Coastal Construction and Continuous Load Paths

Chapters 1 through 4 describe the natural hazards present in coastal environments, regulations applicable to those hazards, and permitting procedures to ensure that regulations are implemented during the construction process. Chapters 5 through 11 discuss how natural hazards and regulations affect building design and construction

A critical aspect of hazard-resistant construction is the ability of a building or structure to carry and resist all loads—including lateral and uplift loads—from the roof, walls, and other components to the foundation and into the ground. The ability of a building to resist these types of loads depends largely upon whether the building's construction provides a continuous load path.

The discussion in this chapter focuses on wind loads; however, the same principles apply to other events (such as earthquakes) that create loads on buildings. Section 2.2 of FEMA 232 contains an excellent discussion of the load path continuity required to resist seismic events.

The location of continuous load path components is also important, particularly for those components that resist lateral loads. Ideally, such components should be located symmetrically with the footprint of the structure. This may require buildings to be designed rectangular in plan or constructed with rectangular sections. The proper use of rectangular elements reduces plan irregularities and minimizes the development of torsional (i.e., twisting) forces within the building. Torsional forces can overload structural elements or cause excessive deflection that can damage non-structural building components. Torsional loading and plan irregularities are complex issues beyond the scope of this guide. (See FEMA 232 for guidance on those issues.)

NOTE

For coastal buildings, wind and flood events will produce lateral loads that must be resisted. Seismic events also produce laterally induced loads through the structure. Complex floor plans and irregularities in the building structure may compound these forces. See FEMA 232 for guidance on seismic-resistant designs for homebuilders.

5.1 Continuous Load Path

The term *continuous load path* describes the structural condition required to resist loads acting on a building. A building may contain hundreds of continuous load paths. The continuous load path starts at the point or surface where loads are applied, then moves through the building itself, continues through the foundation, and terminates where the loads are finally transferred to the soils that support the building. FEMA 55 describes a continuous load path as a type of chain whose links consist of the members and connections that make up a building. As with any chain, a continuous load path is only as strong as its weakest link. Buildings lacking strong and continuous load paths may fail when exposed to forces from coastal hazards, thus causing a breach within the building envelope or even the total collapse of such buildings.

Continuous load paths are important in all buildings. In coastal construction, where wind loads are higher and flood loads exist, paying proper attention to continuous load paths is crucial for ensuring building survival.

The history of past storm damage is replete with instances of failures in load paths (see Figures 5-1 through 5-5). Repeatedly, buildings constructed along the coast have failed when their load paths were not strong enough to withstand the forces exerted upon them. Most load path failures have been observed at connections, as opposed to failure of the individual members themselves. Fortunately, as building codes and standards improve, the knowledge of load paths increases and older buildings are either improved or replaced. As a result, load path failures are becoming less frequent.

As structural systems perform better, other issues related to load path construction become evident. Recent post-disaster damage investigations have revealed performance issues in building envelopes. Chapters 8, 9, and 10 present detailed discussions on building envelope performance for roofs, wall systems, and openings.

Figure 5-1.
DADE COUNTY, FLORIDA, HURRICANE ANDREW (1992): Second-story wood framing (on first-story masonry). Load path failure at end gable. (Source: FEMA 55)

Figure 5-2.
NORTH CAROLINA, HURRICANE FRAN (1996): Load path failure in connections between home and its foundation. (Source: FEMA 55)

Figure 5-3.
PUNTA GORDA, FLORIDA:
Roof framing damage and loss due to load path failure at top of wall/roof structure connection.
(Source: FEMA 488)

Figure 5-4.
PUNTA GORDA, FLORIDA:
Load path failure in connections between roof decking and roof framing.
(Source: FEMA 488)

Figure 5-5.
PASS CHRISTIAN, MISSISSIPPI: Newer home damaged from internal pressurization and inadequate connections.
(Source: FEMA 549)

NOTE

FEMA 499 (*Home Builder's Guide to Coastal Construction – Technical Fact Sheet No. 10, Load Paths*) provides information and descriptions of continuous load paths.

