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Identifying Hazards

Buildings constructed in coastal areas are subject to natural hazards. The most significant natural hazards that affect the coastlines of the United States and territories can be divided into four general categories:

- Coastal flooding (including waves)
- Erosion
- High winds
- Earthquakes

This chapter addresses each of these categories, as well as other hazards and environmental effects, but focuses on flooding and erosion (Sections 3.4 and 3.5). These two hazards are among the least understood and the least discussed in design and construction documents. Designers have numerous resources available that discuss wind and seismic hazards in detail, so they will be dealt with in less detail here.

CROSS REFERENCE

For resources that augment the guidance and other information in this Manual, see the Residential Coastal Construction Web site (http://www.fema.gov/rebuild/mat/fema55.shtm).

WARNING

Natural hazards can act individually, but often act in combination (e.g., high winds and coastal flooding, coastal flooding and erosion, etc.). Long-term changes in underlying conditions—such as sea level rise—can magnify the adverse effects of some of these hazards. For more information on load combinations, see Chapter 8.

In order to construct buildings to resist these natural hazards and reduce existing buildings' vulnerability to such hazards, proper planning, siting, design, and construction are critical and require an understanding of the coastal environment, including coastal geology, coastal processes, regional variations in coastline characteristics, and coastal sediment budgets. Proper siting and design also require accurately assessing the vulnerability of any proposed structure, including the nature and extent of its exposure to coastal hazards. Failure to properly identify and design to resist coastal hazards expected over the life of a building can lead to severe consequences, most often building damage or destruction.

This chapter provides an overview of coastline characteristics (Section 3.1); tropical cyclones and coastal storms (Section 3.2); coastal hazards (Section 3.3); coastal flood effects, including erosion (Sections 3.4 and 3.5); and flood hazard zones and assessments, including hazard mapping procedures used by the NFIP (Sections 3.6 and 3.7). Although general guidance on identifying hazards that may affect a coastal building site is provided, this chapter does not provide specific hazard information for a particular site. Designers should consult the sources of information listed in Chapter 4 of this Manual and in the resource titled "Information about Storms, Big Waves, and Water Levels" on the FEMA Residential Coastal Construction Web page. Siting considerations are discussed in more detail in Chapter 4.

3.1 Coastline Characteristics

This section contains general information on the coastal environment and the characteristics of the United States coastline.

3.1.1 Coastal Environment

Coastal geology and geomorphology refer to the origin, structure, and characteristics of the rocks and sediments that make up the coastal region. The coastal region is considered the area from the uplands to the nearshore as shown in Figure 3-1. Coastal sediments can vary from small particles of silt or sand (a

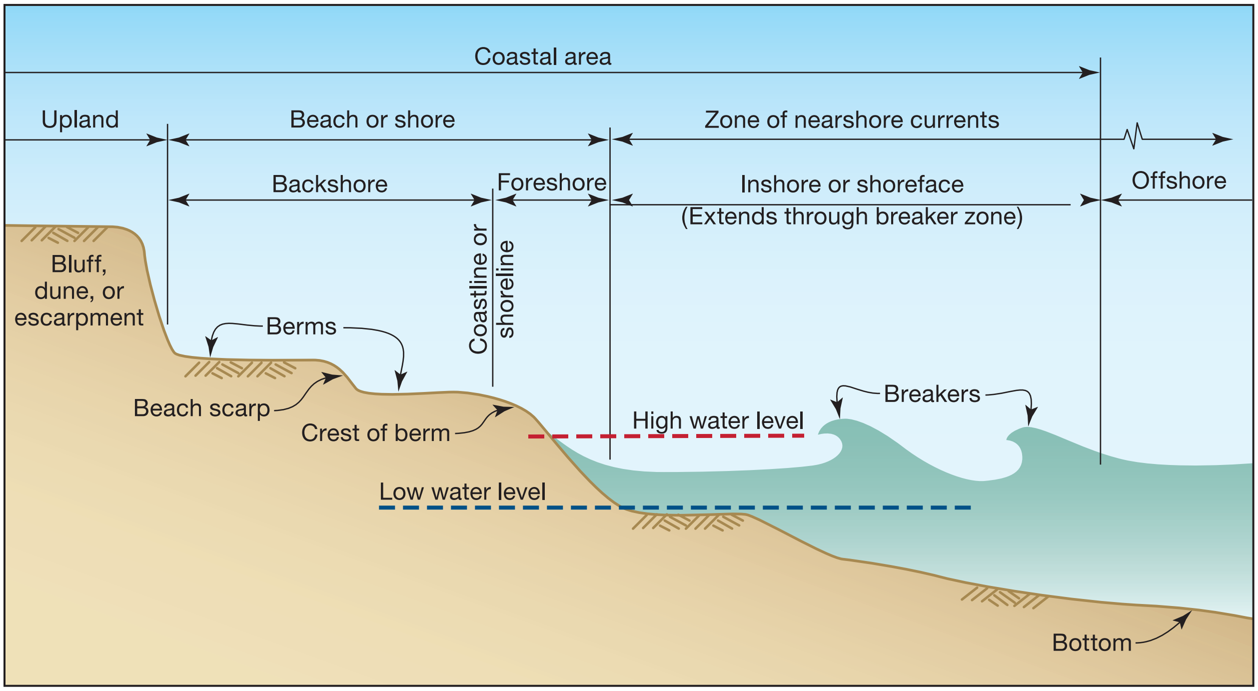


Figure 3-1. Coastal region terminology

SOURCE: ADAPTED FROM USACE 2008

few thousandths or hundredths of an inch across), to larger particles of gravel and cobble (up to several inches across), to formations of consolidated sediments and rock. The sediments can be easily erodible and transportable by water and wind, as in the case of silts and sands, or can be highly resistant to erosion. The sediments and rock units that compose a coastline are the product of physical and chemical processes that take place over thousands of years.

Coastal processes refer to physical processes that act upon and shape the coastline. These processes, which influence the configuration, orientation, and movement of the coast, include the following:

- Tides and fluctuating water levels
- Waves
- Currents (usually generated by tides or waves)
- Winds

Coastal processes interact with the local coastal geology to form and modify the physical features that are referred to frequently in this Manual: beaches, dunes, bluffs, and upland areas. Water levels, waves, currents, and winds vary with time at a given location (according to short-term, seasonal, or longer-term patterns) and vary geographically at any point in time. A good analogy is weather; weather conditions at a given location undergo significant variability over time, but tend to follow seasonal and other patterns. Further, weather conditions can differ substantially from one location to another at the same point in time.

Regional variations in coastlines are the product of variations in coastal processes and coastal geology. These variations can be quite substantial, as described in the following sections of this chapter. Thus, shoreline siting and design practices appropriate to one area of the coastline may not be suitable for another.

The ***coastal sediment budget*** is based on the identification of sediment sources and sinks, and refers to the quantification of the amounts and rates of sediment transport, erosion, and deposition within a defined region. Sediment budgets are used by coastal engineers and geologists to analyze and explain shoreline changes and to project future shoreline behavior. Typical sediment sources include longshore transport of sediment into an area, beach nourishment, and dune or bluff erosion (which supply sediment to the beach). Typical sediment sinks include longshore sediment transport out of an area, storm overwash (sediment carried inland from the beach), and loss of sediment into tidal inlets or submarine canyons.

While calculating sediment budgets is beyond the scope of typical planning and design studies for coastal residential structures, sediment budgets may have been calculated by others for the shoreline segment containing a proposed building

NOTE

Although calculating coastal sediment budgets can be complicated, the premise behind it is simple: if more sediment is transported by coastal processes or human actions into a given area than is transported out, shore accretion results; if more sediment is transported out of an area than is transported in, shore erosion results.

TERMINOLOGY

LONGSHORE SAND TRANSPORT is wave- and/or tide-generated movement of shallow-water coastal sediments parallel to the shoreline.

CROSS-SHORE SAND TRANSPORT is wave- and/or tide-generated movement of shallow-water coastal sediments toward or away from the shoreline.

site. Designers should contact State coastal management agencies and universities to determine if sediment budget and shoreline change information for their site is available, since this information will be useful in site selection, planning, and design.

The concept of sediment budgets does not apply to all coastlines, particularly rocky coastlines that are resistant to erosion and whose existence does not depend on littoral sediments transported by coastal processes. Rocky coastlines typical of many Pacific, Great Lakes, New England, and Caribbean areas are better represented by Figure 3-2. The figure illustrates the slow process by which rocky coasts erode in response to elevated water levels, waves, and storms.

3.1.2 United States Coastline

The estimated total shoreline length of the continental United States, Alaska, and Hawaii is 84,240 miles, including 34,520 miles of exposed shoreline and 49,720 miles of sheltered shoreline (USACE 1971). The shoreline length of the continental United States alone is estimated as 36,010 miles (13,370 miles exposed, 22,640 miles sheltered).

Several sources (National Research Council 1990, Shepard and Wanless 1971, USACE 1971) were used to characterize and divide the coastline of the United States into six major segments and several smaller subsegments (see Figure 3-3). Each of the subsegments includes coastlines of similar origin, characteristics, and hazards.

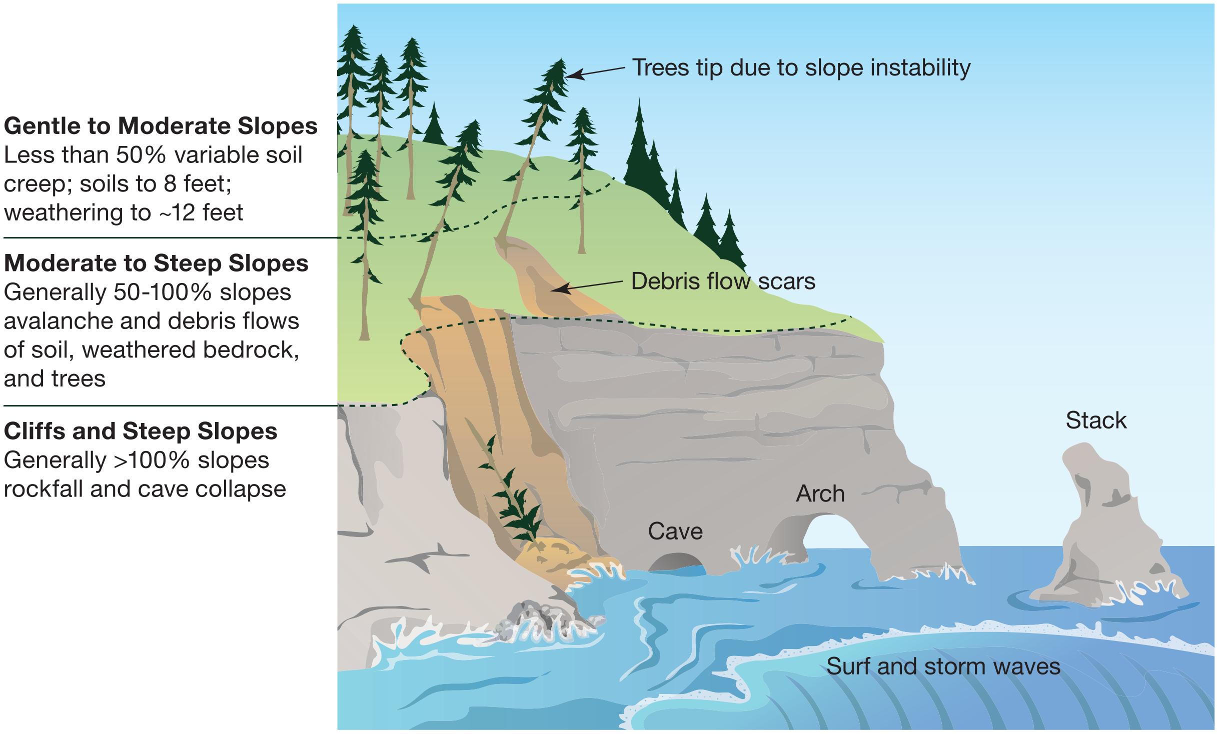


Figure 3-2.
Generalized depiction of erosion process along a rocky coastline
SOURCE: ADAPTED FROM HORNING GEOSCIENCES 1998

