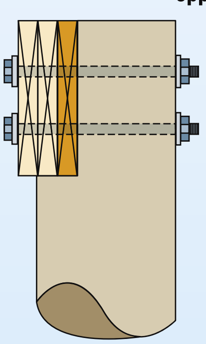
If bearing area under beam is insufficient, deepen notch and install scabbed member to achieve bearing; do not overnotch

Detail D1 **Insufficient uplift capacity – steel plate(s) for uplift resistance**

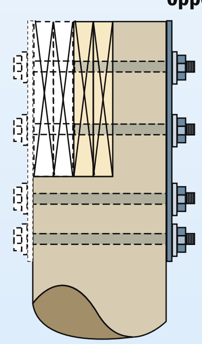


Notch side of pile that leaves the greatest pile section; use 1/4" or thicker galvanized steel plate(s) to satisfy uplift resistance requirements; connection to be designed by an engineer

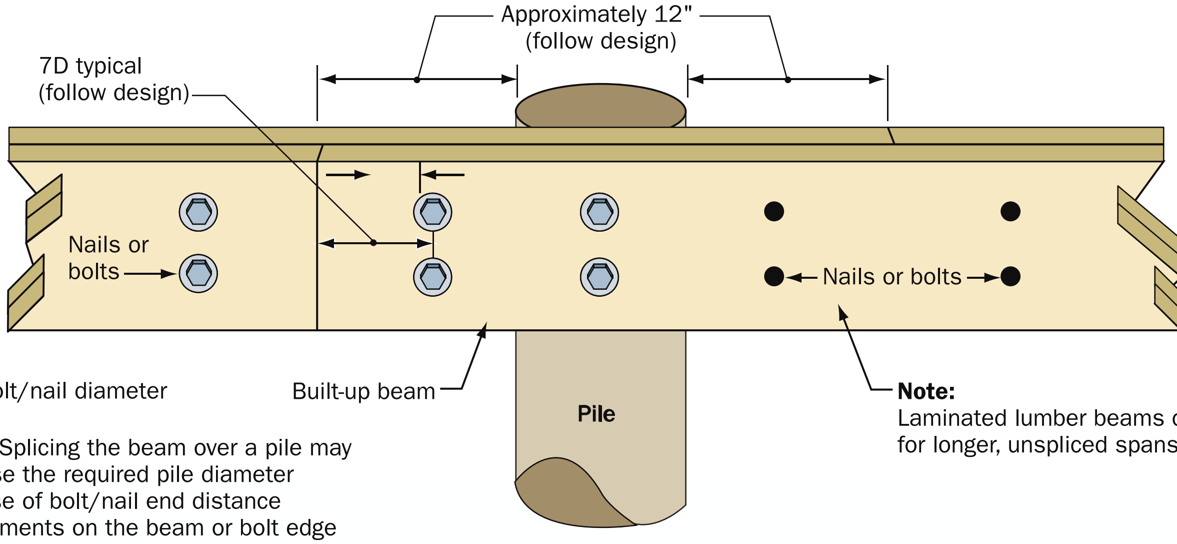
Detail B2 **Scabbed member with pile notched on opposite side to avoid overnotching**



Detail D2 **Steel plate(s) with pile notched on opposite side to avoid overnotching**



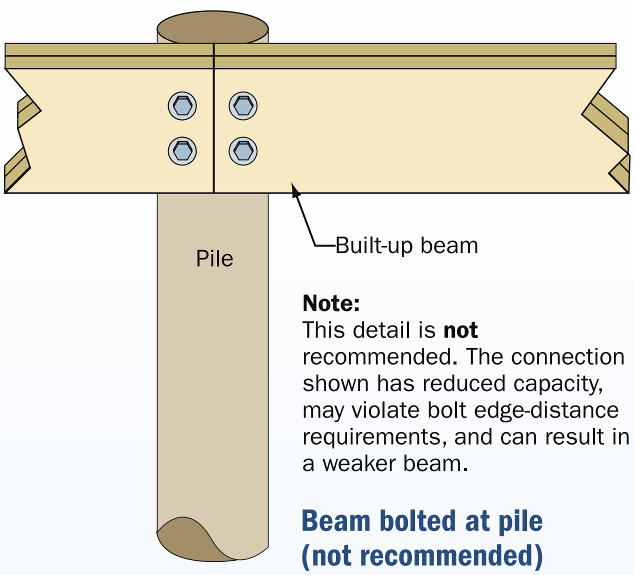
Note: Pile-to-beam connections must be designed by an engineer.



Note: Laminated lumber beams can be used for longer, unspliced spans.

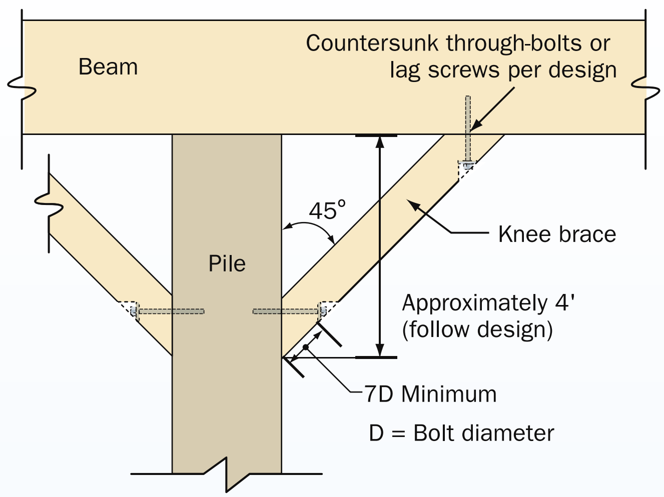
Note: Splicing the beam over a pile may increase the required pile diameter because of bolt/nail end distance requirements on the beam or bolt edge distance requirements on the pile.

Lapped splice (built-up beam)



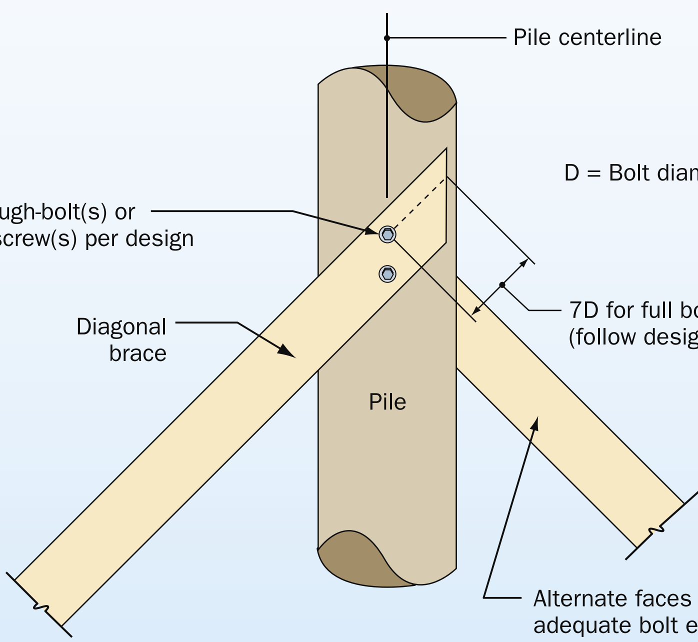
Note:
This detail is **not** recommended. The connection shown has reduced capacity, may violate bolt edge-distance requirements, and can result in a weaker beam.

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.



Note: Pile-to-beam connections must be designed by an engineer.

Diagonal brace connections on round pile

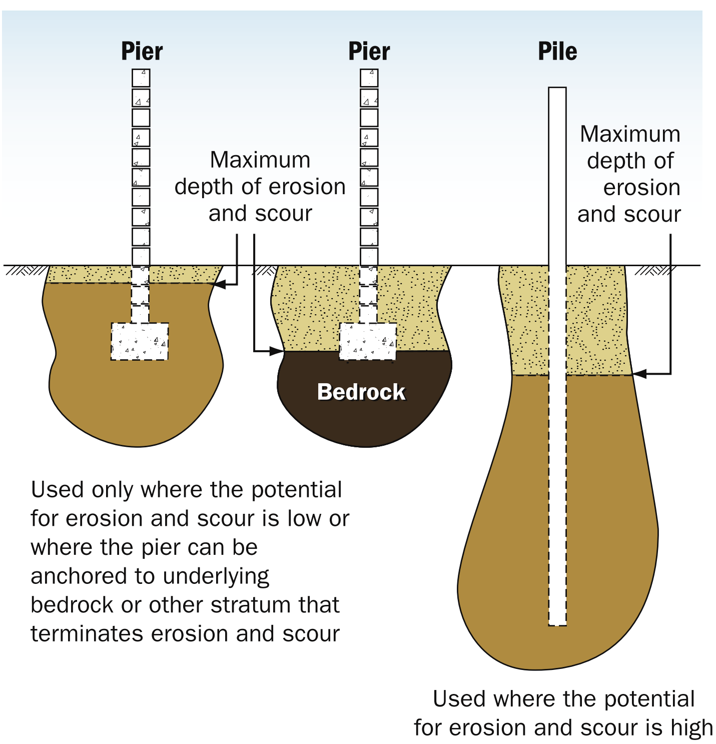
Reinforced Masonry Pier Construction

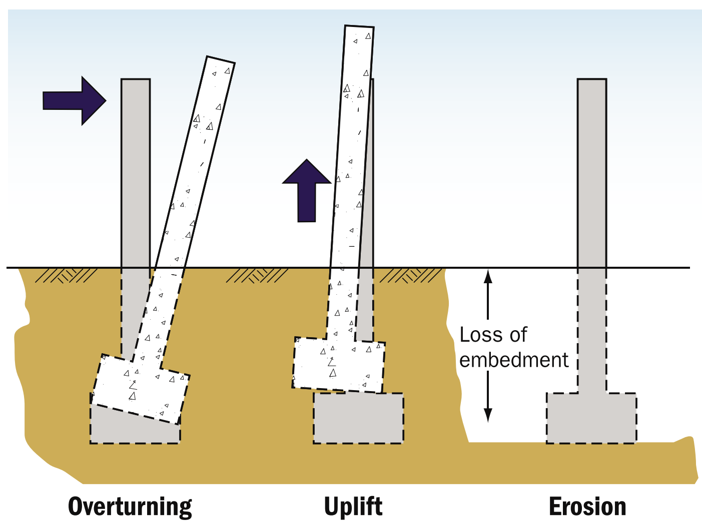
Purpose: To provide an alternative to piles in V zones and A zones in coastal areas where soil properties preclude pile installation, yet the need for an "open foundation system" still exists. Examples of appropriate conditions for the use of piers are where rock is at or near the surface or where the 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.

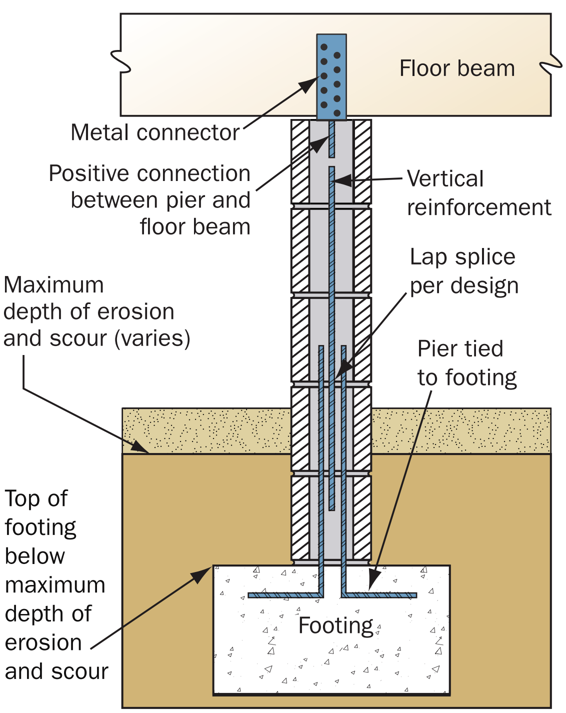
The small footings on the piers in this photograph did not prevent these piers from overturning during Hurricane Iniki.

