

Building on Strong and Safe Foundations

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 bathymetry 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).

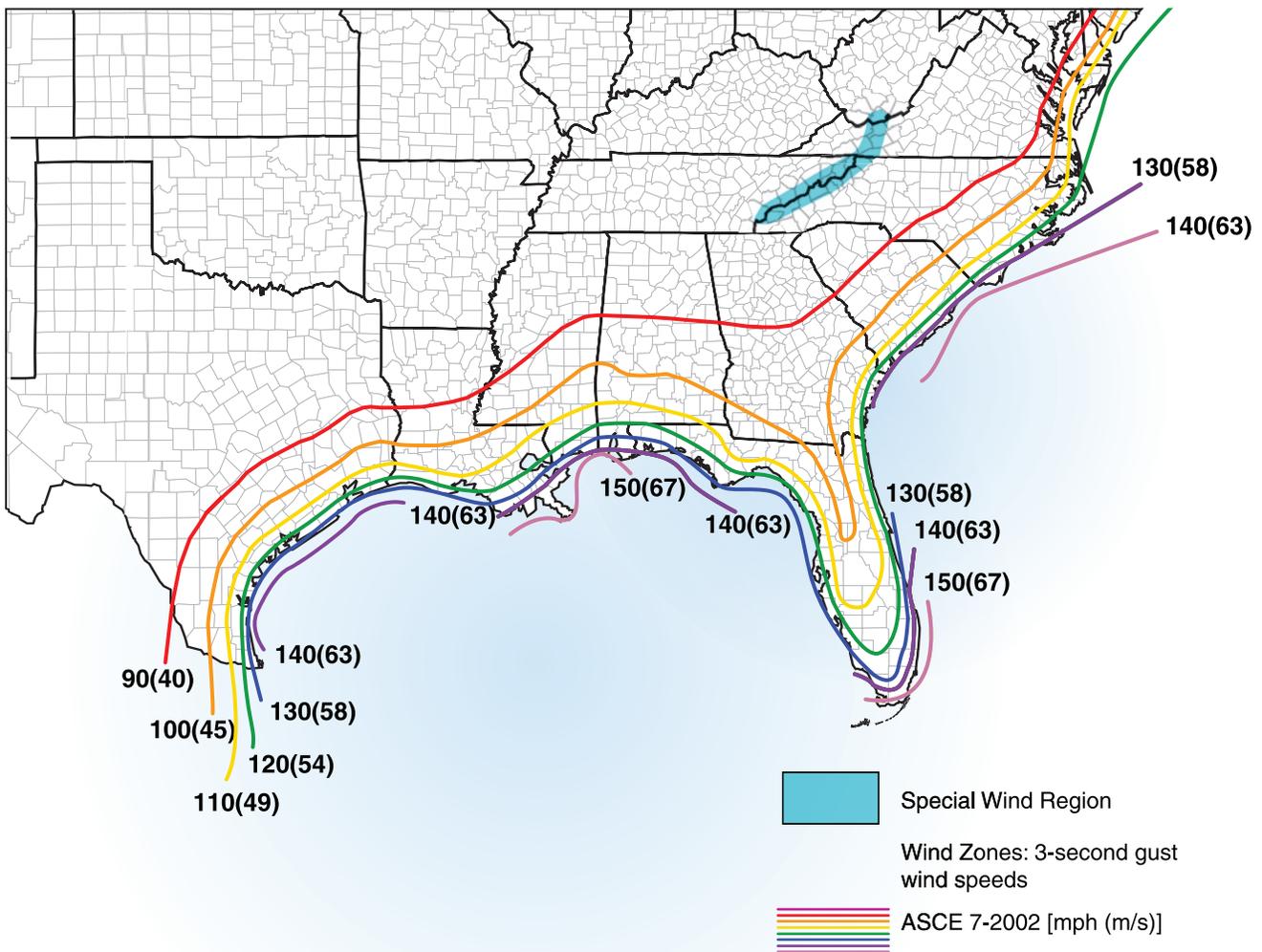


Figure 1-3. Design wind speed map for portions of the Gulf Coast. Contours are 3-second gust wind speeds (in miles per hour [meters per second]) for Exposure Category C, 33 feet height.