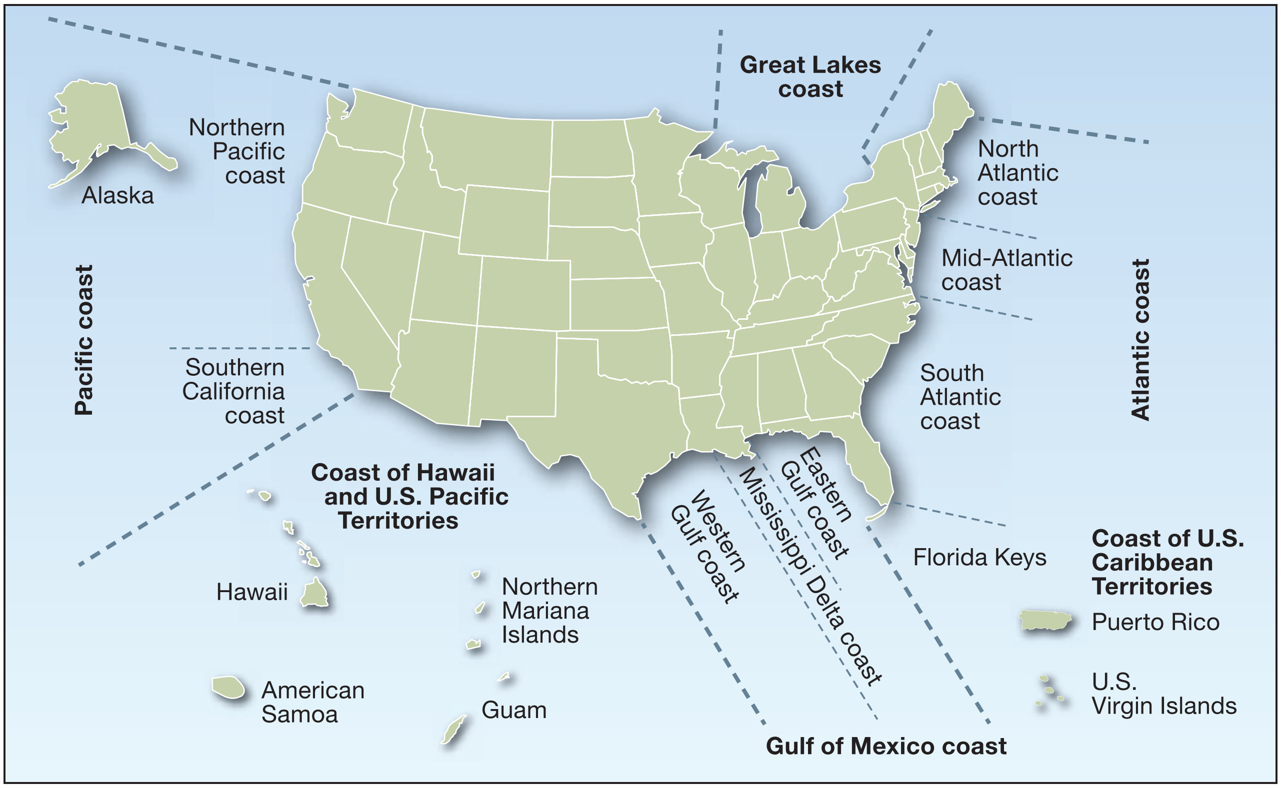


Figure 3-3.
United States coastline

Atlantic Coast

The Atlantic coast extends from Maine to the Florida Keys and includes the North Atlantic coast, the Mid-Atlantic coast, the South Atlantic coast, and the Florida Keys.

The ***North Atlantic coast***, extending from Maine to Long Island, NY, is glacial in origin. It is highly irregular, with erosion-resistant rocky headlands and pocket beaches in northern New England, and erodible bluffs and sandy barrier islands in southern New England and along Long Island, NY.

The ***Mid-Atlantic coast*** extends from New Jersey to Virginia, and includes two of the largest estuaries in the United States; Delaware Bay and Chesapeake Bay. The open coast shoreline is generally composed of long barrier islands separated by tidal inlets and bay entrances.

The ***South Atlantic coast*** extends from North Carolina to South Florida and consists of three regions: (1) the North Carolina and northern South Carolina shoreline, composed of long barrier and mainland beaches (including the Outer Banks and the South Carolina Grand Strand region); (2) the region extending from Charleston, SC, to the St. Johns River entrance at Jacksonville, FL (a tide-dominated coast composed of numerous short barrier islands, separated by large tidal inlets and backed by wide expanses of tidal marsh); and (3) the east coast of Florida (composed of barrier and mainland beaches backed by narrow bays and rivers).

The ***Florida Keys*** are a series of low-relief islands formed by limestone and reef rock, with narrow, intermittent carbonate beaches.

The entire Atlantic coast is subject to waves and high storm surges from hurricanes and/or nor'easters. Wave runup on steeply sloping beaches and shorelines in New England is also a common source of coastal flooding.

Gulf of Mexico Coast

The Gulf of Mexico coast extends from the Florida Keys to Texas. It can be divided into three regions: (1) the ***eastern Gulf Coast*** from southwest Florida to Mississippi, which is composed of low-lying sandy barrier islands south of Tarpon Springs, FL, and west of St. Marks, FL, with a marsh-dominated coast in between in the Big Bend area of Florida; (2) the ***Mississippi Delta Coast*** of southeast Louisiana, characterized by wide, marshy areas and a low-lying coastal plain; and (3) the ***western Gulf Coast***, including the cheniers of southwest Louisiana, and the long, sandy barrier islands of Texas.

The entire Gulf of Mexico coast is vulnerable to high storm surges and waves from hurricanes. Some areas (e.g., the Big Bend area of Florida) are especially vulnerable because of the presence of a wide, shallow continental shelf and low-lying upland areas.

Coast of U.S. Caribbean Territories

The islands of Puerto Rico and the U.S. Virgin Islands are the products of ancient volcanic activity. The coastal lowlands of Puerto Rico, which occupy nearly one-third of the island's area, contain sediment eroded and transported from the steep, inland mountains by rivers and streams. Ocean currents and wave activity rework the sediments on pocket beaches around each island. Coastal flooding is usually due to hurricanes, although tsunami events are not unknown in the Caribbean.

Great Lakes Coast

The shorelines of the Great Lakes coast extend from Minnesota to New York. They are highly variable and include wetlands, low and high cohesive bluffs, low sandy banks, and lofty sand dunes perched on bluffs (200 feet or more above lake level). Storm surges along the Great Lakes are generally less than 2 feet except in small bays (2 to 4 feet) and on Lake Erie (up to 8 feet). Large waves can accompany storm surges. Periods of active erosion are triggered by heavy precipitation events, storm waves, rising lake levels, and changes in groundwater outflow along the coast.

Pacific Coast

The Pacific coast extends from California to Washington, and includes Alaska. It can be divided into three regions: (1) the ***southern California coast***, which extends from San Diego County to Point Conception (Santa Barbara County), CA, and is characterized by long, sandy beaches and coastal bluffs; (2) the ***northern Pacific coast,*** which extends from Point Conception, CA, to Washington and is characterized by rocky cliffs, pocket beaches, and occasional long sandy barriers near river mouths; and (3) the ***coast of Alaska***.

Open coast storm surges along the Pacific shoreline are generally small (less than 2 feet) because of the narrow continental shelf and deep water close to shore. However, storm wave conditions along the Pacific shoreline are severe, and the resulting wave runup can be very destructive. In some areas of the Pacific coast, tsunami flood elevations can be much higher than flood elevations associated with coastal storms.

The ***coast of Alaska*** can further be divided into two areas: (1) the southern coast, dominated by steep mountainous islands indented by deep fjords, and (2) the Bering Sea and Arctic coasts, backed by a coastal plain dotted with lakes and drained by numerous streams and rivers. The climate of Alaska and the action of ice along the shorelines set it apart from most other coastal areas of the United States.

Coast of Hawaii and U.S. Pacific Territories

The islands that make up Hawaii are submerged volcanoes; thus, the coast of Hawaii is formed by rocky cliffs and intermittent sandy beaches. Coastlines along the Pacific Territories are similar to those of Hawaii. Coastal flooding can be due to two sources: storm surges and waves from hurricanes or cyclones, and wave runup from tsunamis.

3.2 Coastal Storm Events

Tropical cyclones and coastal storms occur in varying strengths and intensities in all coastal regions of the United States and its territories. These storms are the primary source of the flood and wind damage that the recommendations of this Manual aim to reduce. Tropical cyclones and coastal storms include all storms associated with circulation around an area of atmospheric low pressure. When the storm origin is tropical and the circulation is closed, tropical storms, hurricanes, or typhoons result.

Tropical cyclones and coastal storms are capable of generating high winds, coastal flooding, high-velocity flows, damaging waves, significant erosion, and intense rainfall (see Figure 3-4). Like all flood events, they are also capable of generating and moving large quantities of water-borne sediments and floating debris. Consequently, the risk to improperly sited, designed, or constructed coastal buildings can be great.

Figure 3-4.
Storm surge flooded this home in Ascension Parish, LA (Tropical Storm Allison, 2001)

One parameter not mentioned in the storm classifications described in the following sections—***storm coincidence with spring tides or higher than normal water levels***—also plays a major role in determining storm impacts and property damage. If a tropical cyclone or other coastal storm coincides with abnormally high water levels or with the highest monthly, seasonal, or annual tides, the flooding and erosion impacts of the storm are magnified by the higher water levels, to which the storm surge and wave effects are added.

CROSS REFERENCE

See Section 3.5.5 for a discussion of high water levels and sea level rise.

3.2.1.1 Tropical Cyclones

Tropical storms have 1-minute sustained winds averaging 39 to 74 miles per hour (mph). When sustained winds intensify to greater than 74 mph, the resulting storms are called ***hurricanes*** (in the North Atlantic basin or in the Central or South Pacific basins east of the International Date Line) or ***typhoons*** (in the western North Pacific basin).

NOTE

NOAA has detailed tropical storm and hurricane track information from 1848 to the present (http://csc.noaa.gov/hurricanes).

Hurricanes are divided into five classes according to the Saffir-Simpson Hurricane Wind Scale (SSHWS), which uses 1-minute sustained wind speed at a height of 33 feet over open water as the sole parameter to categorize storm damage potential (see Table 3-1). The SSHWS, which replaces the Saffir-Simpson Hurricane Scale, was introduced for the 2010 hurricane season to reduce confusion about the impacts associated with the hurricane categories and to provide a more scientifically defensible scale (there is not a strict correlation between wind speed and storm surge, as the original scale implied, as demonstrated by recent storms [e.g., Hurricanes Katrina and Ike] which produced devastating surge damage even though wind speeds at landfall were associated with lower hurricane categories). The storm surge ranges, flooding impact, and central pressure statements were removed from the original scale, and only peak wind speeds are included in the SSHWS (NOAA 2010). The categories and associated peak wind speeds in the SSHWS are the same as they were in the Saffir-Simpson Hurricane Scale.

Typhoons are divided into two categories; those with sustained winds less than 150 mph are referred to as typhoons, while those with sustained winds equal to or greater than 150 mph are known as ***super typhoons.***

CROSS REFERENCE

See Chapter 2 for a summary of the storms listed in Table 3-1. More details can be found in the “Coastal Flood and Wind Event Summaries” resource on the FEMA Residential Coastal Construction Web page.

Tropical cyclone records for the period 1851 to 2009 show that approximately one in five named storms (tropical storms and hurricanes) in the North Atlantic basin make landfall as hurricanes along the Atlantic or Gulf of Mexico coast of the United States. Figure 3-5 shows the average percentages of landfalling hurricanes in the United States.

Tropical cyclone landfalls are not evenly distributed on a geographic basis. In fact, the incidence of landfalls varies greatly. Approximately 40 percent of all U.S. landfalling hurricanes directly hit Florida, and 83 percent of Category 4 and 5 hurricane strikes have directly hit either Florida or Texas. Table 3-2 shows direct hurricane hits to the mainland U.S. from 1851 to 2009 categorized using the Saffir-Simpson Hurricane Scale.

Table 3-1. Saffir-Simpson Hurricane Wind Scale

Scale Number (Category)	Over Water Wind Speed in mph 1-Minute Sustained (3-Second Gust)	Property Damage	Examples[(a)]
1	74–95 (89–116)	Minimal	**Agnes** (1972 – Florida) **Earl** (1998 – Florida) **Dolly** (2008 – Texas)
2	96–110 (117–134)	Moderate	**Bob** (1991 – Rhode Island) **Marilyn** (1995 – U.S. Virgin Islands) **Frances** (2004 – Florida) **Ike** (2008 – Texas, Louisiana)
3	111–130 (135–159)	Extensive	**Alicia** (1983 – Texas) **Ivan** (2004 – Alabama)
4	131–155 (160–189)	Extreme	**Hugo** (1989 – South Carolina) **Andrew** (1992 – Florida) **Katrina** (2005 – Louisiana)
5	>155 (>189)	Catastrophic	**Florida Keys** (1935) **Camille** (1969 – Louisiana, Mississippi)

DATA SOURCE: NOAA HISTORICAL HURRICANE TRACKS (http://csc.noaa.gov/hurricanes)

(a) Hurricanes are listed according to their respective category at landfall based on wind speed.