5.2 Types of Load Paths

Load paths run from the point (or surface) where loads are applied (see Figure 5-6) through building to the foundation, where they are transferred to the soil. In a building, the path that loads follow (i.e., from where they are applied to the structure down to the foundation) depends upon many factors, such as load sharing, load distribution, and building stiffness. While load paths are complex, designers consider them in categories of "vertical" or "horizontal" paths (see Figure 5-7 and 5-8). Most designers, builders, and homeowners understand that downward gravity forces must be resisted by vertical load paths. Vertical load paths must also resist uplift forces from flood, wind, or seismic events. Large uplift forces may be the result of flood loads from buoyancy, from breaking waves hitting horizontal surfaces (such as decks or the undersides of buildings), or from wind acting on all sides of a building. Horizontal load paths, like vertical load paths, transfer lateral loads from wind, flood, and seismic events into the ground.

A schematic example of a complete load path (see Figures 5-7 and 5-8) shows the chain of connections from the roof to the foundation; these connections were designed and constructed to resist lateral and uplift forces from a wind event. The load path consists of fasteners securing the roof covering (such as roof shingles and metal roofing) to the roof deck; nails or screws securing the roof deck to the roof framing; metal anchors securing the roof framing to the wall's top plate; wall sheathing or metal straps securing the wall's top plate to wall studs; and the wall stud secured to the bottom plate (or sill plate). The load path continues with anchor bolts securing the foundation bottom plate to the main floor beams and then to the pile foundation, in order to account for all vertical and lateral loads.

All loads applied to a structure must be transferred to the foundation of the building and, finally, the ground. It is important to remember:

- Loads acting on a building follow many paths through the building and must eventually be resisted by the ground. Otherwise, the building may fail during an event.
- Loads accumulate as they are routed through key connections in a building.
- Member connections are usually the weak links within a load path.
- Failed or missed connections cause loads to be rerouted through unintended load paths, often resulting in building damage or collapse.

Failure to adequately maintain a proper load path has been observed where building elements failed after hurricanes. (For example, fasteners were commonly spaced too far apart, were too small, or had weak connections.) Numerous examples showing failures to follow well-established basic construction practices exist, such as ensuring minimum edge distances for fasteners.

Figures 5-7 and 5-8 show a complete load path and identify what to look for when evaluating plans or inspecting framing and what building inspection points to address. Each link is important and must be considered by the engineer or designer. Even with a good design, however, unsatisfactory construction of the structure will exert the most impact on the building's performance during a storm event. If the construction is not completed in accordance with codes, plans, and drawings, the entire structure remains at risk. Specific details related to foundations, building framing, and the building envelope are discussed in following chapters.

5.3 Identifying Load Paths in Buildings

It is important to identify both vertical and horizontal load paths in the building designs and during construction of the building. (Vertical load paths were discussed in Section 5.2.)

Horizontal load paths consist of structural elements that transfer horizontal (or lateral) loads through the building to the foundation. Horizontal load paths in a typical one- or two-family dwelling consist of exterior siding that transfers loads to wall sheathing; wall sheathing that transfers loads to wall framing; wall framing that transfers loads to horizontal roof and floor diaphragms; and horizontal diaphragms that transfer horizontal loads to the foundations through vertical shear walls and their shear wall tie-downs.

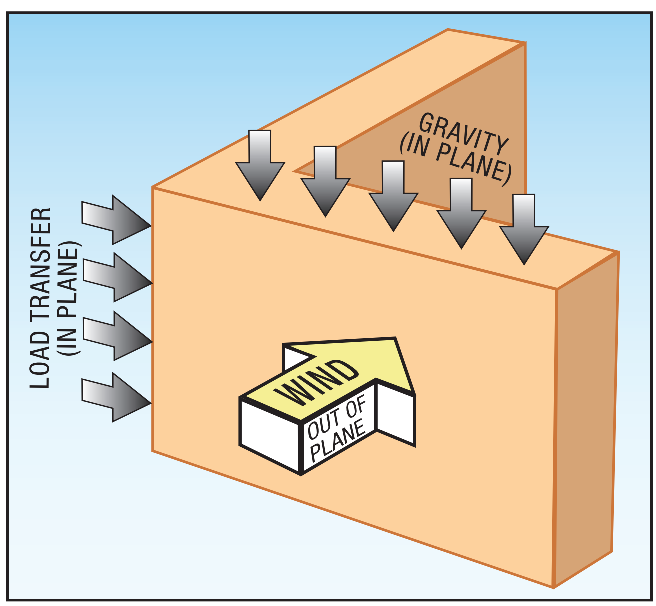


Figure 5-6.
Loads applied to the exterior wall of a building.