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.

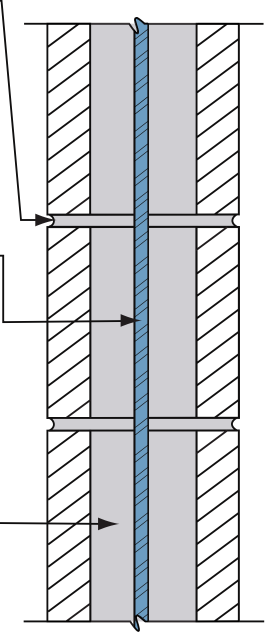
Recommendations for Masonry Piers in Coastal Regions



Head and bed joints must be well mortared and tooled to prevent water intrusion. Type S mortar for below grade is recommended. Concave joints and V-joints provide the best moisture resistance.

Reinforcing bars must be protected from saltwater to prevent corrosion. Good grout practice will normally protect reinforcing. Galvanized or epoxy-coated bars may enhance pier performance, but holidays and chipped coatings must be painted, and lap splice lengths must be increased by 50 percent for epoxy-coated bars.

Grout should be in conformance with the requirements of the IBC 2003. Cleanouts should be placed at the bottom of fully grouted cells to ensure that the grout completely fills the cells from top to bottom.



Foundation Walls

HOME BUILDER'S GUIDE TO COASTAL CONSTRUCTION FEMA 499/August 2005 — Technical Fact Sheet No. 15

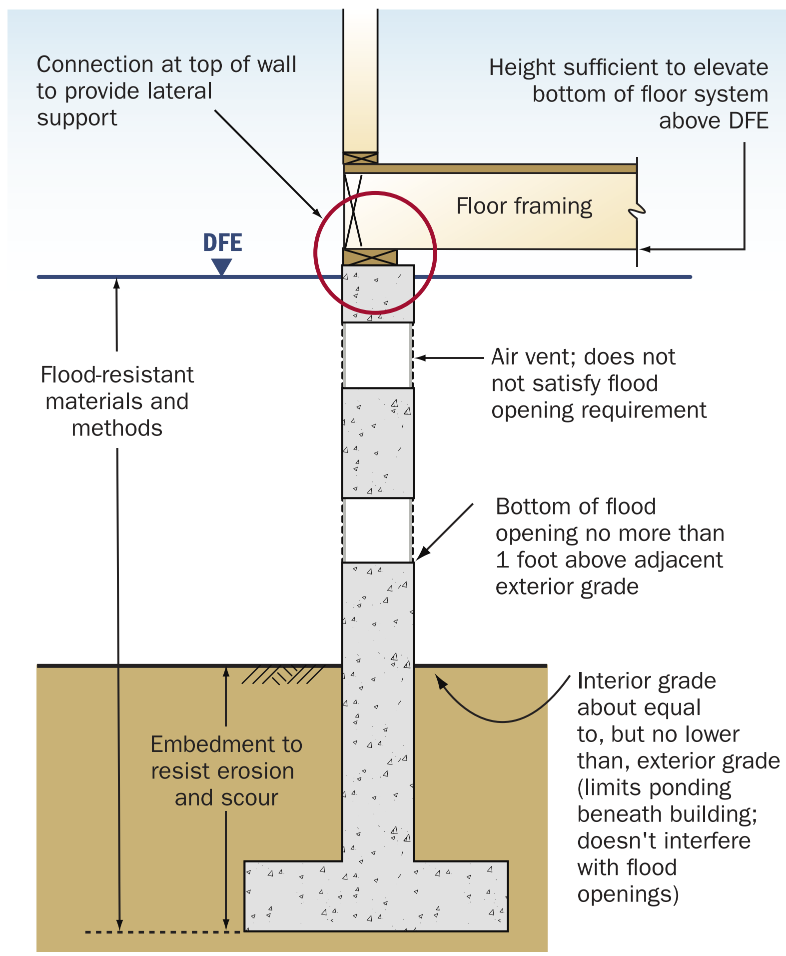
Purpose: To discuss the use of foundation walls in coastal buildings.

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

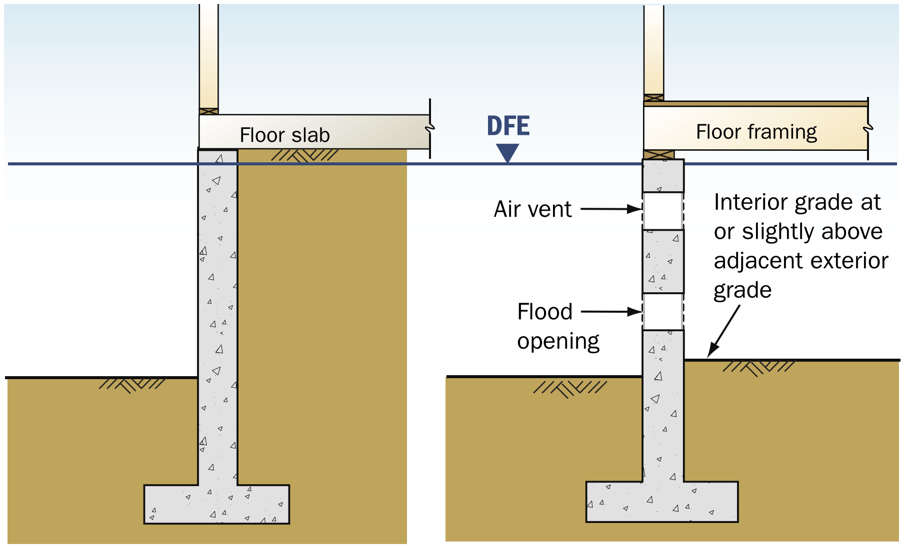
* Note that the use of shearwalls below the Design Flood Elevation (DFE) may be permitted in limited circumstances (e.g., lateral wind/seismic loads cannot be resisted with a braced, open foundation. In such cases, minimize the length of shearwalls and the degree of obstruction to floodwaters and waves, 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

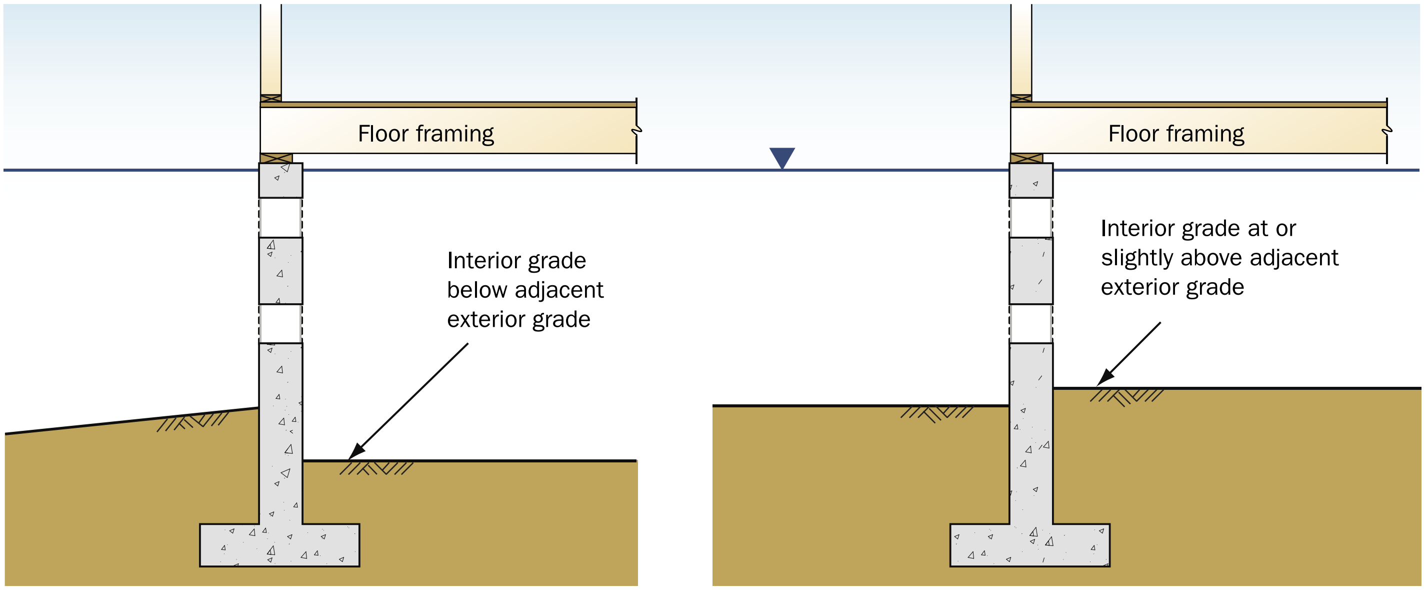
Materials and Workmanship – Foundation walls can be constructed from many materials, but masonry, concrete, and wood are the most common. Each material can be specified and used in a manner to resist damage due to moisture and inundation (see Fact Sheet No. 8). Workmanship for flood-resistant foundations 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

HOME BUILDER'S GUIDE TO COASTAL CONSTRUCTION FEMA 499/August 2005 *Technical Fact Sheet No. 16*

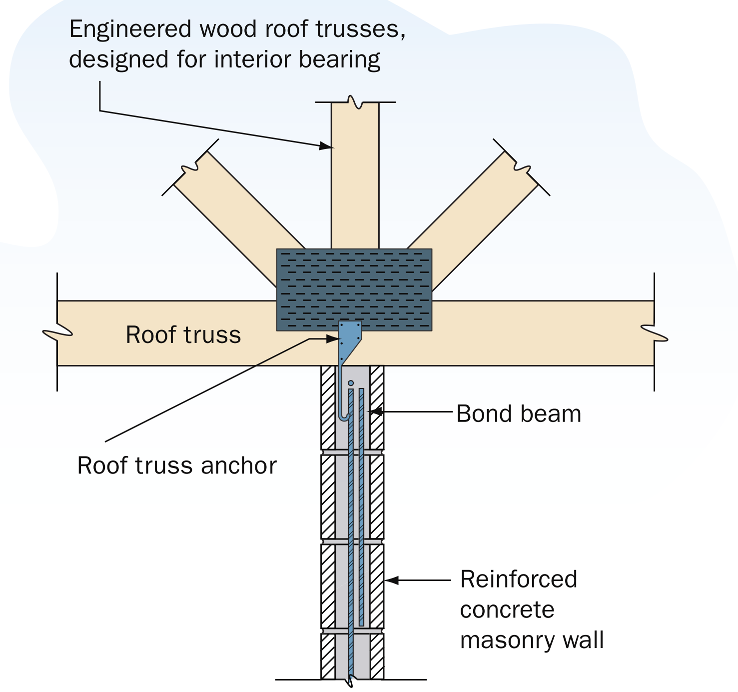
Purpose: To highlight several important details for masonry construction in coastal areas.