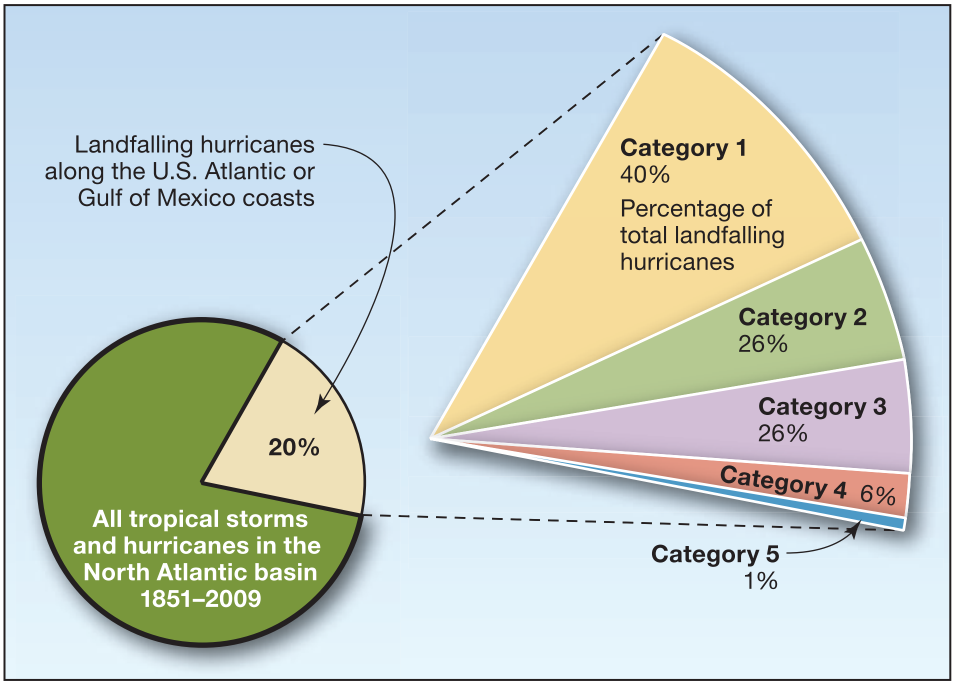


Figure 3-5. Classification (by Saffir-Simpson Hurricane scale) of landfalling tropical cyclones along the U.S. Atlantic and Gulf of Mexico coasts, 1851–2009

DATA SOURCES: BLAKE ET AL. 2005, JARRELL ET AL. 2001, NOAA 2011a

Table 3-2. Direct Hurricane Hits to U.S. Coastline Between 1851 and 2009 from Texas to Maine

Area	Saffir-Simpson Hurricane Scale Category					
	1	2	3	4	5	All
Texas	25	19	12	7	0	63
Louisiana	18	15	15	4	1	53
Mississippi	2	5	8	0	1	16
Alabama	12	5	6	0	0	23
Florida	44	33	29	6	2	114
Georgia	12	5	2	1	0	20
South Carolina	19	6	4	2	0	31
North Carolina	22	13	11	1	0	46
Virginia	9	2	1	0	0	12
Maryland	1	1	0	0	0	2
Delaware	2	0	0	0	0	2
New Jersey	2	0	0	0	0	2
Pennsylvania	1	0	0	0	0	1
New York	6	1	5	0	0	12
Connecticut	4	3	3	0	0	10
Rhode Island	3	2	4	0	0	9
Massachusetts	5	2	3	0	0	10
New Hampshire	1	1	0	0	0	2
Maine	5	1	0	0	0	6
Atlantic/Gulf U.S. Coastline (Texas to Maine)	**115**	**76**	**76**	**18**	**3**	**288**

DATA SOURCES: BLAKE ET AL. 2005, JARRELL ET AL. 2001, NOAA 2011a

Note: A direct hurricane hit means experiencing the core of strong winds and/or storm surge of a hurricane. State totals will not add up to U.S. totals because some storms are counted for more than one State

Another method of analyzing tropical cyclone incidence data is to compute the ***mean return period,*** or the average time (in years) between landfall or nearby passage of a tropical storm or hurricane. Note that over short periods of time, the actual number and timing of tropical cyclone passage/landfall may deviate substantially from the long-term statistics. Some years see little tropical cyclone activity with no landfalling storms; other years see many storms with several landfalls. A given area may not experience the effects of a tropical cyclone for years or decades, and then be affected by several storms in a single year.

3.2.1.2 Other Coastal Storms

Other coastal storms include storms lacking closed circulation, but capable of producing strong winds. These storms usually occur during winter months and can affect the Atlantic coast, Pacific coast, the Great Lakes coast, and, rarely, the Gulf of Mexico coast. Along the ***Atlantic coast***, these storms are known as extratropical storms or nor'easters. Two of the most powerful and damaging nor'easters on record are the March 5–7, 1962 storm (see Figure 3-6) and the October 28–November 3, 1991 storm.

Coastal storms along the ***Pacific coast*** of the United States are usually associated with the passage of weather fronts during the winter months. These storms produce little or no storm surge (generally 2 feet or less) along the ocean shoreline, but they are capable of generating hurricane-force winds and large, damaging waves. Storm characteristics and patterns along the Pacific coast are strongly influenced by the occurrence of the El Niño Southern Oscillation (ENSO)—a climatic anomaly resulting in above-normal ocean temperatures and elevated sea levels along the U.S. Pacific coast. During El Niño years, sea levels along the Pacific shoreline tend to rise as much as 12 to 18 inches above normal, the incidence of coastal storms increases, and the typical storm track shifts from the Pacific Northwest to southern and central California. The net result of these effects is increased storm-induced erosion, changes in longshore sediment transport (due to changes in the direction of wave approach, which changes erosion/deposition patterns along the shoreline), and increases the incidence of rainfall and landslides in coastal regions.

Storms on the ***Great Lakes*** are usually associated with the passage of low-pressure systems or cold fronts. Storm effects (high winds, storm surge, and wave runup) may last a few hours or a few days. Storm surges and damaging wave conditions on the Great Lakes are a function of wind speed, direction, duration, and fetch; if high winds occur over a long fetch for more than an hour or so, the potential for flooding and erosion exists. However, because of the sizes and depths of the Great Lakes, storm surges are usually limited to less than 2 feet, except in embayments (2 to 4 feet) and on Lake Erie (up to 8 feet). Periods of active erosion are triggered by heavy precipitation events, storm waves, rising lake levels, and changes in groundwater outflow along the coast.

Figure 3-6.
Flooding, erosion, and overwash at Fenwick Island, DE, following March 1962 nor'easter

3.3 Coastal Hazards

This section addresses coastal hazards of high wind, earthquakes, tsunamis, and other hazards and environmental effects. Coastal flooding and erosion hazards are discussed separately, in Sections 3.4 and 3.5, respectively.

3.3.1 High Winds

High winds can originate from a number of events. Tropical storms, hurricanes, typhoons, other coastal storms, and tornadoes generate the most significant coastal wind hazards.

The most current design wind speeds are given by the national load standard, ASCE 7-10, *Minimum Design Loads for Buildings and Other Structures* (ASCE 2010). Figure 3-7, taken from ASCE 7-10, shows the geographic distribution of design wind speeds for the continental United States and Alaska, and lists design wind speeds for Hawaii, Puerto Rico, Guam, American Samoa, and the Virgin Islands. The Hawaii State Building Code includes detailed design wind speed maps for all four counties in Hawaii. They are available online at http://hawaii.gov/dags/bcc/comments/wind-maps-for-state-building-code.

NOTE

Basic wind speeds given by ASCE 7-10, shown in Figure 3-7 of this Manual, correspond to a wind with a recurrence interval of 700 years for Risk Category II buildings.

The 2012 IRC contains a simplified table based on ASCE 7-10, which can be used to obtain an effective basic wind speed for sites where topographic wind effects are a concern.

High winds are capable of imposing large lateral (horizontal) and uplift (vertical) forces on buildings. Residential buildings can suffer extensive wind damage when they are improperly designed and constructed and when wind speeds exceed design levels (see Figures 3-8 and 3-9). The effects of high winds on a building depend on many factors, including:

- Wind speed (sustained and gusts) and duration of high winds
- Height of building above ground
- Exposure or shielding of the building (by topography, vegetation, or other buildings) relative to wind direction
- Strength of the structural frame, connections, and envelope (walls and roof)
- Shape of building and building components
- Number, size, location, and strength of openings (e.g., windows, doors, vents)
- Presence and strength of shutters or opening protection
- Type, quantity, and velocity of wind-borne debris

NOTE

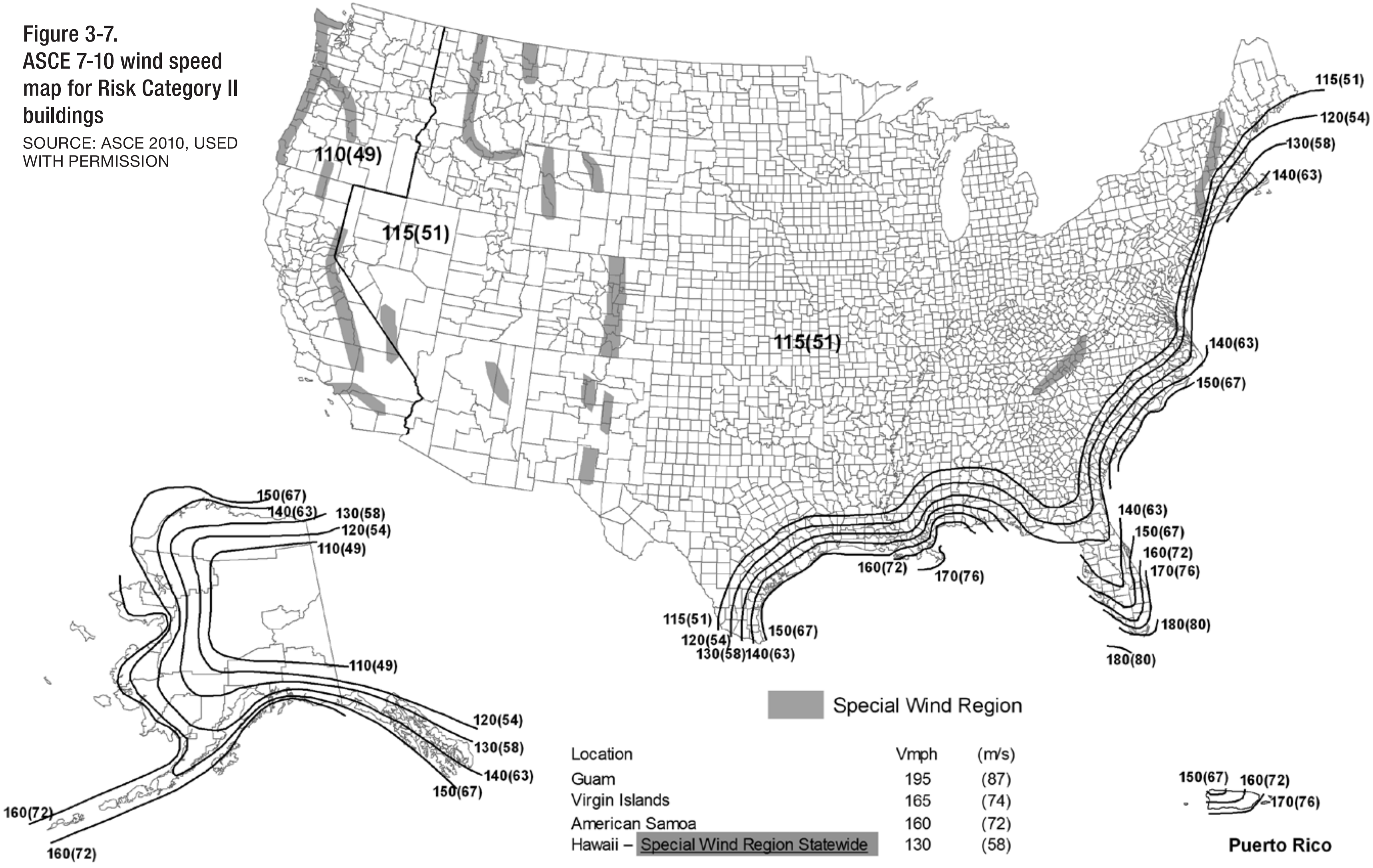
It is generally beyond the scope of most building designs to account for a direct strike by a tornado (the ASCE 7-10 wind map in Figure 3-7 excludes tornado effects). However, use of wind-resistant design techniques will reduce damage caused by a tornado passing nearby.