Load Paths

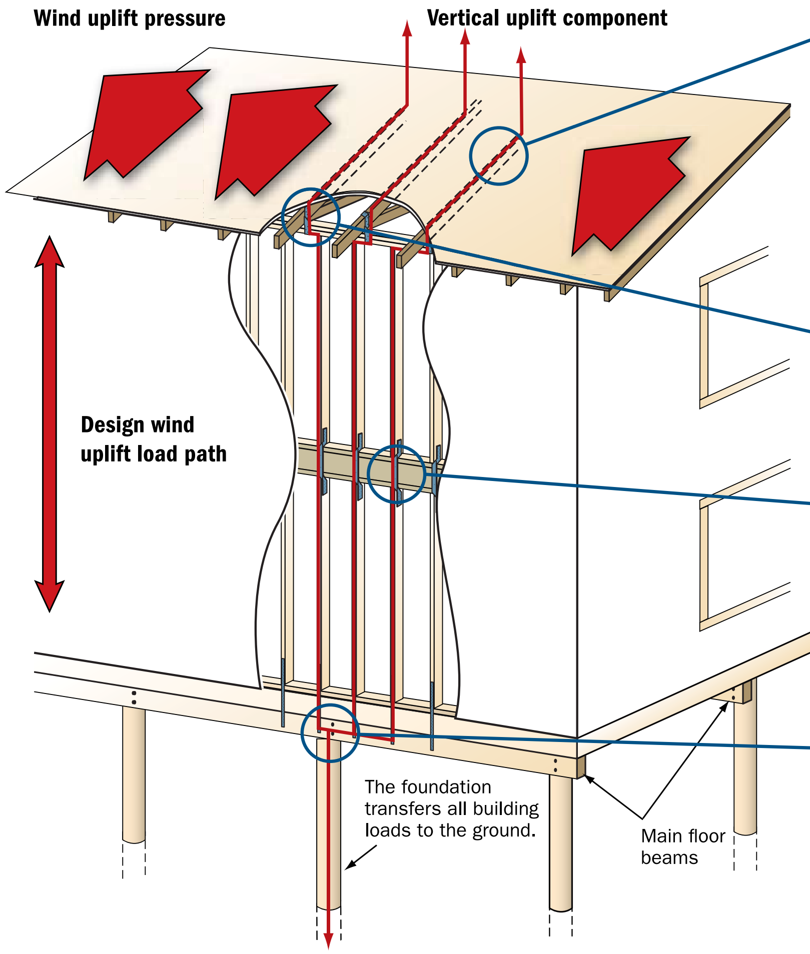
FEMA

HOME BUILDER'S GUIDE TO COASTAL CONSTRUCTION FEMA 499/August 2005 *Technical Fact Sheet No. 10*

Purpose: To illustrate the concept of load paths and highlight important connections in a wind uplift load path.

Key Issues

- Loads acting on a building follow many paths through the building and must eventually be resisted by the ground, or the building will fail.
- Loads accumulate as they are routed through key connections in a building.
- Member connections are usually the weak link in a load path.
- Failed or missed connections cause loads to be rerouted through unintended load paths.



LINK 1
High winds lift the roof upward. Roofing fasteners link the roof covering to the sheathing*, and sheathing fasteners link the sheathing to the roof framing members (see Fact Sheet No. 18).

* Although not a structural connection, the attachment of the roof covering to the roof sheathing is an essential part of protecting the building envelope.

LINK 2
Accumulated roof load is routed through roof-to-wall connections. Special roof ties connect the roof framing to the bearing walls (see Fact Sheet No. 17).

LINK 3
Upper walls transfer loads directly to the lower walls. The floor framing is bypassed by using metal straps or extended exterior sheathing that directly connects upper wall studs to the lower wall studs. A similar connection is used to connect the lower wall to the main floor beam.