Key Issues

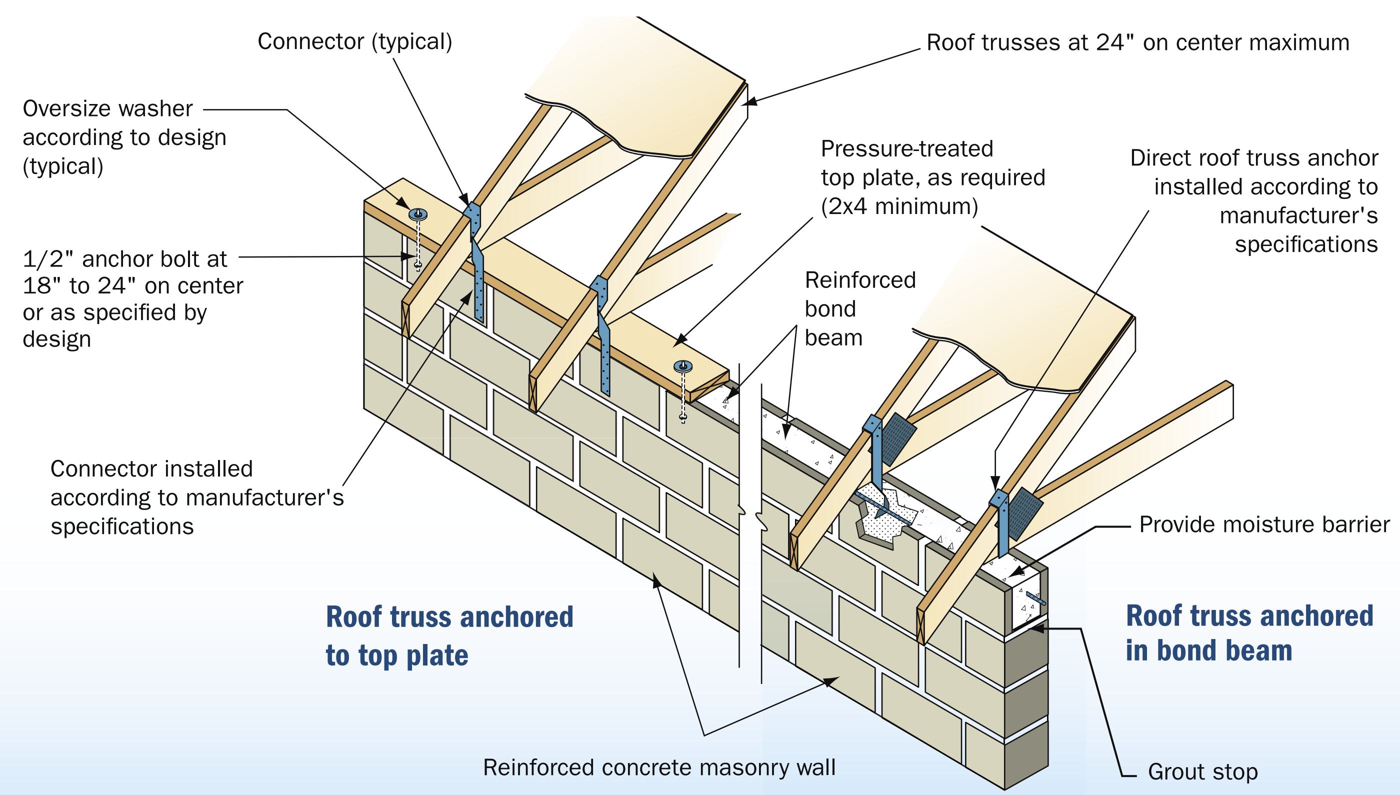
- Continuous, properly connected load paths are essential because of the higher vertical and lateral loads on coastal structures.
- Building materials must be durable enough to withstand the coastal environment.
- Masonry reinforcement requirements are more stringent in coastal areas.

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.

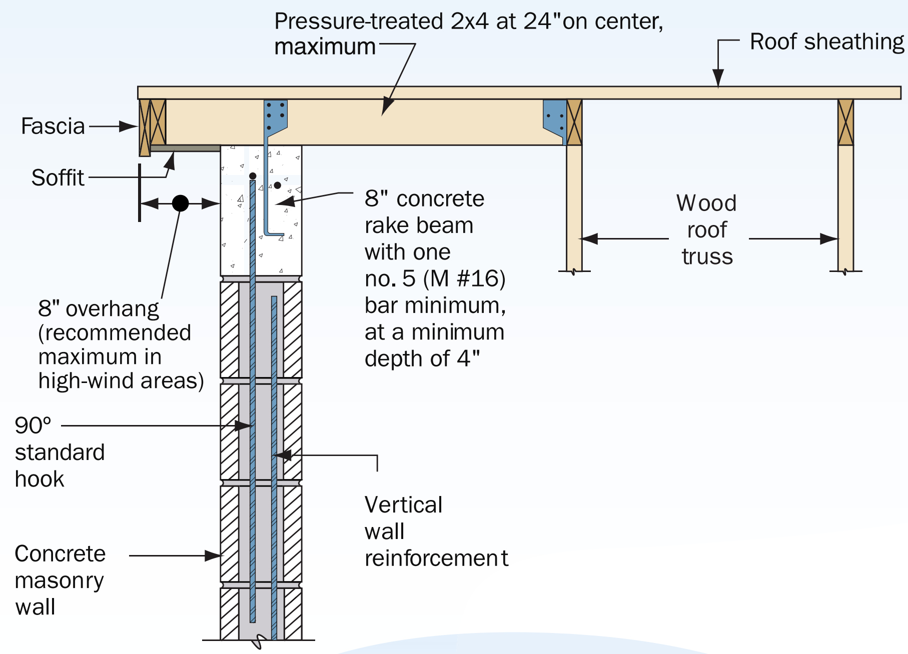


Roof framing to interior masonry wall

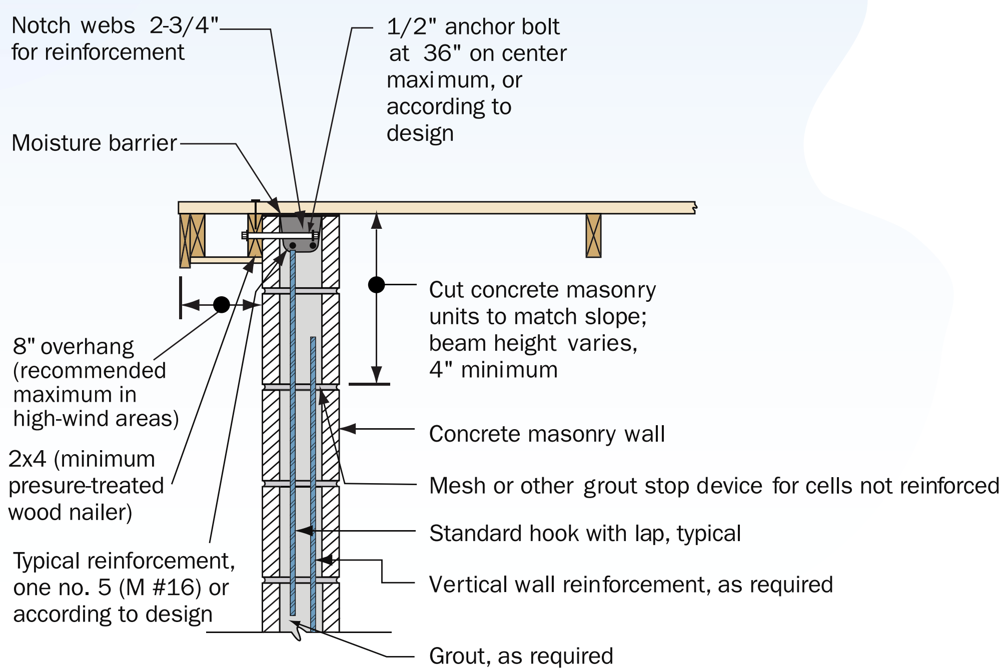


Roof framing to masonry wall.

Gable end wall – cut concrete rake beam with outlooker-type overhang



Gable end wall – cut masonry rake beam with ladder-type overhang

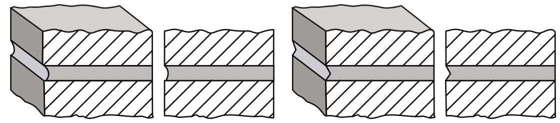


Gable endwall connection.

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.

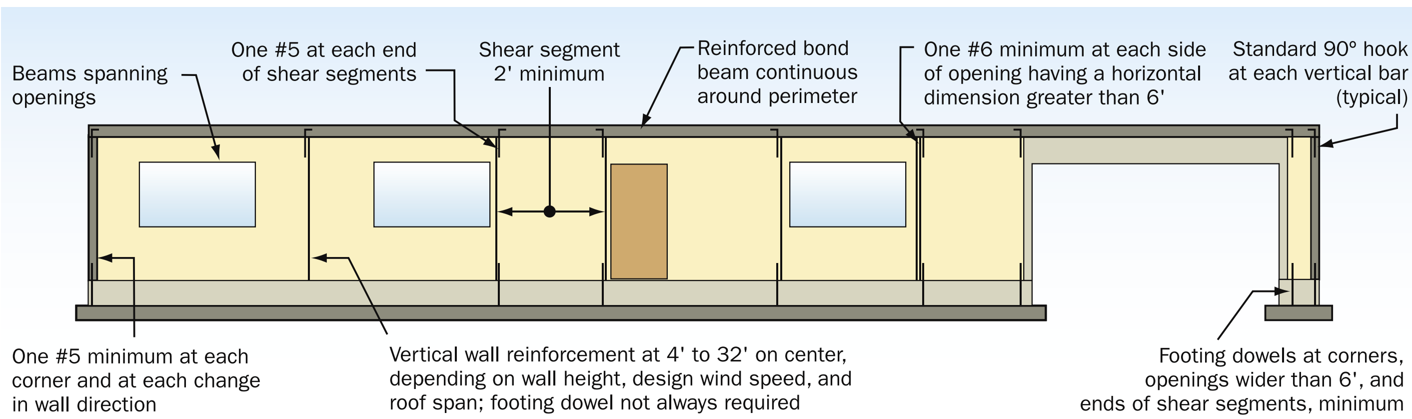
Quality depends on:

- **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.



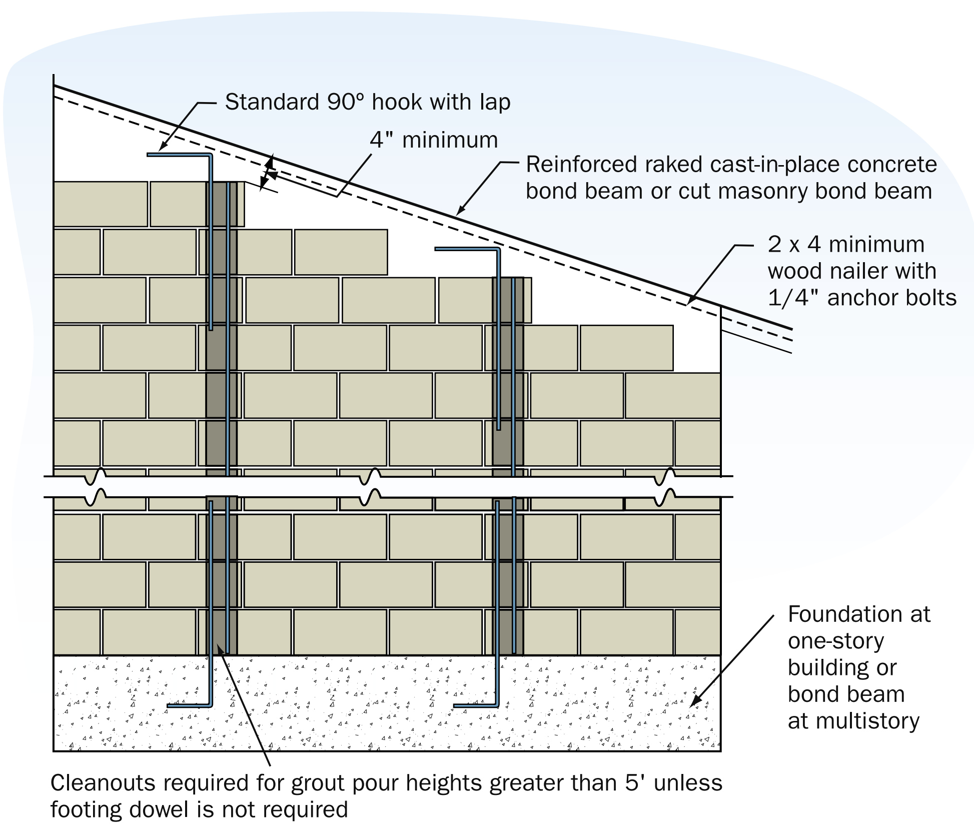
- **Good workmanship –** Head and bed joints must be well mortared and well tooled. Concave joints and V-joints provide the best moisture protection (see detail above). All block walls should be laid with full mortar coverage on horizontal and vertical face shells. Block should be laid using a "double 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.