SOURCE: ASCE 7-02

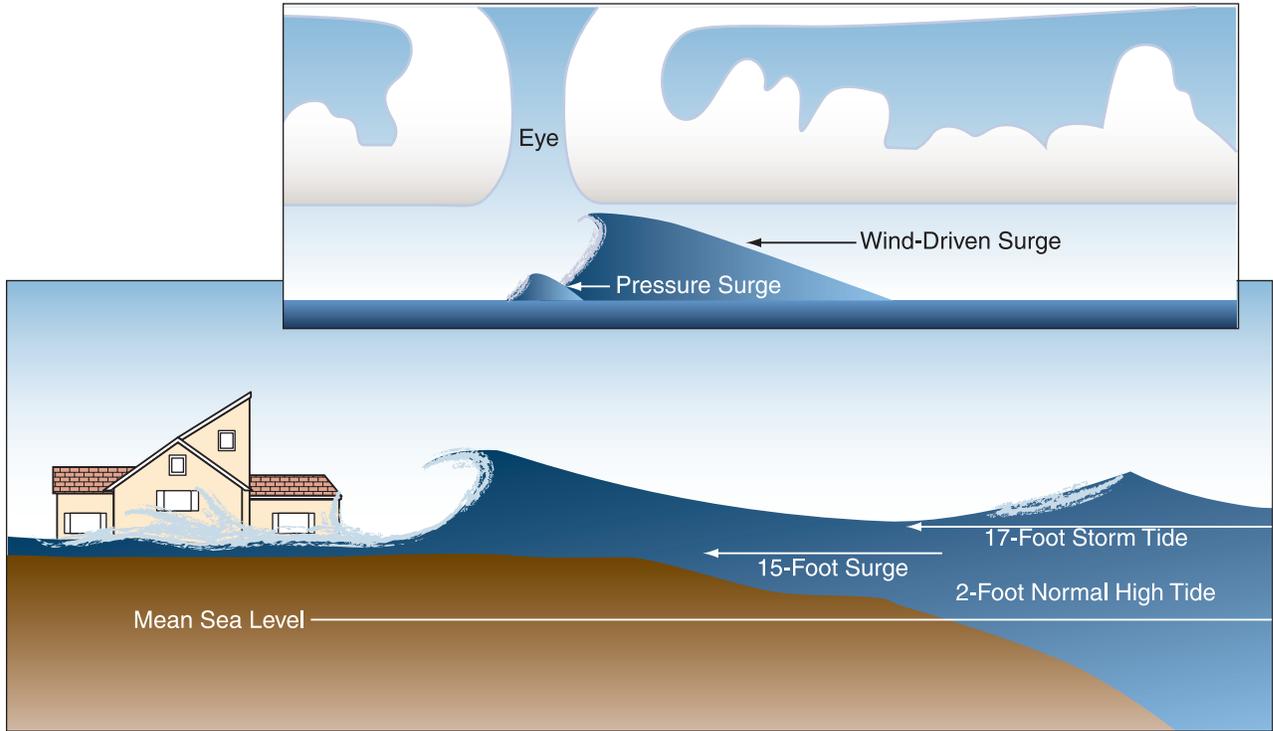


Figure 1-4.
Graphical depiction of a hurricane moving ashore. In this example, a 15-foot surge added to the normal 2-foot tide creates a total storm tide of 17 feet.



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)

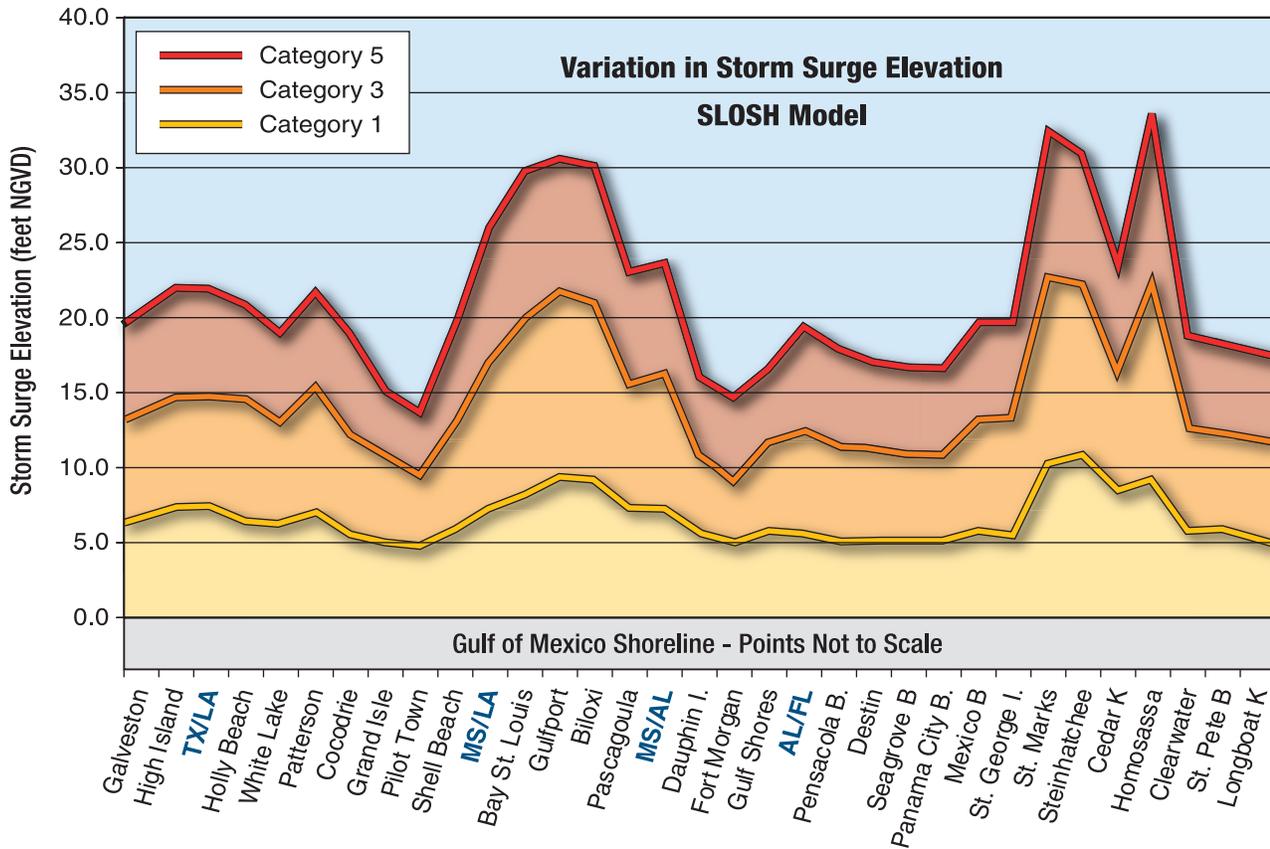


Figure 1-6. Comparison of storm surge levels along the shorelines of the Gulf Coast for Category 1, 3, and 5 storms

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)