LINK 4
The accumulated uplift force is transferred from the main floor beams to the pile foundation with special brackets or bolts (see Fact Sheet No. 13). **Note:** Some of this load is offset by the weight of the building.

Vertical load path from roof to ground on a platform-and-pile-construction building.
Note: Load paths will vary depending on construction type and design.
Adjacent framing members will receive more load if a connection fails.

Note: Horizontal load paths transferring shear from upper stories to the ground must also be analyzed.

Figure 5-7.
Technical Fact Sheet No. 10, Page 1. For more information on load paths and load transfer, see Chapter 7.
(Source: FEMA 499)

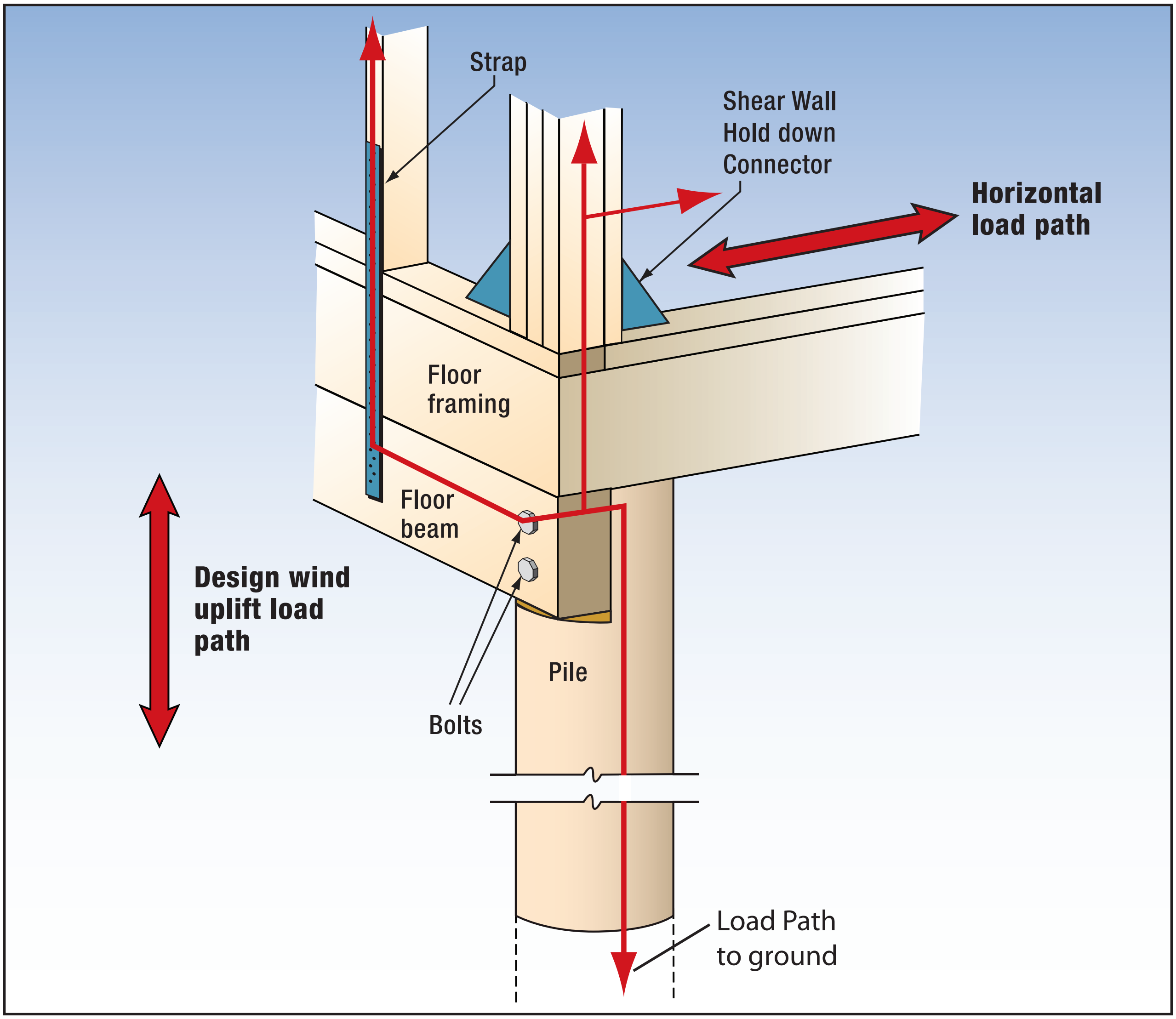


Figure 5-8.
Technical Fact Sheet No. 10, Page 2. (Source: FEMA 499)