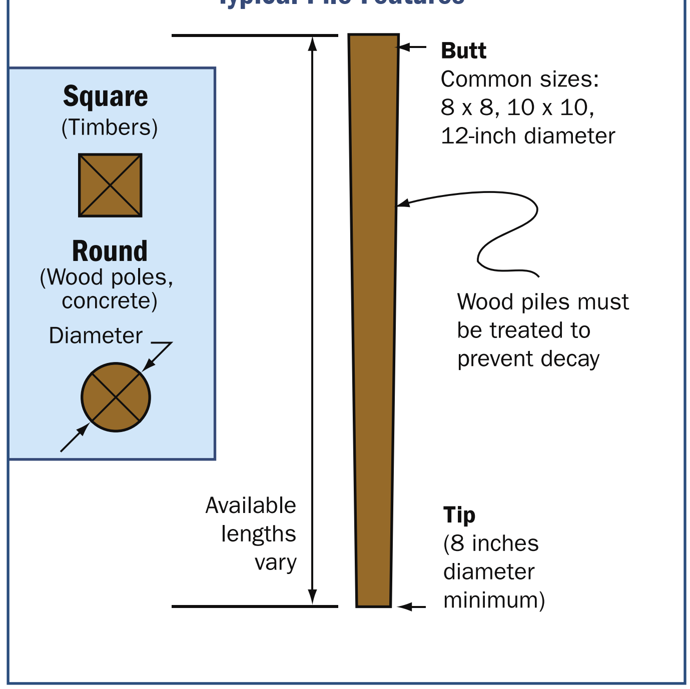
Pile Installation

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.)



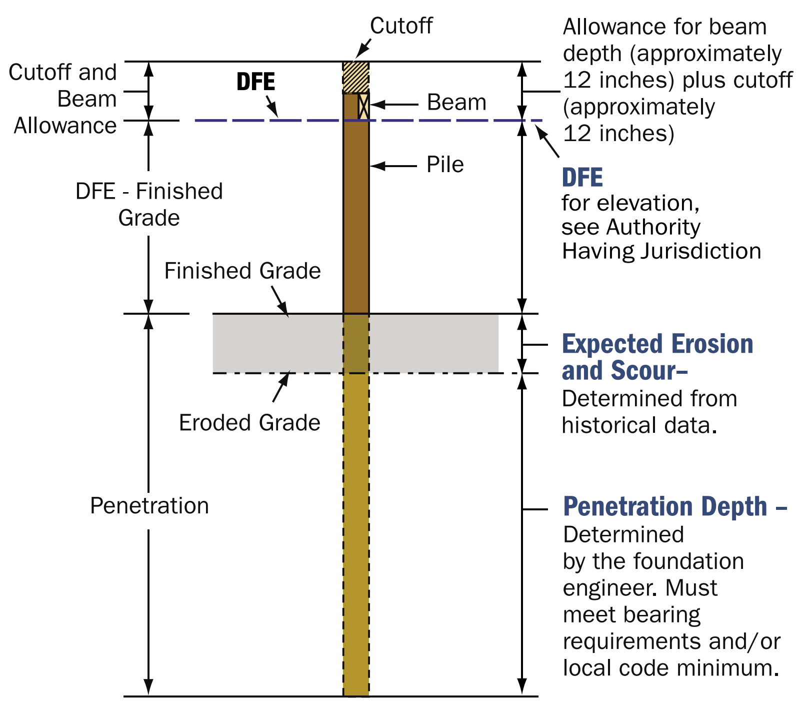
Typical Pile Features

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).

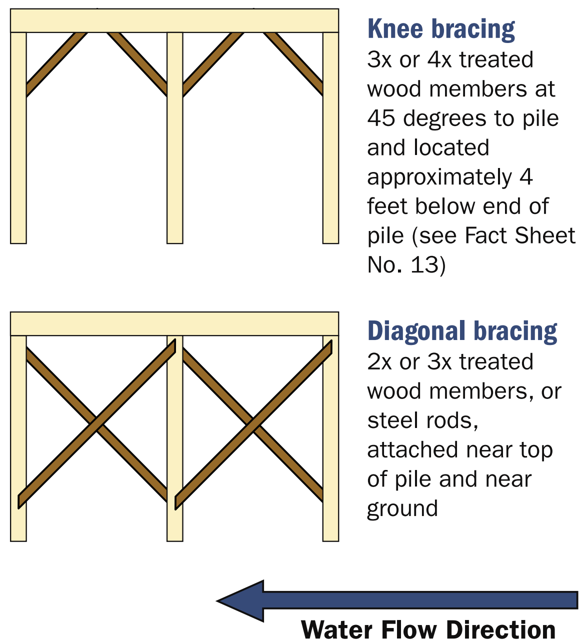
Installation Methods

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.

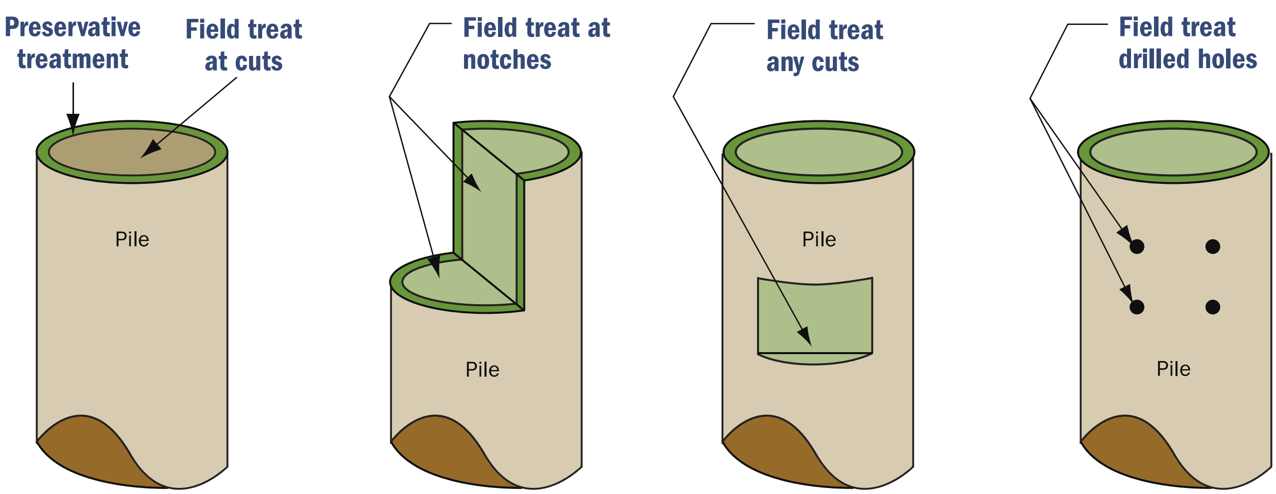
Pile Bracing

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

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.***

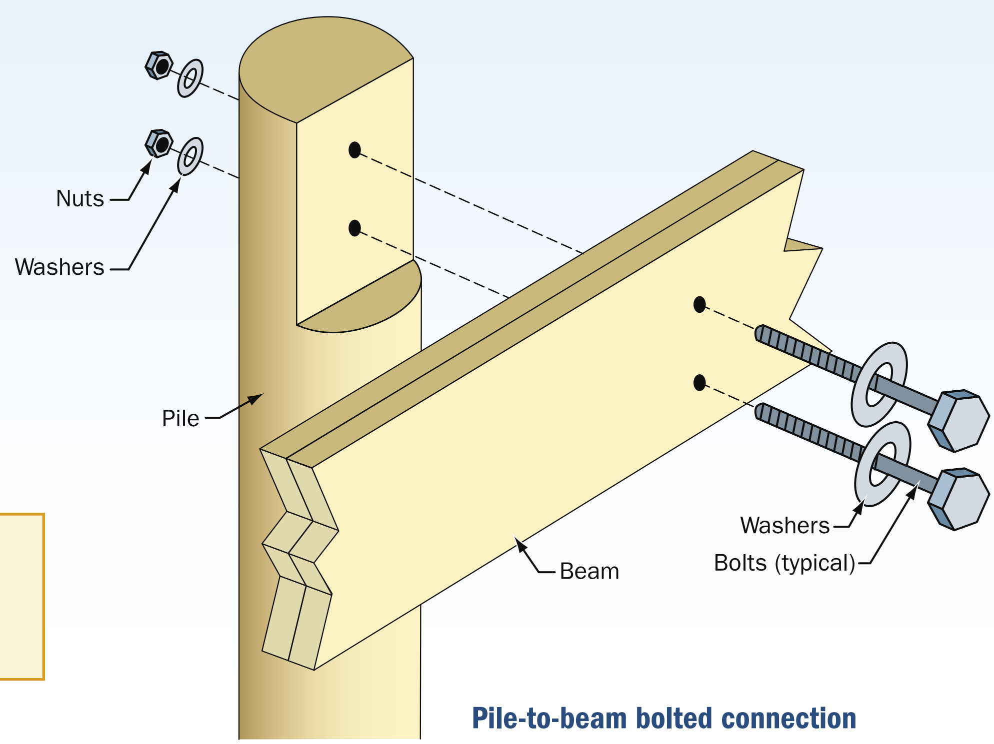
Key Issues

- 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:

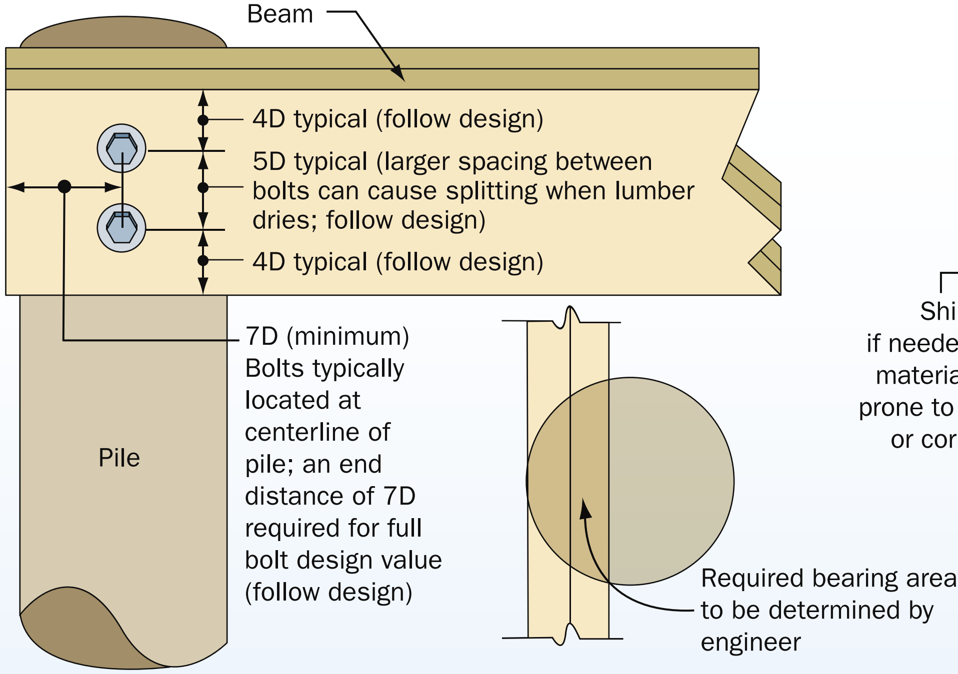
1. provide required ***bearing*** area for beam to rest on pile
2. provide required ***uplift*** (tension) resistance
3. maintain beam in an ***upright*** position
4. be capable of resisting ***lateral*** loads (wind and seismic)
5. be constructed with ***durable*** connectors and fasteners

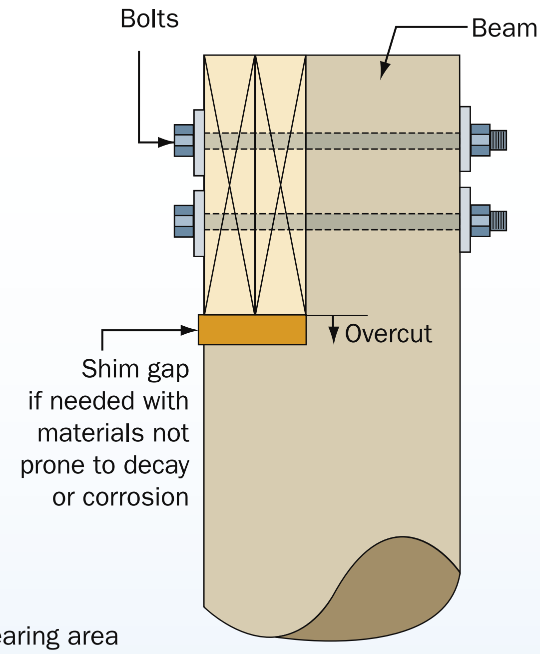
Note: Pile-to-beam connections must be designed by an engineer.