Section 3.3.1.3 discusses tornado effects.

Even when wind speeds do not exceed design levels, such as during Hurricane Ike, residential buildings can suffer extensive wind damage when they are improperly designed and constructed. The beach house shown in Figure 3-10 experienced damage to its roof structure. The apartment building in Figure 3-11 experienced

Figure 3-7.
ASCE 7-10 wind speed map for Risk Category II buildings

SOURCE: ASCE 2010, USED WITH PERMISSION



Location	Vmph	(m/s)
Guam	195	(87)
Virgin Islands	165	(74)
American Samoa	160	(72)
Hawaii – Special Wind Region Statewide	130	(58)

Notes:

1. **Values are nominal design 3-second gust wind speeds in miles per hour (m/s) at 33 ft (10m) above ground for Exposure C category.**
2. **Linear interpolation between contours is permitted.**
3. **Islands and coastal areas outside the last contour shall use the last wind speed contour of the coastal area.**
4. **Mountainous terrain, gorges, ocean promontories, and special wind regions shall be examined for unusual wind conditions.**
5. **Wind speeds correspond to approximately a 7% probability of exceedance in 50 years (Annual Exceedance Probability = 0.00143, MRI = 700 Years).**

Figure 3-8.
End-wall failure of typical first-floor masonry/ second-floor wood-frame building in Dade County, FL (Hurricane Andrew, 1992)

Figure 3-9.
Loss of roof sheathing due to improper nailing design and schedule in Kauai County, HI (Hurricane Iniki, 1992)

Figure 3-10.
Beach house with roof structure removed by Hurricane Ike (Galveston, TX, 2008)

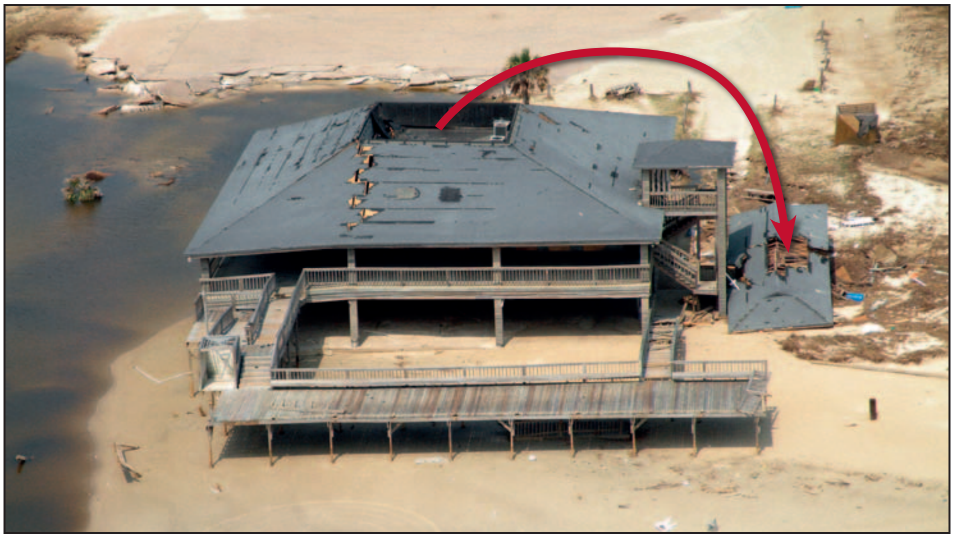


Figure 3-11.
Apartment building with gable end wind damage from Hurricane Ike as a result of poor connection between brick veneer and wall structure (Galveston, TX, 2008)

gable end wall damage when the wall sheathing failed as a result of a poor connection between the brick veneer and the stud walls.

Proper design and construction of residential structures, particularly those close to open water or near the coast, demand that every factor mentioned above be investigated and addressed carefully. Failure to do so may ultimately result in building damage or destruction by wind.

Three wind-related topics that deserve special attention from design professionals are speedup of wind due to topographic effects, wind-borne debris and rainfall penetration into buildings, and tornadoes.

3.3.1.1 Speedup of Winds Due to Topographic Effects

Speedup of winds due to topographic effects can occur wherever mountainous areas, gorges, and ocean promontories exist. Thus, the potential for increased wind speeds should be investigated for any construction on or near the crests of high coastal bluffs, cliffs, or dunes, or in gorges and canyons. ASCE 7-10 provides guidance on calculating increased wind speeds in such situations.

Designers should also consider the effects of long-term erosion on the wind speeds a building may experience over its lifetime. For example, a building sited atop a tall bluff, but away from the bluff edge, is not prone to wind speedup initially, but long-term erosion may move the bluff edge closer to the building and expose the building to increased wind speeds due to topographic changes.

3.3.1.2 Wind-Borne Debris and Rainfall Penetration

Wind loads and wind-borne debris are both capable of causing damage to a building envelope. Even small failures in the building envelope, at best, lead to interior damage by rainfall penetration and winds and, at worst, lead to internal pressurization of the building, roof loss, and complete structural disintegration.

Sparks et al. (1994) investigated the dollar value of insured wind losses following Hurricanes Hugo and Andrew and found the following:

- Most wind damage to houses is restricted to the building envelope
- Rainfall entering a building through envelope failures causes the dollar value of direct building damage to be magnified by a factor of two (at lower wind speeds) to nine (at higher wind speeds)
- Lower levels of damage magnification are associated with water seeping through exposed roof sheathing (e.g., following loss of shingles or roof tiles)
- Higher levels of damage magnification are associated with rain pouring through areas of lost roof sheathing and through broken windows and doors

COST CONSIDERATION

Even minor damage to the building envelope can lead to large economic losses, as the building interior and contents get wet.

3.3.1.3 Tornadoes

A tornado is a rapidly rotating vortex or funnel of air extending groundward from a cumulonimbus cloud. Tornadoes are spawned by severe thunderstorms and by hurricanes. Tornadoes often form in the right forward quadrant of a hurricane, far from the hurricane eye. The strength and number of tornadoes are not related to the strength of the hurricane that generates them. In fact, the weakest hurricanes often produce the most tornadoes. Tornadoes can lift and move huge objects, move or destroy houses, and siphon large volumes from bodies of water. Tornadoes also generate large amounts of debris, which then become wind-borne and cause additional damage.

CROSS REFERENCE

The FEMA MAT program has published several MAT reports and recovery advisories following tornado disasters in the United States. These publications offer both insight into the performance of buildings during tornadoes and solutions. To obtain copies of these publications, see the FEMA MAT Web page (http://www.fema.gov/rebuild/mat).

Tornadoes are rated using the Enhanced Fujita (EF) Scale, which correlates tornado wind speeds to categories EF0 through EF5 based on damage indicators and degrees of damage. Table 3-3 shows the EF Scale. For more information on how to assess tornado damage based on the EF Scale, refer to *A Recommendation for an Enhanced Fujita Scale* by the Texas Tech Wind Science and Engineering Center at http://www.spc.noaa.gov/faq/tornado/ef-ttu.pdf (TTU 2004).

Table 3-3. Enhanced Fujita Scale in Use Since 2007

EF Scale Rating	3-Second Gust Speed (mph)	Type of Damage
EF0	65–85	Light damage
EF1	86–110	Moderate damage
EF2	111–135	Considerable damage
EF3	136–165	Severe damage
EF4	166–200	Devastating damage
EF5	>200	Incredible damage

Hardened buildings and newer structures designed and constructed to modern, hazard-resistant codes can generally resist the wind loads from weak tornadoes. When stronger tornadoes strike, not all damage is from the rotating vortex of the tornado. Much of the damage is caused by straight-line winds being pulled into and rushing toward the tornado itself. Homes built to modern codes may survive some tornadoes without structural failure, but often experience damage to the cladding, roof covering, roof deck, exterior walls, and windows. For most building uses, it is economically impractical to design the entire building to resist tornadoes. Portions of buildings can be designed as safe rooms to protect occupants from tornadoes.

CROSS REFERENCE

FEMA 320, *Taking Shelter from the Storm: Building a Safe Room for Your Home or Small Business* (FEMA 2008a) provides guidance and designs for residential safe rooms that provide near-absolute protection against the forces of extreme winds. For more information, see the FEMA safe room Web page (http://www.fema.gov/plan/prevent/saferoom/index.shtm).

3.3.2 Earthquakes

Earthquakes can affect coastal areas just as they can affect inland areas through ground shaking, liquefaction, surface fault ruptures, and other ground failures. Therefore, coastal construction in seismic hazard areas must take potential earthquake hazards into account. Since basic principles of earthquake-resistant design can contradict flood-resistant design principles, proper design in coastal seismic hazard areas must strike a balance between:

- The need to elevate buildings above flood hazards and minimize obstructions to flow and waves beneath a structure
- The need to stabilize or brace the building against potentially violent accelerations and shaking due to earthquakes

Earthquakes are classified according to magnitude and intensity. Magnitude refers to the total energy released by the event. Intensity refers to the effects at a particular site. Thus, an earthquake has a single magnitude, but the intensity varies with location. The Richter Scale is used to report earthquake magnitude, while the Modified Mercalli Intensity (MMI) Scale is used to report felt intensity. The MMI Scale (see Table 3-4) ranges from I (imperceptible) to XII (catastrophic).

CROSS REFERENCE

Seismic load provisions and earthquake ground motion maps can be found in the following codes and standards:

- IBC Section 1613
- IRC R301.2.2
- ASCE 7 Chapters 11 through 23

For best practices guidance, see FEMA 232, *Homebuilders' Guide to Earthquake Resistant Design and Construction* (FEMA 2006a).

The ground motion produced by earthquakes can shake buildings (laterally and vertically) and cause structural failure by excessive deflection. Earthquakes can cause building failures by rapid uplift, subsidence, ground rupture, soil liquefaction, or consolidation. In coastal areas, the structural effects of ground shaking can be magnified when buildings are elevated above the natural ground elevation to mitigate flooding.

One of the site parameters controlling seismic-resistant design of buildings is the maximum considered earthquake ground motion, which is defined in the IBC as the most severe earthquake effects considered in the IBC, and has been mapped based on the 0.2-second spectral response acceleration and the 1.0-second spectral response acceleration as a percent of the gravitational constant ("g").

Table 3-4. Earthquake MMI Scale

MMI Level	Felt Intensity
I	Not felt except by very few people under special conditions. Detected mostly by instruments.
II	Felt by a few people, especially those on the upper floors of buildings. Suspended objects may swing.
III	Felt noticeably indoors. Standing automobiles may rock slightly.
IV	Felt noticeably indoors, by a few outdoors. At night, some people may be awakened. Dishes, windows, and doors rattle.
V	Felt by nearly everyone. Many people are awakened. Some dishes and windows are broken. Unstable objects are overturned.
VI	Felt by nearly everyone. Many people become frightened and run outdoors. Some heavy furniture is moved. Some plaster falls.
VII	Most people are alarmed and run outside. Damage is negligible in buildings of good construction, considerable in buildings of poor construction.
VIII	Damage is slight in specially designed structures, considerable in ordinary buildings, great in poorly built structures. Heavy furniture is overturned.
IX	Damage is considerable in specially designed buildings. Buildings shift from their foundations and partly collapse. Underground pipes are broken.
X	Some well-built wooden structures are destroyed. Most masonry structures are destroyed. The ground is badly cracked. Considerable landslides occur on steep slopes.
XI	Few, if any, masonry structures remain standing. Rails are bent. Broad fissures appear in the ground.
XII	Virtually total destruction. Waves are seen on the ground surface. Objects are thrown in the air.

SOURCE: FEMA 1997

The structural effects of earthquakes are a function of many factors (e.g., soil characteristics; local geology; and building weight, shape, height, structural system, and foundation type). Design of earthquake-resistant buildings requires careful consideration of both site and structure.

In many cases, elevating a building 8 to 10 feet above grade on a pile or column foundation—a common practice in low-lying Zone V and Coastal A Zone areas—can result in what earthquake engineers term an "inverted pendulum" as well as a discontinuity in the floor diaphragm and vertical lateral force-resisting system. Both conditions require the building be designed for a larger earthquake force. Thus, designs for pile- or column-supported residential buildings should be verified for necessary strength and rigidity below the first-floor level (see Chapter 10) to account for increased stresses in the foundation members during an earthquake. For buildings elevated on fill, earthquake ground motions can be exacerbated if the fill and underlying soils are not properly compacted and stabilized.