5.4 Building Codes and Standards

The importance of continuous (or complete) load paths is clear in building codes and standards. Section R301.1 of the International Residential Code (IRC) states:

> *"Buildings and structures, and all parts thereof, shall be constructed to safely support all loads, including dead loads, live loads, roof loads, flood loads, snow loads, wind loads, and seismic loads as prescribed by this code. The construction of buildings and structures in accordance with the provisions of this code shall result in a system* ***that provides a complete load path*** *that meets all requirements for the transfer of all loads from their point of origin through the load-resisting elements to the foundation. Buildings and structures constructed as prescribed by this code are deemed to comply with the requirements of this section."*

The IRC has specific design requirements for many points within the load paths of buildings for certain basic wind speeds. These requirements can be used by designers, builders, and code officials to select connectors and size framing members. Because the prescriptive designs of the IRC are limited to 110-mph wind speeds, other standards (such as *SSTD-10, Standard for Hurricane Resistant Residential Construction*, the International Code Council's ICC-600, or the American Forest and Paper Association's (AF&PA) *Wood Frame Construction Manual*) can be used to identify prescriptive solutions and construction details in areas with higher basic wind speeds.

The IRC (and Chapter 23 of the IBC) has prescriptive shear wall and shear wall tie-down requirements for conventional construction as an alternative to performance-based design (that is, buildings with lateral-force-resisting systems consisting of horizontal diaphragms and shear walls). For buildings constructed with steel or reinforced concrete frames or other lateral-force-resisting systems, the IBC has performance requirements that engineers and architects use to design a structure's lateral-force-resisting system.

The prescribed loads discussed above in the IRC generally address wind and seismic loads that must be considered during design. In coastal areas, homes are often exposed to flood loads, which can include those from breaking waves, hydrostatic loads, hydrodynamic loads, and loads from floodborne debris. Individuals responsible for plan review should be aware of this limitation to ensure that all loads are being properly considered during building design. Few consensus codes or standards have prescriptive flood-resistant designs. FEMA 550 *(Recommended Residential Construction for the Gulf Coast: Building on Strong and Safe Foundations),* contains designs for several styles of foundations suitable for coastal sites and guidance for engineers in designing custom flood- and wind-resistant foundations.

Similar requirements exist in Section 1604.4 of the IBC:

> "*...shall result in a system that provides* ***a complete load path*** *capable of transferring loads from their point of origin to the load-resisting elements.*"

SSTD 10 (the prescriptive high-wind standard for residential construction), also requires load path continuity, as does ICC-600, *Standard for Residential Construction in High-Wind Regions*.

5.5 Continuous Load Paths and Building Success

Post-event assessments reveal how constructing buildings with strong and continuous load paths can enable structures to survive even when exposed to hurricane-force winds.

For the construction of a coastal building to be considered a "success," the building should meet four conditions:

- It must be designed to withstand anticipated forces and conditions.
- It must be constructed as designed.
- It must be elevated to avoid floodwaters and flood forces.
- Its envelope must protect the habitable areas of the structure.

The designer should only use connections to their published lateral/uplift tested values. If the connection only has a tested uplift value, use another connection that has been tested for the appropriate lateral forces or utilize a designed alternative to resist forces.

Figure 5-9.
BIG LAGOON, FLORIDA:
Elevated building (constructed to newer code) that survived Hurricane Ivan.
(Source: FEMA 489)

Figure 5-10.
BIG LAGOON, FLORIDA:
This house was elevated on piles, preventing severe damage from coastal flooding.
(Source: FEMA 489)

Figure 5-11.
BIG LAGOON, FLORIDA:
This house was elevated on piles, preventing major flood damage.
(Source: FEMA 489)