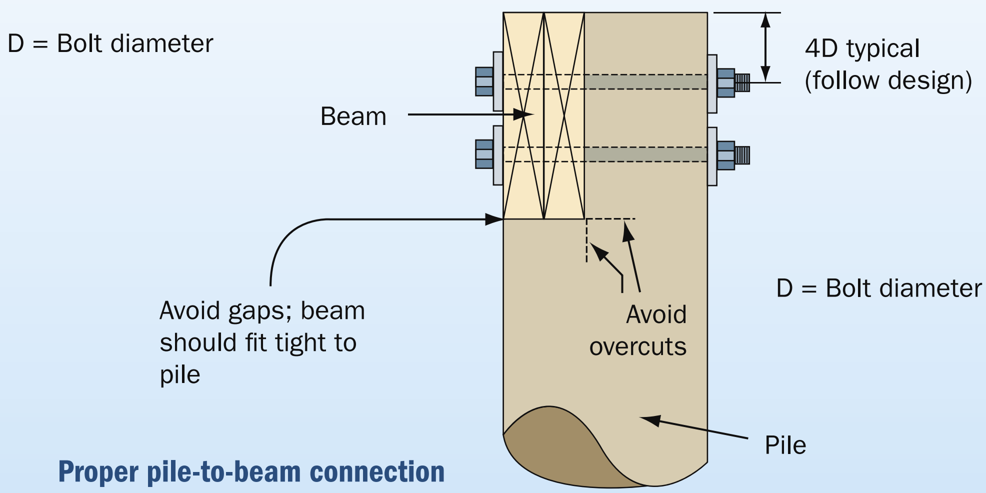
Pile-to-beam bolted connection

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

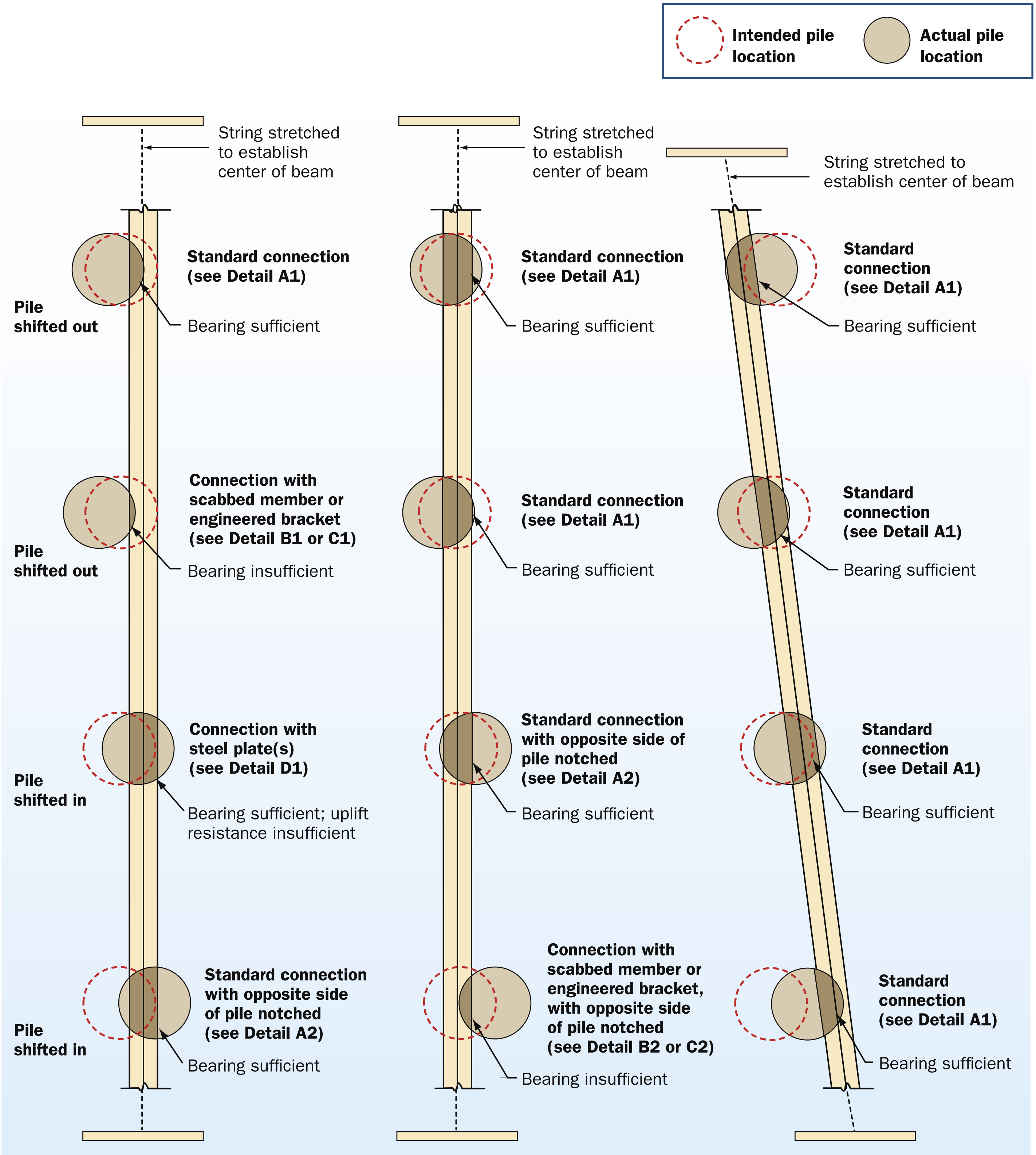
Option 2 (see page 3) – beam can be shifted laterally and remains square to building

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



Option 1
Beam cannot be shifted

Option 2
Beam can be shifted laterally and remains square to building

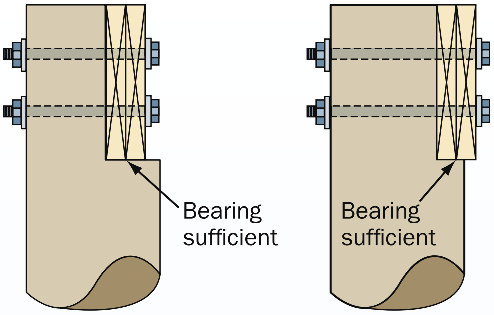
Option 3
Beam can shifted laterally, but does not remain square to building

Note: Pile-to-beam connections must be designed by an engineer.

Connections to misaligned piles (see drawings on page 3 and details below)

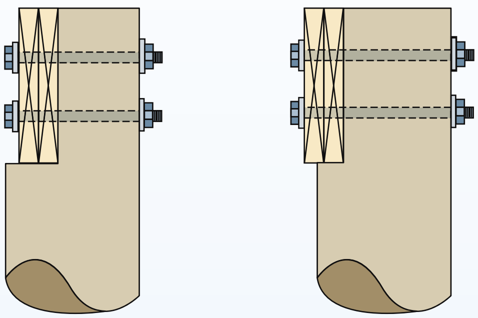
1. The ability to construct the pile-to-beam connections designed by the engineer is directly dependent on the accuracy of pile installation and alignment.
2. Misaligned piles will require the contractor to modify pile-to-beam connections in the field.
3. Badly misaligned piles will require removal and reinstallation, sister piles, or special connections, all to be determined by the engineer.

Detail A1 **Standard connection**



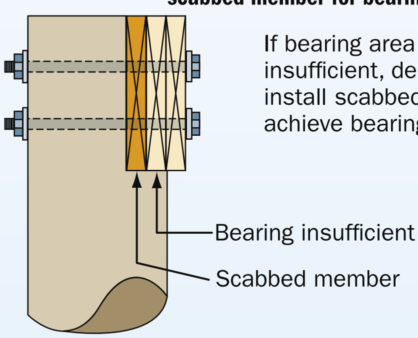
If bearing area under beam is sufficient, a standard bolted connection can be used; if bearing area is insufficient, install scabbed member (Detail B1/B2) or engineered bracket Detail (C1/C2)

Detail A2 **Standard connection with pile notched on opposite side to avoid overnotching**

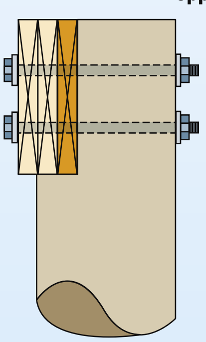


Detail B1 **Insufficient bearing – scabbed member for bearing**

If bearing area under beam is insufficient, deepen notch and install scabbed member to achieve bearing; do not overnotch

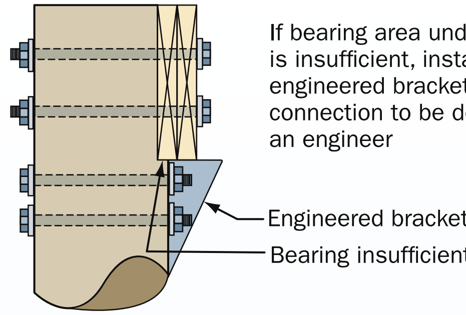


Detail B2 **Scabbed member with pile notched on opposite side to avoid overnotching**

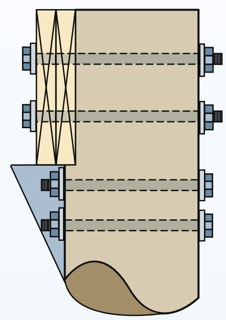


Detail C1 **Insufficient bearing – engineered bracket for bearing**

If bearing area under beam is insufficient, install engineered bracket; connection to be designed by an engineer

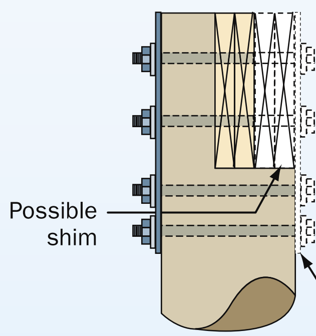


Detail C2 **Engineered bracket with pile notched on opposite side to avoid overnotching**

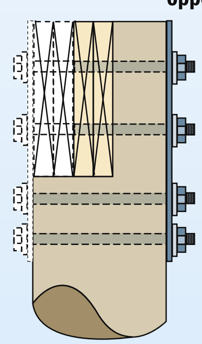


Detail D1 **Insufficient uplift capacity – steel plate(s) for uplift resistance**