Liquefaction of the supporting soil can be another damaging consequence of ground shaking. In granular soils with high water tables (like those found in many coastal areas), the ground motion can create a semi-liquid soil state. The soil then can temporarily lose its bearing capacity, and settlement and differential movement of buildings can result.

Seismic effects on buildings vary with structural configuration, stiffness, ductility, and strength. Properly designed and built wood-frame buildings are quite ductile, meaning that they can withstand large deformations without losing strength. Failures, when they occur in wood-frame buildings, are usually at connections. Properly designed and built steel construction is also inherently ductile, but can fail at non-ductile connections, especially at welded connections. Bolted connections have performed better than welded connections under seismic loads. Modern concrete construction can be dimensioned and reinforced to provide sufficient strength and ductility to resist earthquakes; older concrete structures are typically more vulnerable. Elements of existing concrete structures can be retrofitted with a variety of carbon-fiber, glass-fiber, glass-fiber-reinforced or fiber-reinforced polymer wraps and strips to increase the building's resistance to seismic effects, although this is typically a costly option. Failures in concrete masonry structures are likely to occur if reinforcing and cell grouting do not meet seismic-resistant requirements.

3.3.3 Tsunamis

Tsunamis are long-period water waves generated by undersea shallow-focus earthquakes, undersea crustal displacements (subduction of tectonic plates), landslides, or volcanic activity. Tsunamis can travel great distances, undetected in deep water, but shoaling rapidly in coastal waters and producing a series of large waves capable of destroying harbor facilities, shore protection structures, and upland buildings (see Figure 3-12). Tsunamis have been known to damage some structures thousands of feet inland and over 50 feet above sea level.

Coastal construction in tsunami hazard zones must consider the effects of tsunami runup, flooding, erosion, and debris loads. Designers should also be aware that the "rundown" or return of water to the sea can also damage the landward sides of structures that withstood the initial runup.

Tsunami effects at a site are determined by four basic factors:

- Magnitude of the earthquake or triggering event
- Location of the triggering event
- Configuration of the continental shelf and shoreline
- Upland topography

NOTE

Information about tsunamis and their effects is available from the National Tsunami Hazard Mitigation Program Web site: http://nthmp.tsunami.gov.

Figure 3-12. Damage from the 2009 tsunami (Amanave, American Samoa)

SOURCE: ASCE, USED WITH PERMISSION

The ***magnitude of the triggering event*** determines the period of the resulting waves, and generally (but not always) the tsunami magnitude and damage potential. Unlike typical wind-generated water waves with periods between 5 and 20 seconds, tsunamis can have wave periods ranging from a few minutes to over 1 hour (Camfield 1980). As wave periods increase, the potential for coastal inundation and damage also increases. Wave period is also important because of the potential for resonance and wave amplification within bays, harbors, estuaries, and other semi-enclosed bodies of coastal water.

The ***location of the triggering event*** has two important consequences. First, the distance between the point of tsunami generation and the shoreline determines the maximum available warning time. Tsunamis generated at a remote source take longer to reach a given shoreline than locally generated tsunamis.

Second, the point of generation determines the direction from which a tsunami approaches a given site. Direction of approach can affect tsunami characteristics at the shoreline because of the sheltering or amplification effects of other land masses and offshore bathymetry. The ***configuration of the continental shelf and shoreline*** affect tsunami impacts at the shoreline through wave reflection, refraction, and shoaling. Variations in offshore bathymetry and shoreline irregularities can focus or disperse tsunami wave energy along certain shoreline reaches, increasing or decreasing tsunami impacts.

Upland elevations and topography also determine tsunami impacts at a site. Low-lying tsunami-prone coastal sites are more susceptible to inundation, tsunami runup, and damage than sites at higher elevations.

Table 3-5 lists areas where tsunami events have been observed in the United States and its territories, and the sources of those events. Note that other areas may be subject to rare tsunami events.

Table 3-5. Areas of Observed Tsunami Events in the United States and Territories

Area		Principal Source of Tsunamis
Alaska:	North Pacific coast	Locally generated events (landslides, subduction, submarine landslides, volcanic activity)
	Aleutian Islands	Locally generated events and remote source earthquakes
	Gulf of Alaska coast	Locally generated events and remote source earthquakes
Hawaii		Locally generated events and remote source earthquakes
American Samoa		Locally generated events and remote source earthquakes
Oregon		Locally generated events and remote source earthquakes
Washington		Locally generated events and remote source earthquakes
California		Locally generated events and remote source earthquakes
Puerto Rico		Locally generated events
U.S. Virgin Islands		Locally generated events

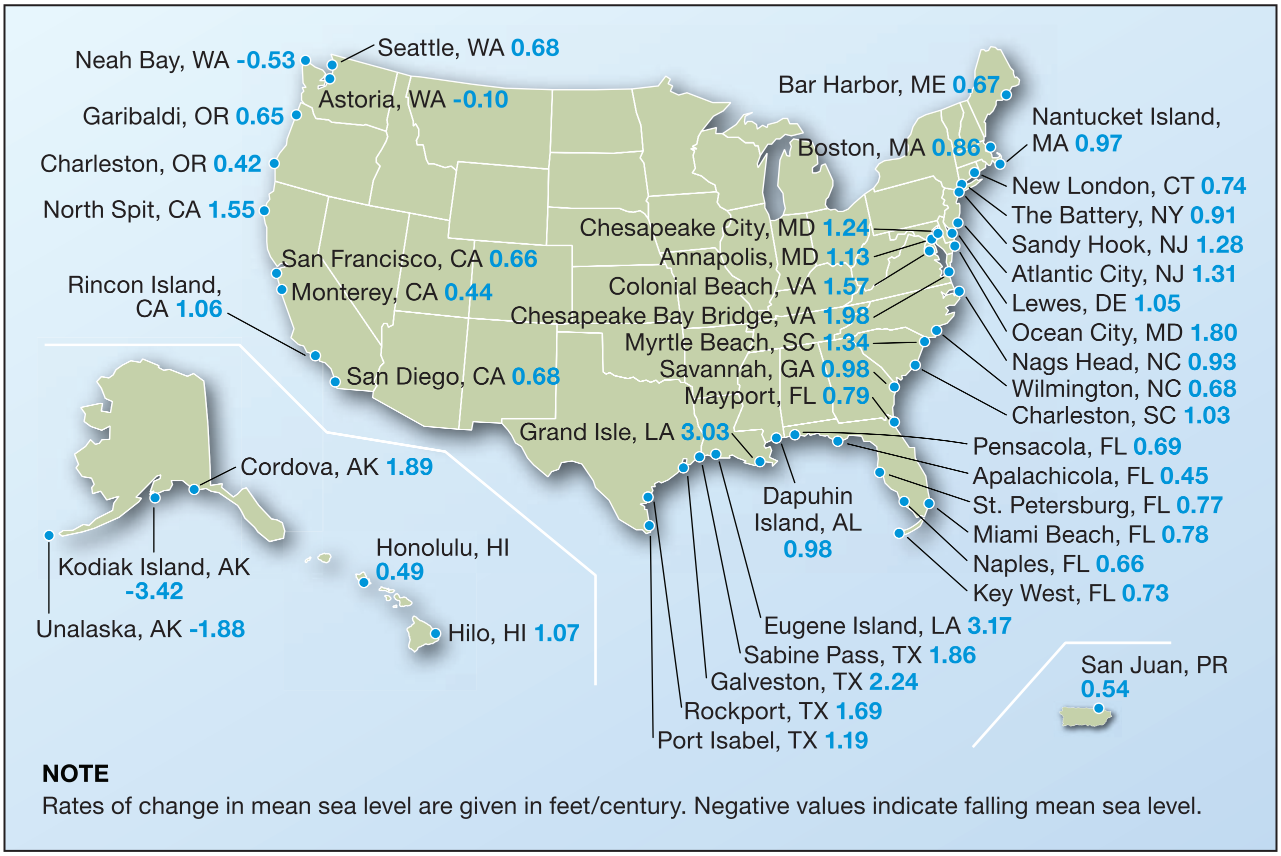
3.3.4 Other Hazards and Environmental Effects

Other hazards to which coastal construction may be exposed include a wide variety of hazards whose incidence and severity may be highly variable and localized. Examples include subsidence and uplift, landslides and ground failures, salt spray and moisture, rain, hail, wood decay and termites, wildfires, floating ice, snow, and atmospheric ice. These hazards do not always come to mind when coastal hazards are mentioned, but like the other hazards described in this chapter, they can affect coastal construction and should be considered in siting, design, and construction decisions.

3.3.4.1 Sea and Lake Level Rise

Coastal flood effects, described in detail in Section 3.4, typically occur over a period of hours or days. However, longer-term water level changes also occur. Sea level tends to rise or fall over centuries or thousands of years, in response to long-term global climate changes. Great Lakes water levels fluctuate both seasonally and over decades in response to regional climate changes. In either case, medium- and long-term increases in water levels increase the damage-causing potential of coastal flood and storm events and often cause a permanent horizontal recession of the shoreline.

Global mean sea level has been rising at long-term rates averaging 1.7 (+/-0.5) millimeters annually for the twentieth century (over 6 inches total during the twentieth century) (Intergovernmental Panel on Climate Change [IPCC] 2007). Rates of mean sea level rise along the Louisiana and Texas coasts, as well as portions of the Atlantic coast, are significantly higher than the global average (as high as 3.03 feet per century in Grand Isle, LA). Records for U.S. Pacific coast stations show that some areas have experienced rises in relative sea levels of over 1 foot per century. Other areas have experienced a fall in relative sea levels; Alaska's relative sea level fall rate is as high as 3.42 feet per century (see Figure 3-13).



NOTE

Rates of change in mean sea level are given in feet/century. Negative values indicate falling mean sea level.

Figure 3-13.
Observations of rates of change in mean sea level in the United States in feet per century

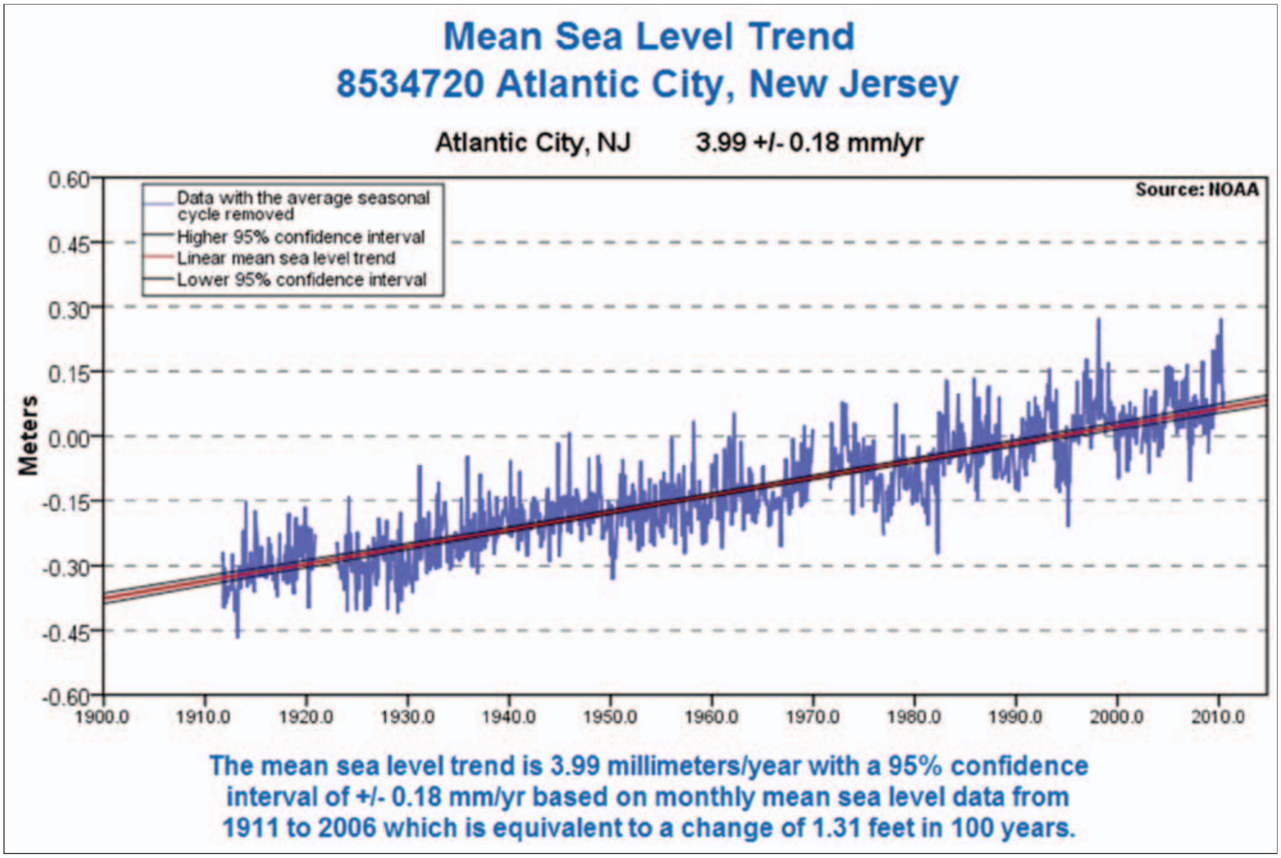
DATA SOURCE: NOAA CENTER FOR OPERATIONAL OCEANOGRAPHIC PRODUCTS AND SERVICES (http://tidesandcurrents.noaa.gov/sltrends/sltrends.html)

- Detailed historical and recent sea level data for U.S. coastal stations are available from NOAA Center for Operational Oceanographic Products and Services at http://tidesandcurrents.noaa.gov/sltrends/sltrends.html (see Figure 3-14 for an example of mean sea level trend for a station in Atlantic City, NJ).
- The EPA provides links to recent reports (including those of the IPCC) and data at http://www.epa.gov/climatechange/science/recentslc.html.