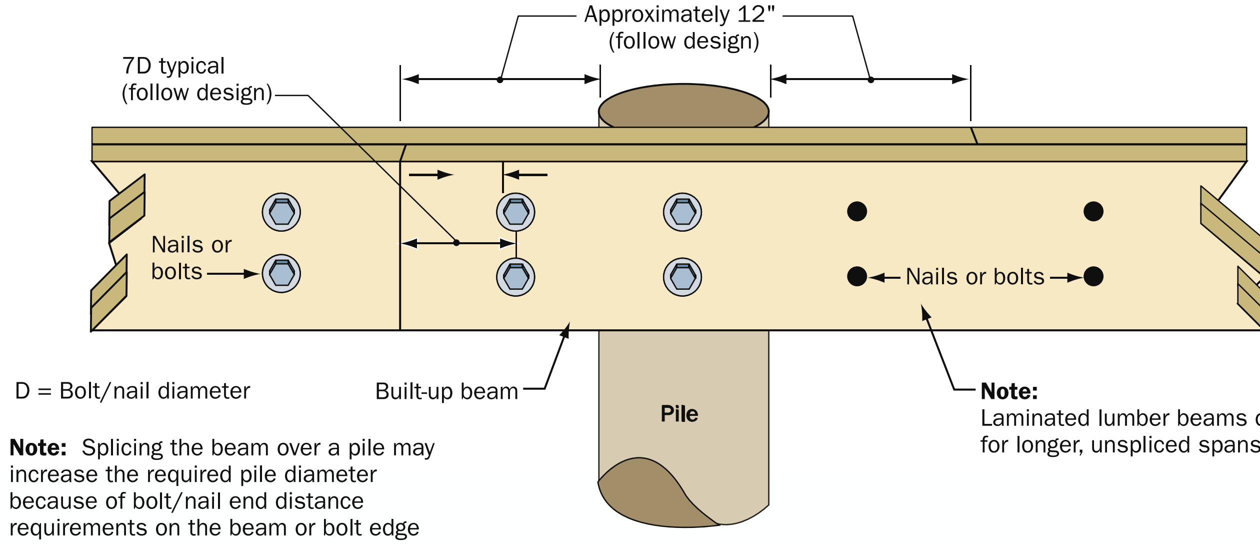
Notch side of pile that leaves the greatest pile section; use 1/4" or thicker galvanized steel plate(s) to satisfy uplift resistance requirements; connection to be designed by an engineer



Detail D2 **Steel plate(s) with pile notched on opposite side to avoid overnotching**



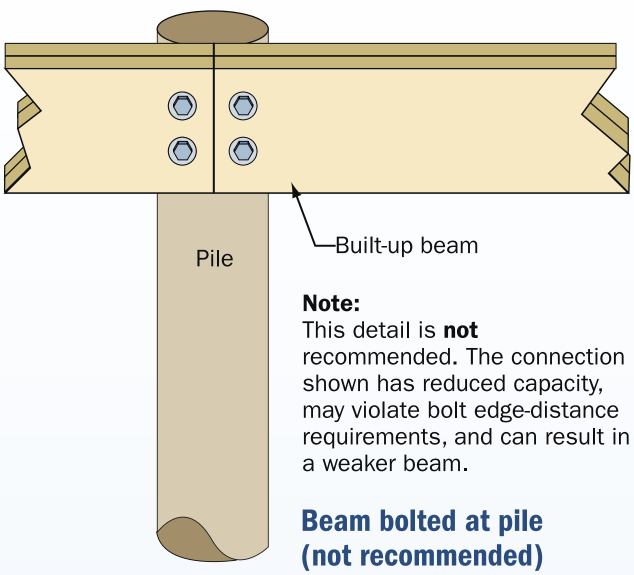
Note: Pile-to-beam connections must be designed by an engineer.



Note: Splicing the beam over a pile may increase the required pile diameter because of bolt/nail end distance requirements on the beam or bolt edge distance requirements on the pile.

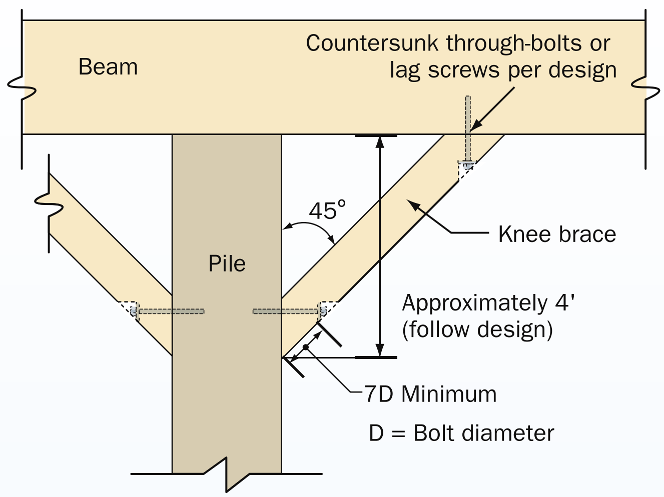
Note:
Laminated lumber beams can be used for longer, unspliced spans.

Lapped splice (built-up beam)



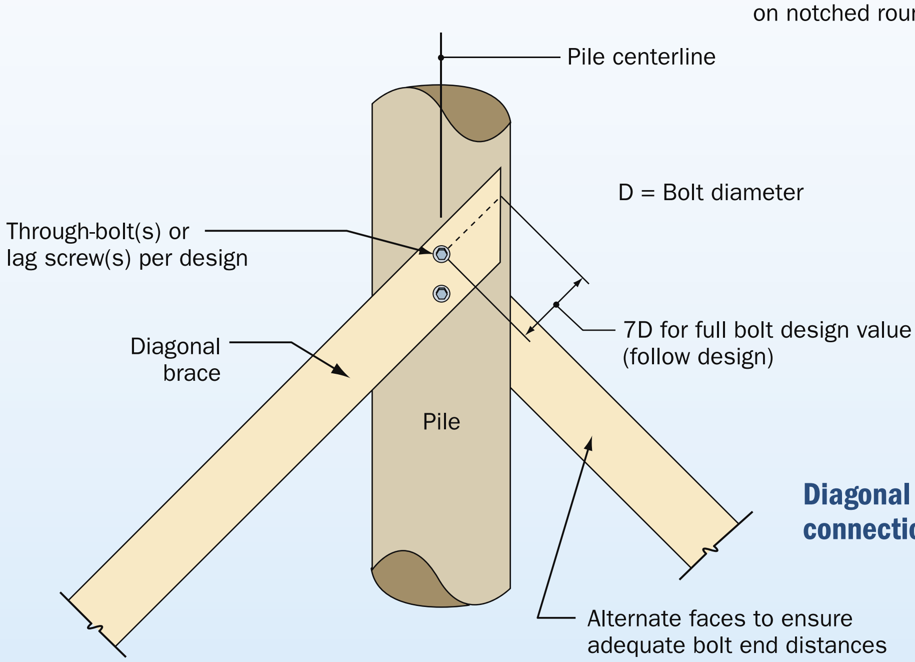
Note:
This detail is **not** recommended. The connection shown has reduced capacity, may violate bolt edge-distance requirements, and can result in a weaker beam.

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.



Note: Pile-to-beam connections must be designed by an engineer.

Diagonal brace connections on round pile

Reinforced Masonry Pier Construction

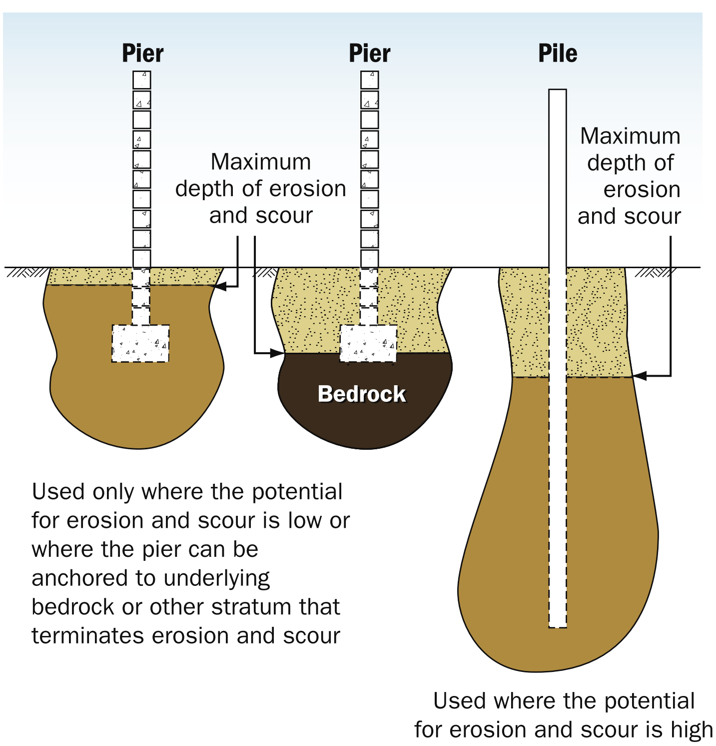
HOME BUILDER'S GUIDE TO COASTAL CONSTRUCTION FEMA 499/August 2005 *Technical Fact Sheet No. 14*

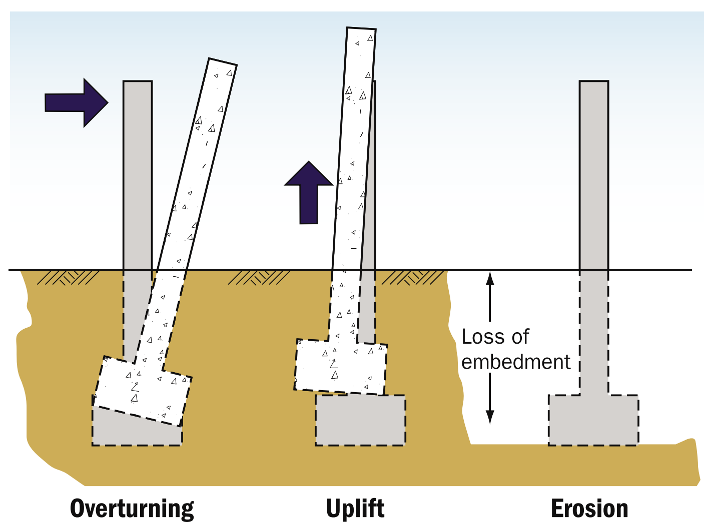
Purpose: To provide an alternative to piles in V zones and A zones in coastal areas where soil properties preclude pile installation, yet the need for an "open foundation system" still exists. Examples of appropriate conditions for the use of piers are where rock is at or near the surface or where the 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.

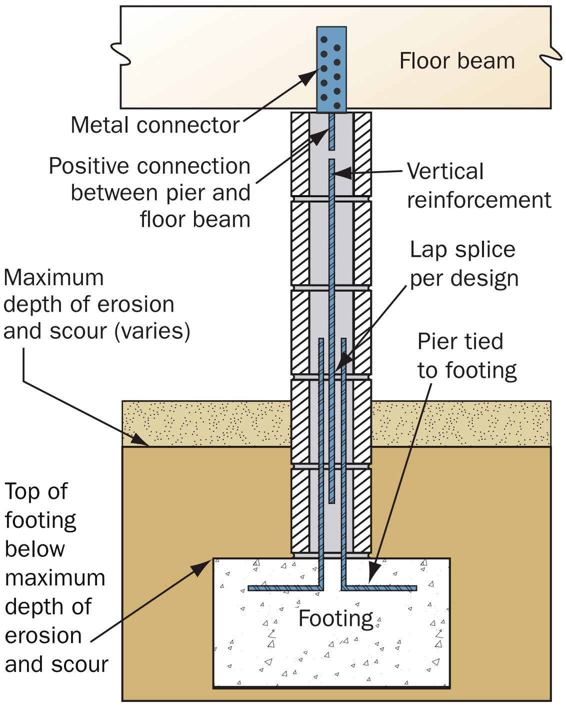
The small footings on the piers in this photograph did not prevent these piers from overturning during Hurricane Iniki.

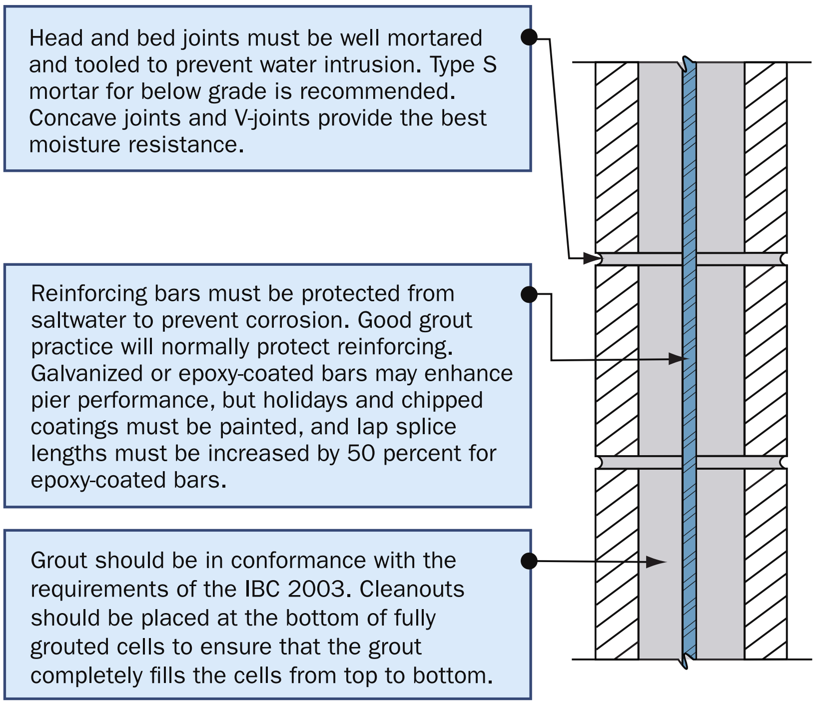
The combination of high winds and moist (sometimes salt-laden) air can have a damaging effect on masonry construction by forcing moisture into even the smallest of cracks or openings in the masonry joints. The entry of moisture into reinforced masonry construction can lead to corrosion of the reinforcement 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*

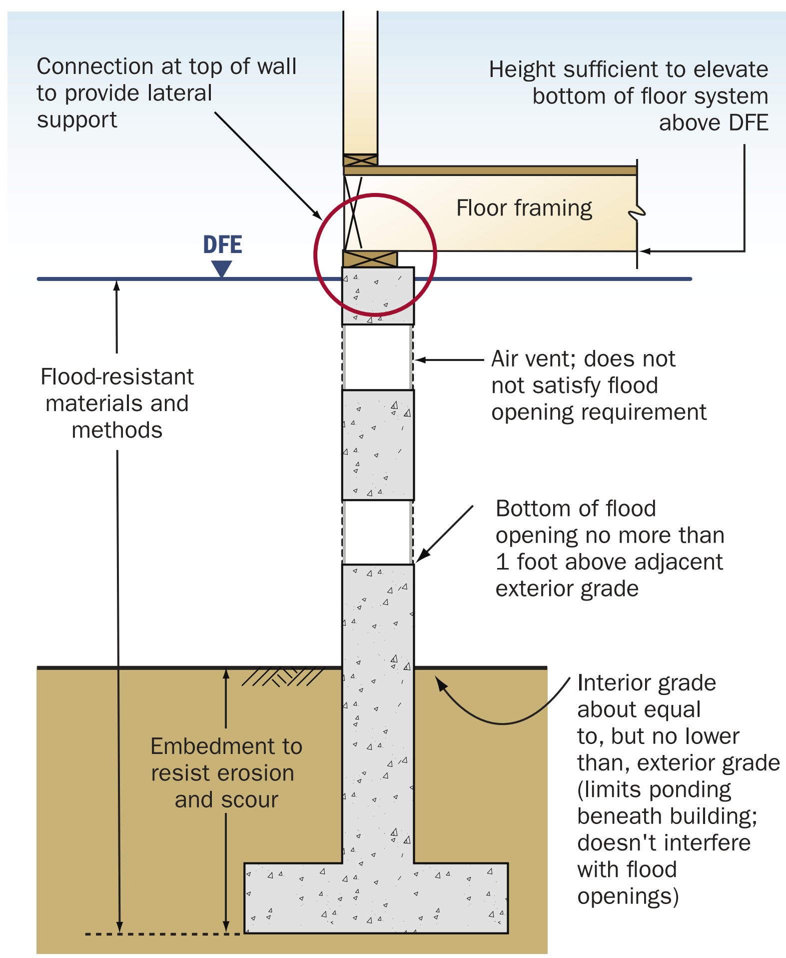
Purpose: To discuss the use of foundation walls in coastal buildings.

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

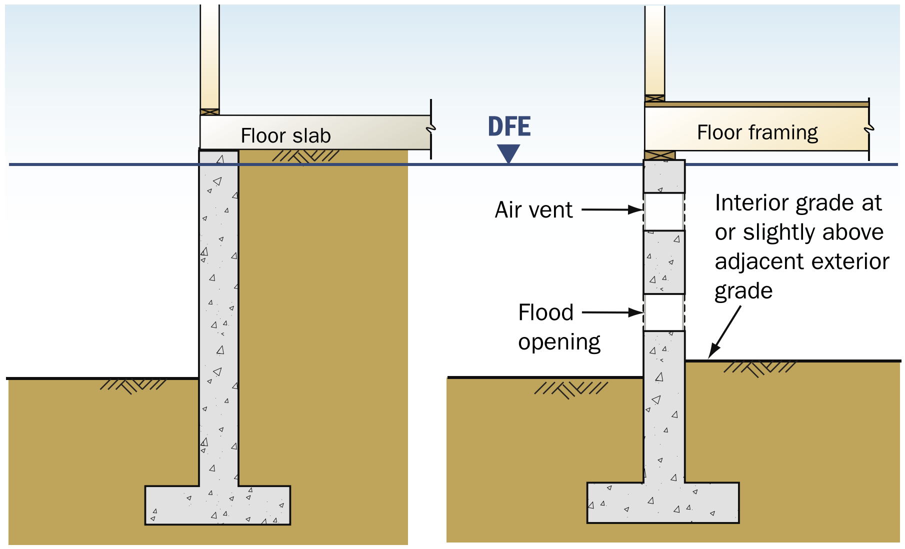
* Note that the use of shearwalls below the Design Flood Elevation (DFE) may be permitted in limited circumstances (e.g., lateral wind/seismic loads cannot be resisted with a braced, open foundation. In such cases, minimize the length of shearwalls and the degree of obstruction to floodwaters and waves, 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

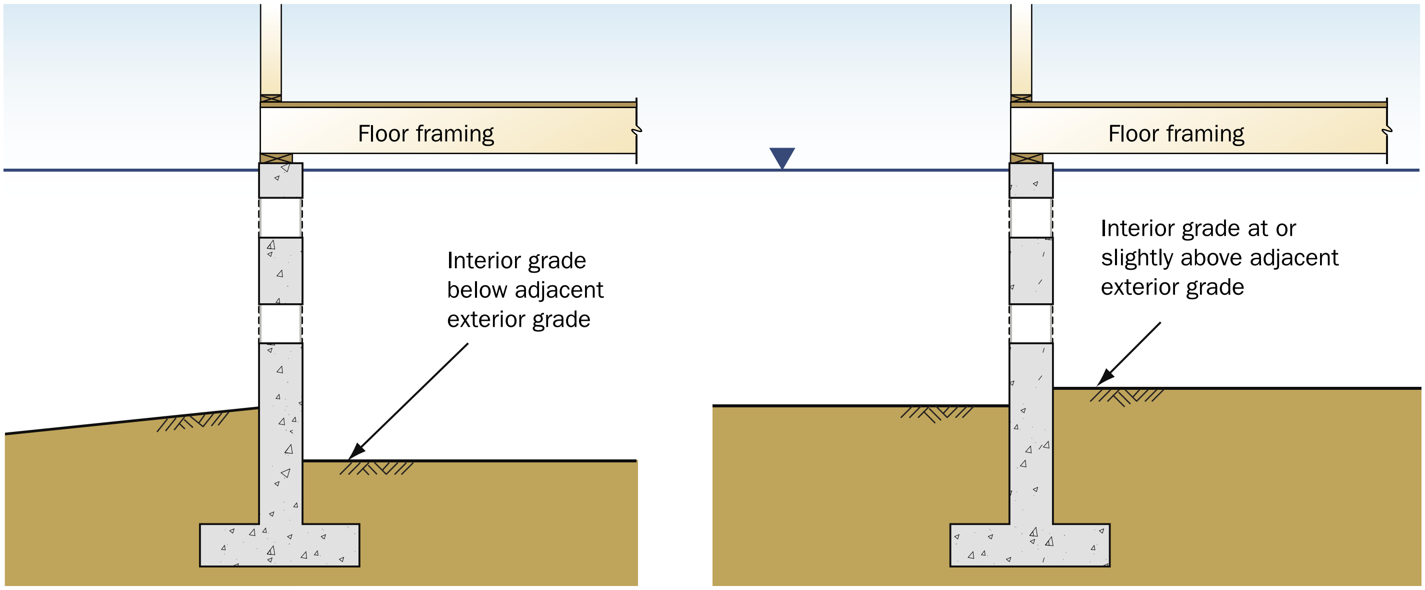
Materials and Workmanship – Foundation walls can be constructed from many materials, but masonry, concrete, and wood are the most common. Each material can be specified and used in a manner to resist damage due to moisture and inundation (see Fact Sheet No. 8). Workmanship for flood-resistant foundations 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

HOME BUILDER'S GUIDE TO COASTAL CONSTRUCTION FEMA 499/August 2005 Technical Fact Sheet No. 16

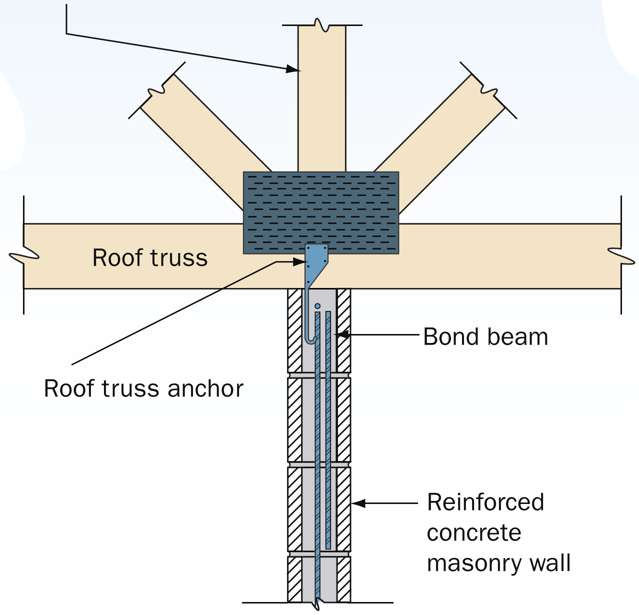
Purpose: To highlight several important details for masonry construction in coastal areas.