CROSS REFERENCE

For more information on measured and projected Great Lakes water levels, see the USACE Detroit District Monthly Bulletin of Great Lakes Water Levels Web page at http://www.lre.usace.army.mil/greatlakes/hh/greatlakeswaterlevels/waterlevelforecasts/monthlybulletinofgreatlakeswaterlevels.

Great Lakes water-level records dating from 1860 are maintained by the USACE Detroit District. The records show seasonal water levels typically fluctuate between 1 and 2 feet. The records also show that long-term (approximately 100 years) water levels in Lakes Michigan, Huron, Erie, and Ontario have fluctuated approximately 6 feet, and water levels in Lake Superior have fluctuated approximately 4 feet. Figure 3-15 shows a typical plot of actual and projected lake levels for Lakes Michigan and Huron.



The mean sea level trend is 3.99 millimeters/year with a 95% confidence interval of +/- 0.18 mm/yr based on monthly mean sea level data from 1911 to 2006 which is equivalent to a change of 1.31 feet in 100 years.

Figure 3-14.
Mean sea level rise data for a station in Atlantic City, NJ
SOURCE: NOAA 2011b

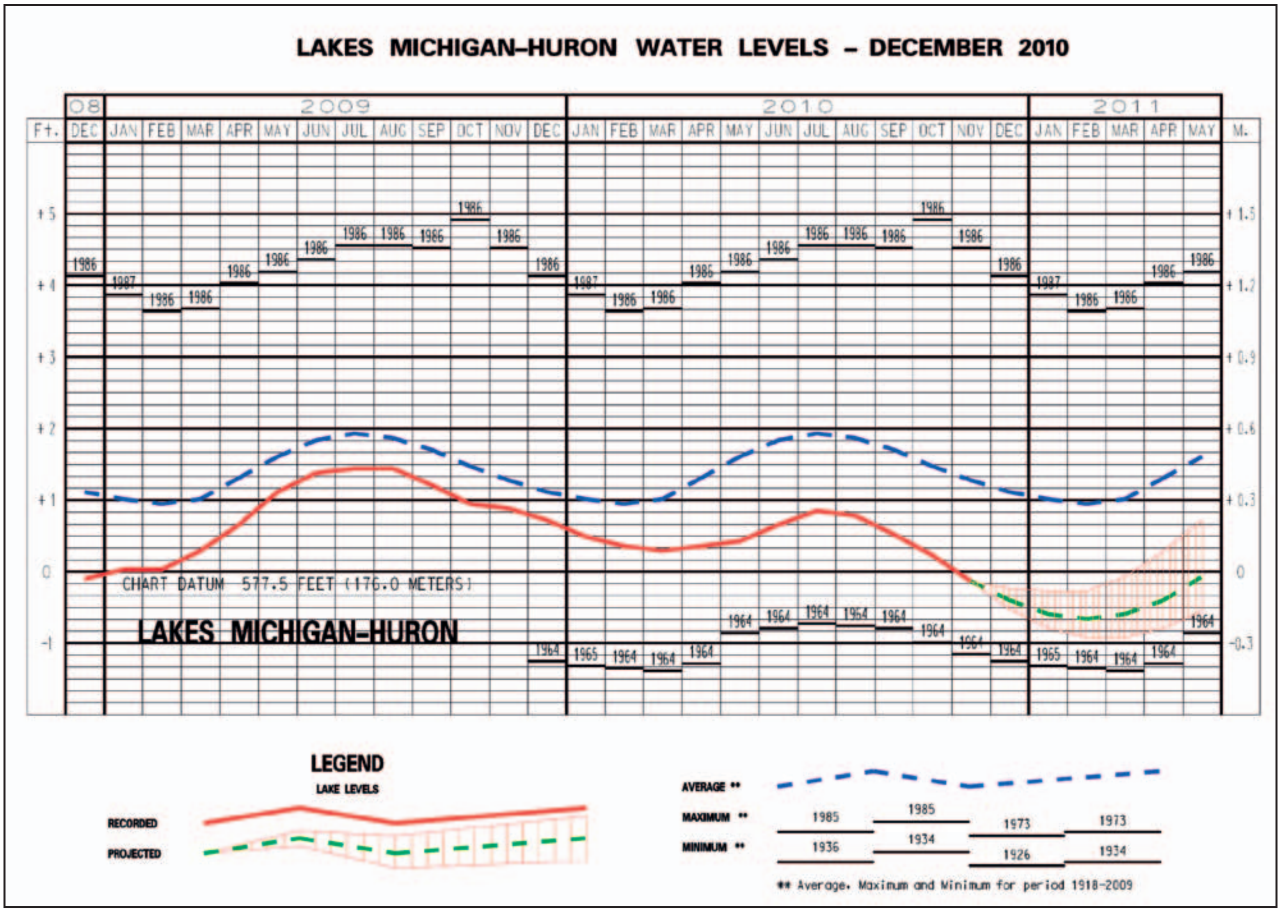


Figure 3-15.
Monthly bulletin of lake levels for Lakes Michigan and Huron
SOURCE: USACE DETROIT DISTRICT, ACCESSED DECEMBER 2010

Keillor (1998) discusses the implications of both high and low lake levels on Great Lakes shorelines. In general, beach and bluff erosion rates tend to increase as water levels rise over a period of several years, such as occurred in the mid-1980s. As water levels fall, erosion rates diminish. Low lake levels lead to generally stable shorelines and bluffs, but make navigation through harbor entrances difficult (see Section 3.5 for more information on coastal bluff erosion).

NOTE

Because coastal land masses can move up (uplift) or down (subsidence) independent of water levels, discussions related to water level change must be expressed in terms of relative sea level or relative lake level.

Designers, community officials, and owners should note that FIRMs do not account for sea level rise or Great Lakes water level trends. Relying on FIRMs for estimates of elevations for future water and wave effects is not advised for any medium- to long-term planning horizon (10 to 20 years or longer). Instead, forecasts of future water levels should be incorporated into project planning. This has been done at the Federal level in the USACE publication titled *Water Resource Policies and Authorities Incorporating Sea-Level Change Considerations in Civil Works Program* (USACE 2009a), which includes guidance on where to obtain water level change information and how to interpret and use such information. The USACE publication contains a flow chart and a step-by-step process to follow. Although the publication was written with USACE projects in mind, the guidance will be helpful to those planning and designing coastal residential buildings.

3.3.4.2 Subsidence and Uplift

Subsidence is a hazard that typically affects areas where (1) withdrawal of groundwater or petroleum has occurred on a large scale, (2) organic soils are drained and settlement results, (3) younger sediments deposit over older sediments and cause those older sediments to compact (e.g., river delta areas), or (4) surface sediments collapse into underground voids. The last of these four is most commonly associated with mining and rarely affects coastal areas (coastal limestone substrates would be an exception because these areas could be affected by collapse). The remaining three causes (groundwater or petroleum withdrawal, organic soil drainage, and sediment compaction) have all affected coastal areas in the past (FEMA 1997). One consequence of coastal subsidence, even when small in magnitude, is an increase in coastal flood hazards due to an increase in flood depth. For example, Figure 3-16 shows land subsidence in the Houston-Galveston area. In portions of Texas, subsidence has been measured for over 100 years, and subsidence of several feet has been recorded over a wide area; some land areas in Texas have dropped 10 feet in elevation since 1906. Subsidence also complicates flood hazard mapping and can render some flood hazard maps obsolete before they would otherwise need to be updated.

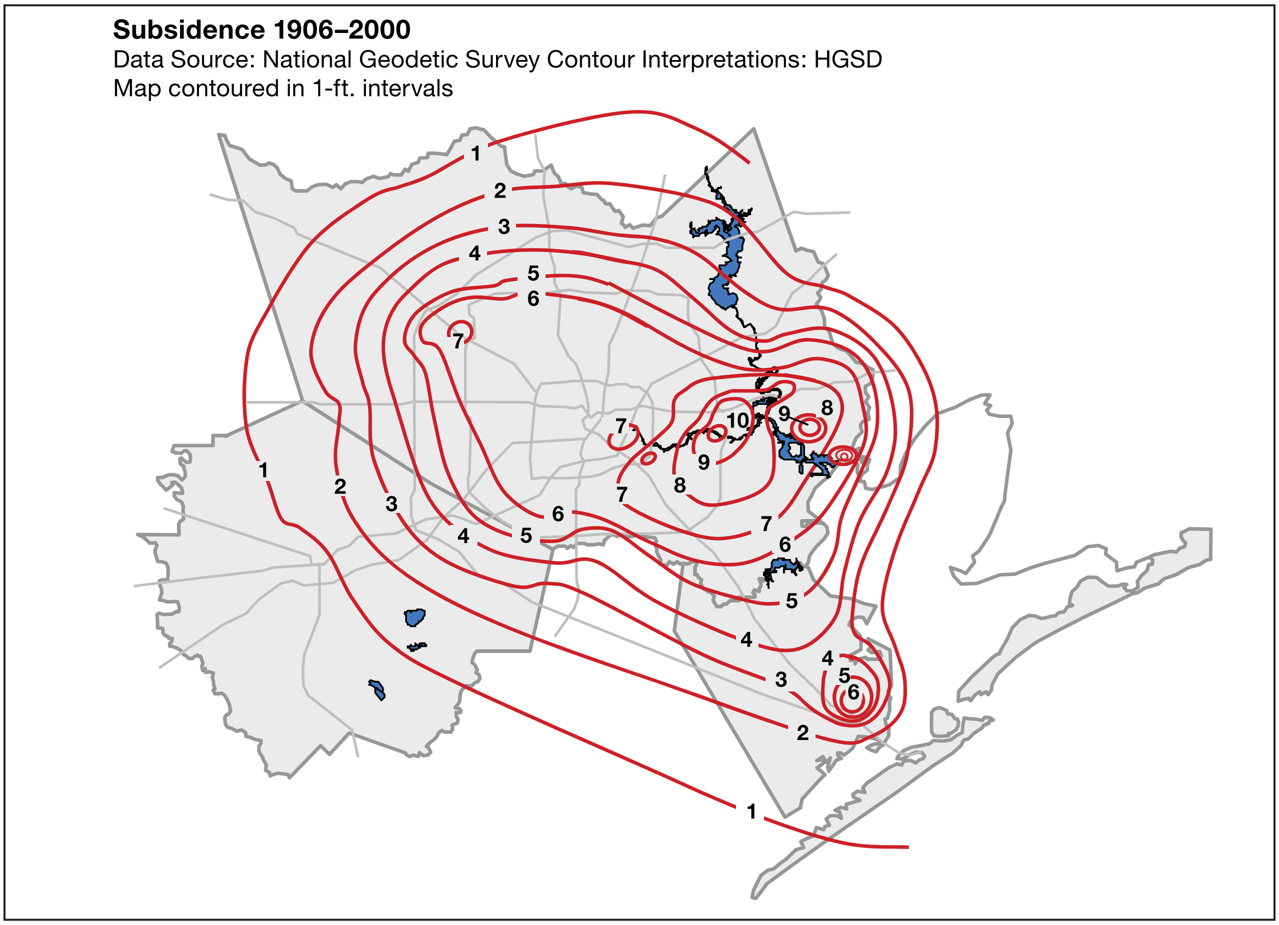


Figure 3-16.
Land subsidence in the Houston-Galveston area, 1906–2000
SOURCE: HARRIS-GALVESTON SUBSIDENCE DISTRICT 2010

Land uplift is the result of the ground rising due to various geological processes. Although few people regard land uplift as a coastal hazard, Larsen (1994) has shown that differential uplift in the vicinity of the Great Lakes can lead to increased water levels and flooding. As the ground rises in response to the removal of the great ice sheet, it does so in a non-uniform fashion. On Lake Superior, the outlet at the eastern end of the lake is rising at a rate of nearly 10 inches per century, relative to the city of Duluth-Superior at the western end of the lake. This causes a corresponding water level rise at Duluth-Superior. Similarly, the northern ends of Lakes Michigan and Huron are rising relative to their southern portions. On Lake Michigan, the northern outlet at the Straits of Mackinac is rising at a rate of 9 inches per century, relative to Chicago, at the southern end of the lake. The outlet of Lakes Michigan and Huron is rising only about 3 inches per century relative to the land at Chicago.

3.3.4.3 Salt Spray and Moisture

Salt spray and moisture effects frequently lead to corrosion and decay of building materials in the coastal environment. These hazards are commonly overlooked or underestimated by designers. Any careful inspection of coastal buildings (even new or recent buildings) near a large body of water will reveal deterioration of improperly selected or installed materials.

For example, metal connectors, straps, and clips used to improve a building's resistance to high winds and earthquakes often show signs of corrosion (see Figure 3-17). Corrosion is affected by many factors, but the primary difference between coastal and inland/Great Lakes areas is the presence of salt spray, tossed into the air by breaking waves and blown onto land by onshore winds. Salt spray accumulates on metal surfaces, accelerating the electrochemical processes that cause corrosion, particularly in the humid conditions common along the coast.

Corrosion severity varies considerably from community to community along the coast, from building to building within a community, and even within an individual building.

CROSS REFERENCE

See Chapter 14, Section 14.2, for a discussion of salt spray and moisture effects.

Figure 3-17.
Example of corrosion, and resulting failure, of metal connectors

SOURCE: SPENCER ROGERS, USED WITH PERMISSION

Factors affecting the rate of corrosion include humidity, wind direction and speed, seasonal wave conditions, distance from the shoreline, elevation above the ground, orientation of the building to the shoreline, rinsing by rainfall, shelter and air flow in and around the building, and the component materials.

CROSS REFERENCE

See FEMA Technical Bulletin 8, *Corrosion Protection for Metal Connectors in Coastal Areas* (1996), for more information about corrosion and corrosion-resistant connectors.

Wood decay is most commonly caused by moisture. Moisture-related decay is prevalent in all coastal areas—it is not exclusive to buildings near the shoreline. Protection against moisture-related decay can be accomplished by one or more of the following: use of preservative-treated or naturally durable wood, proper detailing of wood joints to eliminate standing water, avoidance of cavity wall systems, and proper installation of water-resistive barriers. Sunlight, aging, insects, chemicals, and temperature can also lead to decay. FEMA P-499 Fact Sheet 1.7, *Coastal Building Materials*, has more information on the use of materials to resist corrosion, moisture, and decay (FEMA 2010).

3.3.4.4 Rain

Rain presents two principal hazards to coastal residential construction:

- Penetration of the building envelope during high-wind events (see Section 3.3.1.2)
- Vertical loads due to rainfall ponding on the roof

Ponding usually occurs on flat or low-slope roofs where a parapet or other building element causes rainfall to accumulate, and where the roof drainage system fails. Every inch of accumulated rainfall causes a downward-directed load of approximately 5 pounds per square foot. Excessive accumulation can lead to progressive deflection and instability of roof trusses and supports.

3.3.4.5 Hail

Hailstorms develop from severe thunderstorms, and generate balls or lumps of ice capable of damaging agricultural crops, buildings, and vehicles. Severe hailstorms can damage roofing shingles and tiles, metal roofs, roof sheathing, skylights, glazing, and other building components. Accumulation of hail on flat or low-slope roofs, like the accumulation of rainfall, can lead to significant vertical loads and progressive deflection of roof trusses and supports.

3.3.4.6 Termites

Infestation by termites is common in coastal areas subject to high humidity and frequent and heavy rains. Improper preservative treatments, improper design and construction, and even poor landscaping practices, can all contribute to infestation problems. The IRC includes a termite infestation probability map, which shows that most coastal areas have a moderate to very heavy probability of infestation (ICC 2012b).

Protection against termites can be accomplished by one or more of the following: use of preservative-treated wood products (including field treatment of notches, holes, and cut ends), use of naturally termite-resistant wood species, chemical soil treatment, and installation of physical barriers to termites (e.g., metal or plastic termite shields).

3.3.4.7 Wildfire

Wildfires can occur virtually everywhere in the United States and can threaten buildings constructed in coastal areas. Topography, the availability of vegetative fuel, and weather are the three principal factors that influence wildfire hazards. FEMA has produced several reports discussing the reduction of the wildfire hazard and the vulnerability of structures to wildfire hazards, including *Wildfire Mitigation in the 1998 Florida Wildfires* (FEMA 1998) and FEMA P-737, *Home Builder's Guide to Construction in Wildfire Zones* (FEMA 2008b). Some communities have adopted the *International Wildland-Urban Interface Code* (ICC 2012c), which includes provisions that address the spread of fire and defensible space for buildings constructed near wildland areas.

Experience with wildfires has shown that the use of fire-rated roof assemblies is one of the most effective methods of preventing loss of buildings to wildfire. Experience has also shown that replacing highly flammable vegetation around buildings with minimally flammable vegetation is also an effective way of reducing possible wildfire damage. Clearing vegetation around some buildings may be appropriate, but this action can lead to slope instability and landslide failures on steeply sloping land. Siting and construction on steep slopes requires careful consideration of multiple hazards with sometimes conflicting requirements.

3.3.4.8 Floating Ice

Some coastal areas of the United States are vulnerable to problems caused by floating ice. These problems can take the form of erosion and gouging of coastal shorelines, flooding due to ice jams, and lateral and vertical ice loads on shore protection structures and coastal buildings. On the other hand, the presence of floating ice along some shorelines reduces erosion from winter storms and wave effects. Designers should investigate potential adverse and beneficial effects of floating ice in the vicinity of their building site. Although this Manual does not discuss these issues in detail, additional information can be found in Caldwell and Crissman (1983), Chen and Leidersdorf (1988), and USACE (2002).

3.3.4.9 Snow

The principal hazard associated with snow is its accumulation on roofs and the subsequent deflection and potential failure of roof trusses and supports. Calculation of snow loads is more complicated than rain loads, because snow can drift and be distributed non-uniformly across a roof. Drainage of trapped and melted snow, like the drainage of rain water, must be addressed by the designer. In addition, particularly in northern climates such as New England and the Great Lakes, melting snow can result in ice dams. Ice dams can cause damage to roof coverings, drip edges, gutters, and other elements along eaves, leaving them more susceptible to future wind damage.

CROSS REFERENCE

Chapter 7 of ASCE 7 includes maps and equations for calculating snow loads. It also includes provisions for additional loads due to ice dams (ASCE 2010).

CROSS REFERENCE

State CZM programs (see Section 5.6, in Chapter 5) are a good source of hazard information, vulnerability analyses, mitigation plans, and other information about coastal hazards.

3.3.4.10 Atmospheric Ice

Ice can sometimes form on structures as a result of certain atmospheric conditions or processes (e.g., freezing rain or drizzle or in-cloud icing—accumulation of ice as supercooled clouds or fog comes into contact with a structure). The formation and accretion of this ice is termed ***atmospheric ice***. Fortunately, typical coastal residential buildings are not considered ice-sensitive structures and are not subject to structural failures resulting from atmospheric ice. However, designers should consider proximity of coastal residential buildings to ice-sensitive structures (e.g., utility towers, utility lines, and similar structures) that may fail under atmospheric ice conditions. Designers should also be aware that ice build-up on structures, trees, and utility lines can result in a falling ice hazard to building occupants.

3.4 Coastal Flood Effects

Coastal flooding can originate from a number of sources. Tropical cyclones, other coastal storms, and tsunamis generate the most significant coastal flood hazards, which usually take the form of hydrostatic forces, hydrodynamic forces, wave effects, and flood-borne debris effects. Regardless of the source of coastal flooding, a number of flood parameters must be investigated at a coastal site to correctly characterize potential flood hazards:

- Origin of flooding
- Flood frequency
- Flood depth
- Flood velocity
- Flood direction
- Flood duration
- Wave effects
- Erosion and scour
- Sediment overwash
- Flood-borne debris

CROSS REFERENCE

See Section 8.5 for procedures used to calculate flood loads.

If a designer can determine each of these parameters for a site, the specification of design flood conditions is straightforward and the calculation of design flood loads will be more precise. Unfortunately, determining some of these parameters (e.g., flood velocity, debris loads) is difficult for most sites, and design flood conditions and loads may be less exact.

3.4.1 Hydrostatic Forces

Standing water or slowly moving water can induce horizontal hydrostatic forces against a structure, especially when floodwater levels on different sides of the structure are not equal. Also, flooding can cause vertical hydrostatic forces, or flotation (see Figure 3-18).

3.4.2 Hydrodynamic Forces

Hydrodynamic forces on buildings are created when coastal floodwaters move at high velocities. These high-velocity flows are capable of destroying solid walls and dislodging buildings with inadequate foundations. High-velocity flows can also move large quantities of sediment and debris that can cause additional damage.

High-velocity flows in coastal areas are usually associated with one or more of the following:

- Storm surge and wave runup flowing landward, through breaks in sand dunes or across low-lying areas (see Figure 3-19)

CROSS REFERENCE

Predicting the speed and direction of high-velocity flows is difficult. Designers should refer to the guidance contained in Section 8.5.6 and should assume that the flow can originate from any direction.

Figure 3-18.
Intact houses floated off their foundations and carried inland during Hurricane Hugo in 1989 (Garden City, SC)

Figure 3-19.
Storm surge at Horseshoe Beach, FL, during Tropical Storm Alberto in 2006

SOURCE: NOAA NATIONAL WEATHER SERVICE FORECAST OFFICE

- Tsunamis
- Outflow (flow in the seaward direction) of floodwaters driven into bay or upland areas
- Strong currents parallel to the shoreline, driven by the obliquely incident storm waves

NOTE

Storm surge does not correlate to hurricane category according to the earlier Saffir-Simpson Hurricane Scale, so the scale was renamed (Saffir Simpson Hurricane Wind Scale) and changed in 2010 to eliminate any reference to storm surge (see Table 3-1).

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 roads and access paths that cross dunes, bridges or shore-normal canals, channels, or drainage features. For example, evidence after Hurricane Opal struck Navarre Beach, FL, in 1995 suggests that large engineered buildings channeled flow between them (see Figure 3-20). The channelized flow caused deep scour channels across the island, undermining a pile-supported house between the large buildings (see Figure 3-21), and washing out roads and houses (see Figure 3-22) situated farther landward.