Key Issues

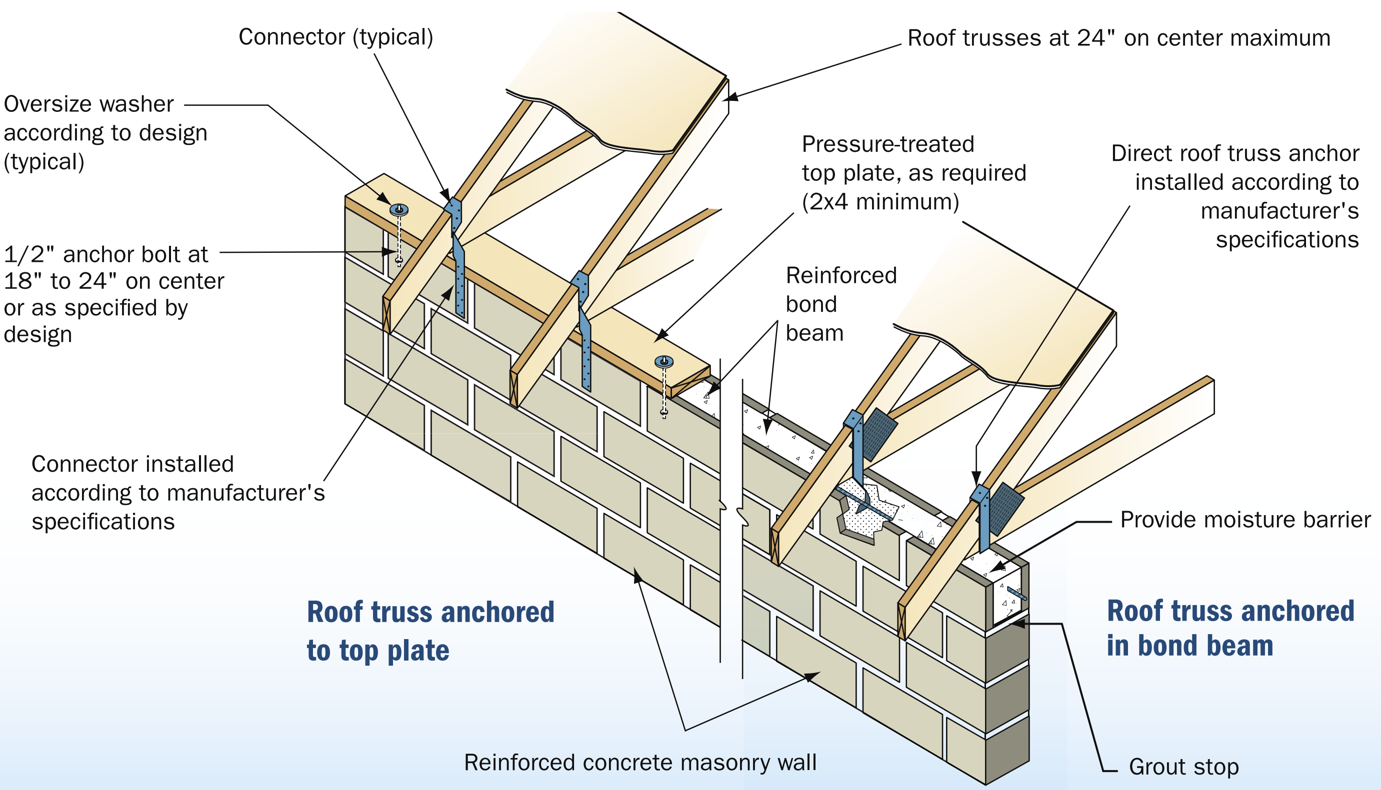
- Continuous, properly connected load paths are essential because of the higher vertical and lateral loads on coastal structures.
- Building materials must be durable enough to withstand the coastal environment.
- Masonry reinforcement requirements are more stringent in coastal areas.

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.

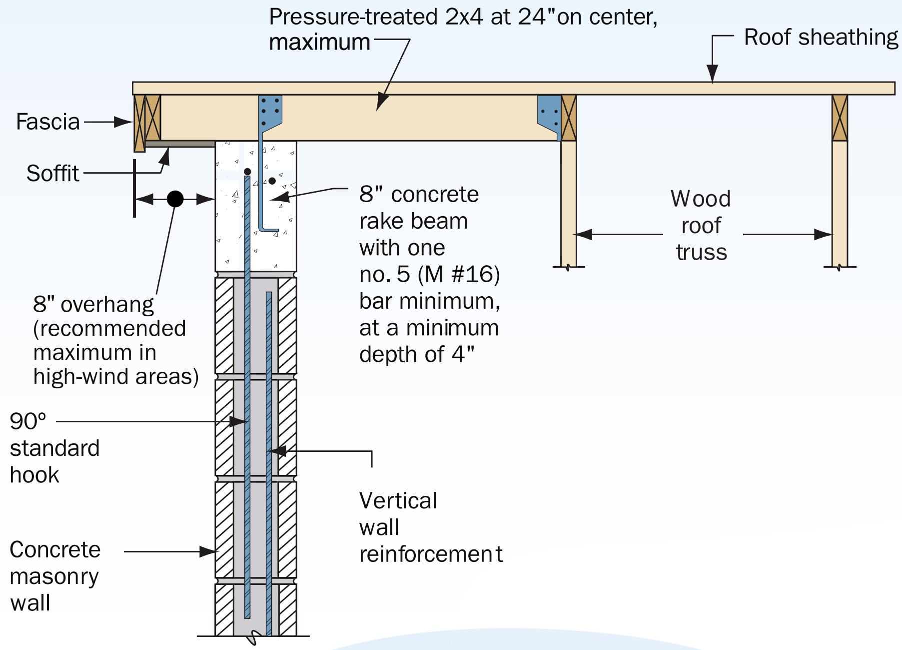


Roof framing to interior masonry wall

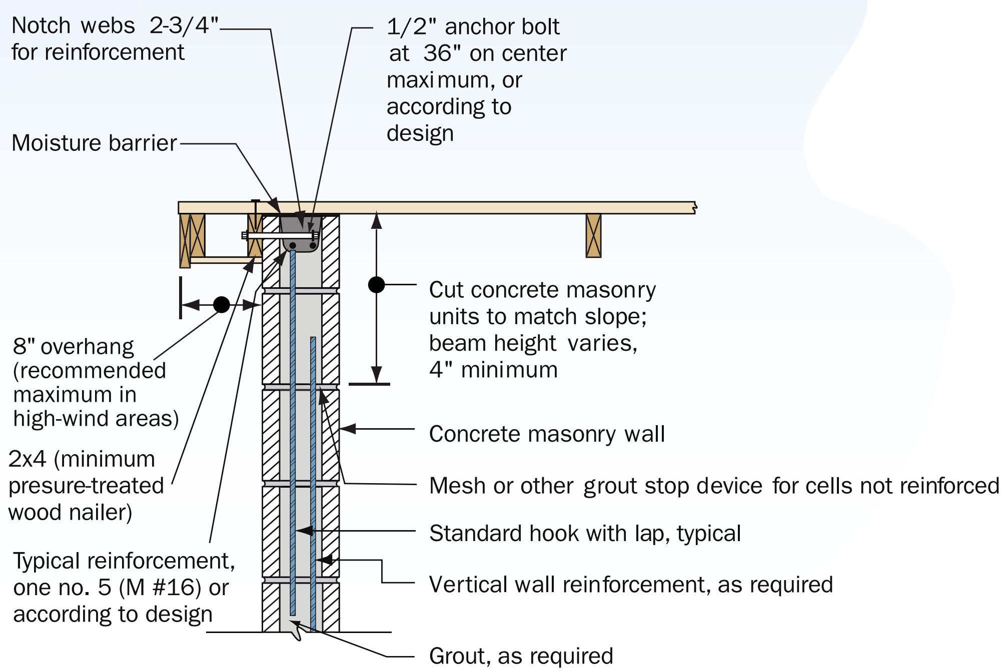


Roof framing to masonry wall.

Gable end wall – cut concrete rake beam with outlooker-type overhang



Gable end wall – cut masonry rake beam with ladder-type overhang

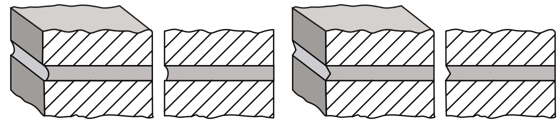


Gable endwall connection.

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.

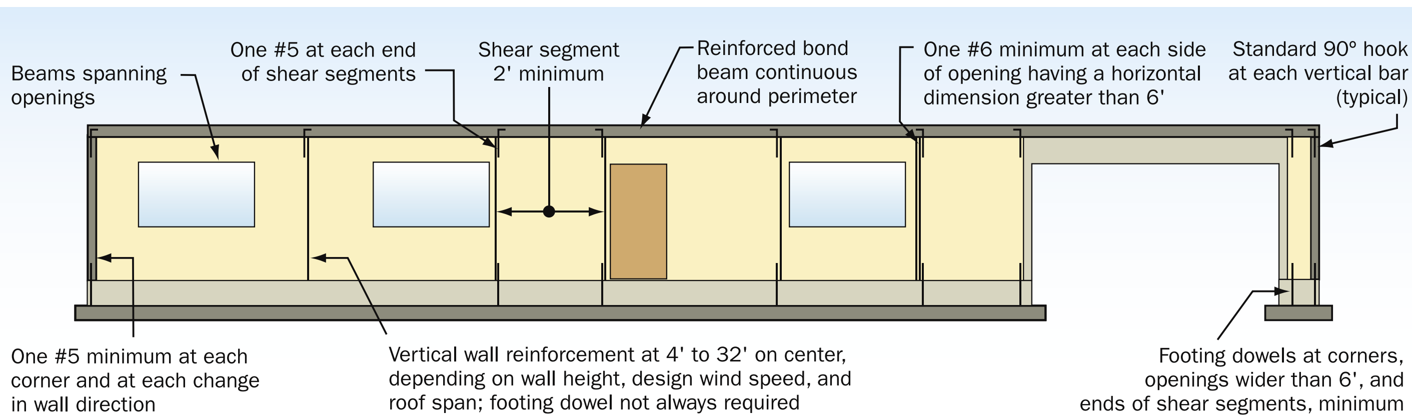
Quality depends on:

- **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.



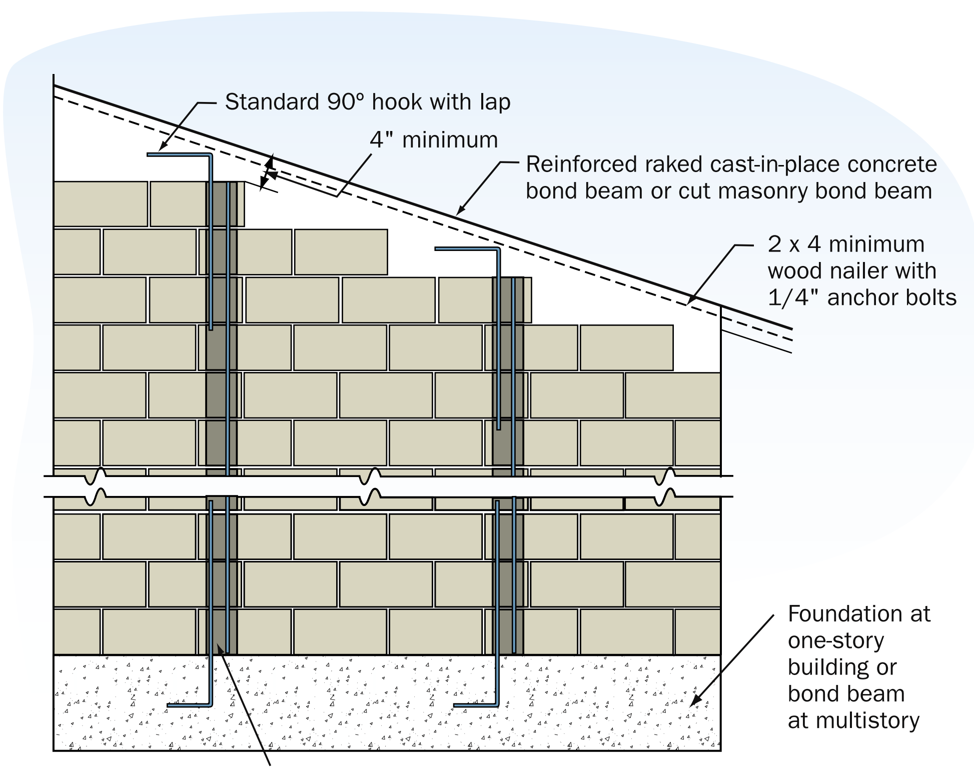
- **Good workmanship –** Head and bed joints must be well mortared and well tooled. Concave joints and V-joints provide the best moisture protection (see detail above). All block walls should be laid with full mortar coverage on horizontal and vertical face shells. Block should be laid using a “double 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.