Figure 3-20.
Flow channeled between large buildings during Hurricane Opal in 1995 scoured a deep channel and damaged infrastructure and houses at Navarre Beach, FL

SOURCE: FLORIDA DEPARTMENT OF ENVIRONMENTAL PROTECTION, USED WITH PERMISSION

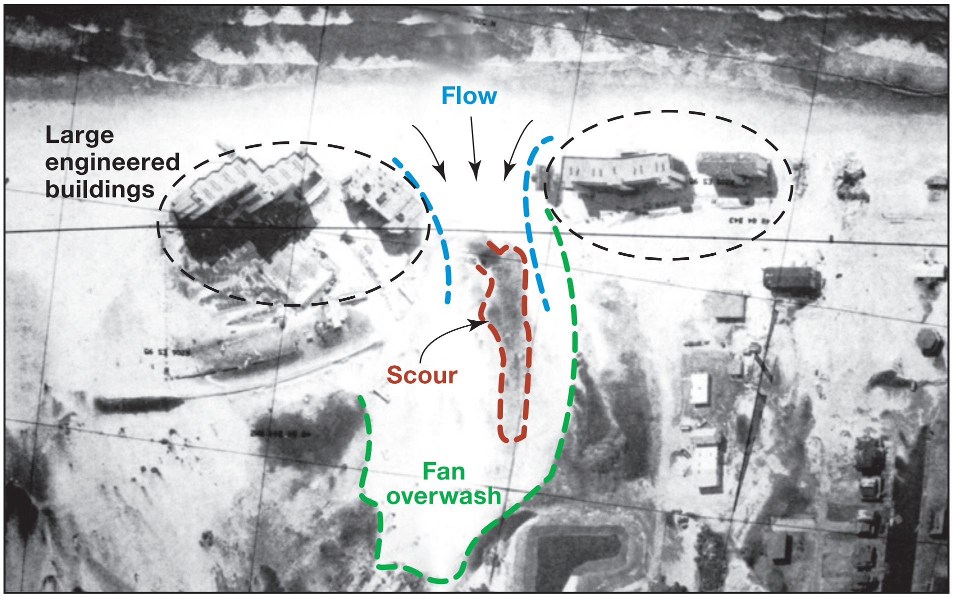


Figure 3-21.
Pile-supported house in the area of channeled flow shown in Figure 3-20. The building foundation and elevation successfully prevented high-velocity flow, erosion, and scour from destroying this building

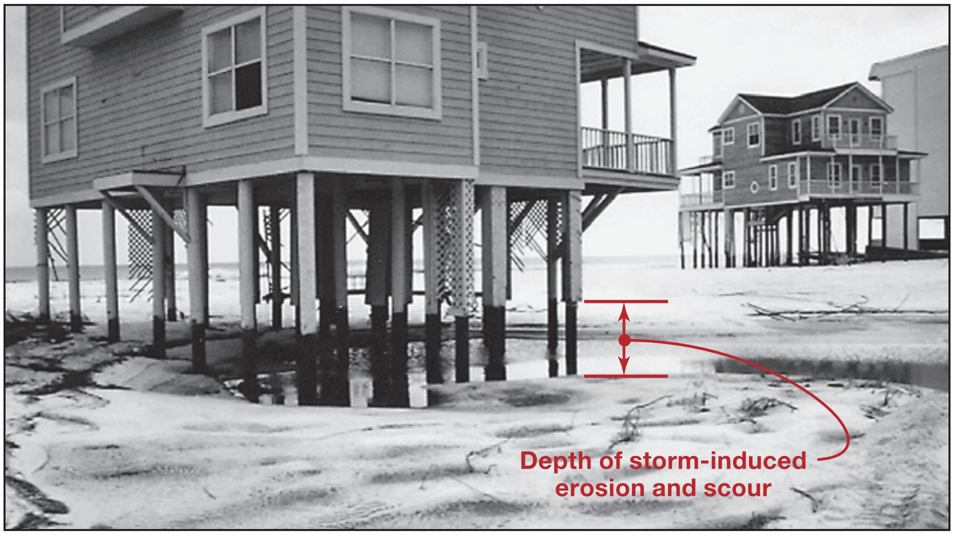


Figure 3-22.
This house, located in an area of channeled flow near that shown in Figure 3-20, was undermined, washed into the bay behind the barrier island, and became a threat to navigation

3.4.3 Waves

Waves can affect coastal buildings in a number of ways, including breaking waves, wave runup, wave reflection and deflection, and wave uplift. The most severe damage is caused by ***breaking waves*** (see Figure 3-23). The force created by waves breaking against a vertical surface is often 10 or more times higher than the force created by high winds during a storm event.

Figure 3-23. Storm waves breaking against a seawall in front of a coastal residence at Stinson Beach, CA

SOURCE: LESLEY EWING, USED WITH PERMISSION

Wave runup occurs as waves break and run up beaches, sloping surfaces, and vertical surfaces. Wave runup (see Figure 3-24) can drive large volumes of water against or around coastal buildings, inducing fluid impact forces (albeit smaller than breaking wave forces), current drag forces, and localized erosion and scour (see Figure 3-25). Wave runup against a vertical wall generally extends to a higher elevation than runup on a sloping surface and is capable of destroying overhanging decks and porches. ***Wave reflection*** or ***deflection*** from adjacent structures or objects can produce forces similar to those caused by wave runup.

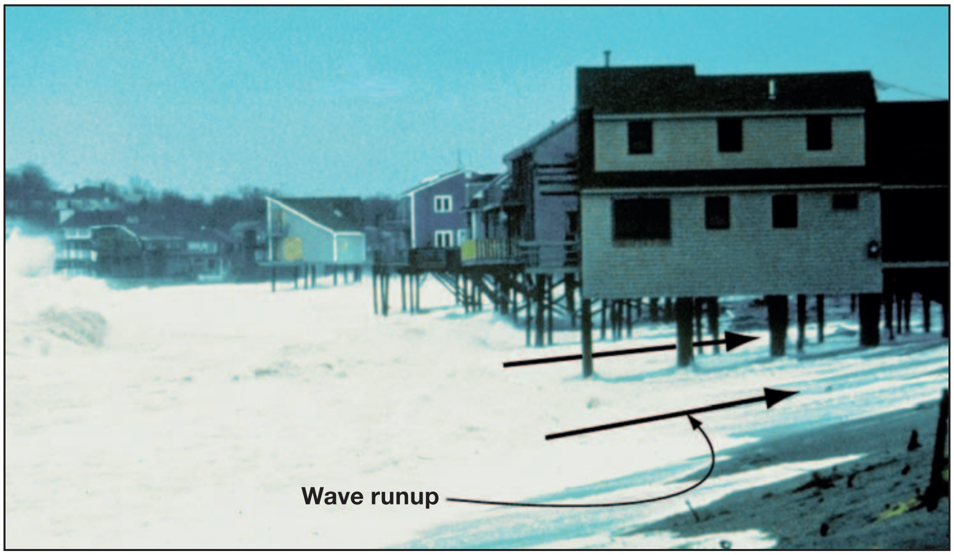


Figure 3-24. Wave runup beneath elevated buildings at Scituate, MA, during the December 1992 nor'easter storm

SOURCE: JIM O'CONNELL, USED WITH PERMISSION

Shoaling waves beneath elevated buildings can lead to ***wave uplift*** forces. The most common example of wave uplift damage occurs at fishing piers, where pier decks are commonly lost close to shore, when shoaling storm waves lift the pier deck from the pilings and beams. The same type of damage can sometimes be observed at the lowest floor of insufficiently elevated, but well-founded, residential buildings and underneath slabs-on-grade below elevated buildings (see Figure 3-26).

Figure 3-25.
The sand underneath this Pensacola Beach, FL, building was eroded due to wave runup and storm surge (Hurricane Ivan, 2004)

Figure 3-26.
Concrete slab-on-grade flipped up by wave action came to rest against two foundation members, generating large unanticipated loads on the building foundation (Topsail Island, NC, Hurricane Fran, 1996)

3.4.4 Flood-Borne Debris

Flood-borne debris produced by coastal flood events and storms typically includes decks, steps, ramps, breakaway wall panels, portions of or entire houses (see Figure 3-27), heating oil and propane tanks, vehicles, boats, decks and pilings from piers (see Figure 3-28), fences, destroyed erosion control structures, and a variety of smaller objects. Flood-borne debris is often capable of destroying unreinforced masonry walls, light wood-frame construction, and small-diameter posts and piles (and the components of structures they support). Figure 3-29 shows debris generated by destroyed buildings at Pass Christian, MS, that accumulated approximately 1,000 feet inland from the highway. The debris from buildings closest to the Gulf of Mexico undoubtedly accentuated damage to buildings in the area and contributed to their destruction. Debris trapped by cross bracing, closely spaced pilings, grade beams, or other components or obstructions below the BFE is also capable of transferring flood and wave loads to the foundation of an elevated structure. Parts of the country are exposed to more massive debris, such as the drift logs shown in Figure 3-30.

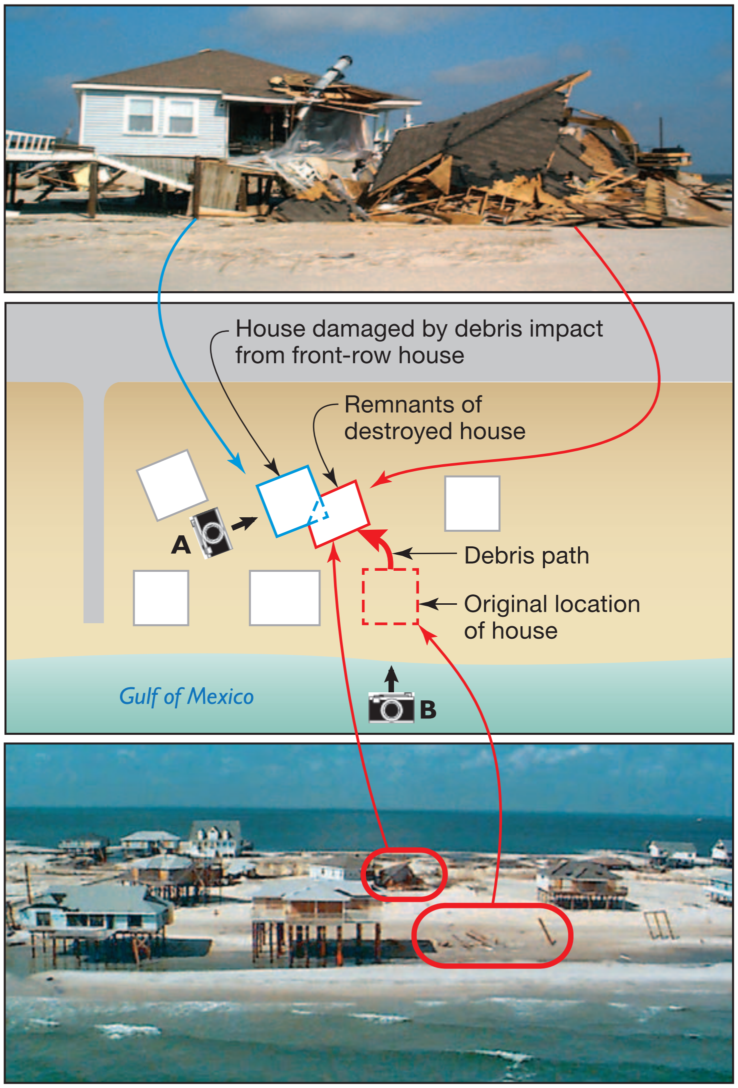


Figure 3-27. A pile-supported house at Dauphin Island, AL, was toppled and washed into another house, which suffered extensive damage (Hurricane Georges, 1998)

Figure 3-28.
Pier pilings were carried over 2 miles by storm surge and waves before they came to rest against this elevated house in Pensacola Beach, FL (Hurricane Opal, 1995)

Figure 3-29.
Debris generated by destroyed buildings at Pass Christian, MS (Hurricane Katrina, 2005)

Figure 3-30.
Drift logs driven into coastal houses at Sandy Point, WA, during a March 1975 storm

SOURCE: KNOWLES AND TERICH 1977, *SHORE AND BEACH*, USED WITH PERMISSION

3.5 Erosion

Erosion refers to the wearing or washing away of coastal lands. Although the concept of erosion is simple, erosion is one of the most complex hazards to understand and predict at a given site. Therefore, designers should develop an understanding of erosion fundamentals, but rely on coastal erosion experts (at Federal, State, and local agencies; universities; and private firms) for specific guidance regarding erosion potential at a site.

The term "erosion" is commonly used to refer to the horizontal recession of the shore (i.e., ***shore erosion****)*, but can apply to other types of erosion. For example, ***seabed*** or ***lakebed erosion*** (also called ***downcutting***) occurs when fine-grained sediments in the nearshore zone are eroded and carried into deep water. These sediments are lost permanently, resulting in a lowering of the seabed or lakebed. This process has several important consequences: increased local water depths, increased wave heights reaching the shoreline, increased shore erosion, and undermining of erosion control structures. Downcutting has been documented along some ocean-facing shorelines, but also along much of the Great Lakes shoreline

NOTE

This section reviews basic concepts related to coastal erosion, but cannot provide a comprehensive treatment of the many aspects of erosion that should be considered in planning, siting, and designing coastal residential buildings.

NOTE

Erosion is one of the most complex hazards faced by designers. However, given erosion data provided by experts, assessing erosion effects on building design can be reduced to three basic steps:

1. Define the most landward shoreline location expected during the life of the building.
2. Define the lowest expected ground elevation during the life of the building.
3. Define the highest expected BFE during the life of the building.

(which is largely composed of fine-grained glacial deposits). Designers should refer to Keillor (1998) for more information on this topic.

Erosion is capable of threatening coastal residential buildings in a number of ways:

- Destroying dunes or other natural protective features (see Figure 3-31)
- Destroying erosion control devices (see Figure 3-32)
- Lowering ground elevations, undermining shallow foundations, and reducing penetration depth of pile foundations (see Figure 3-33)
- Transporting beach and dune sediments landward, where they can bury roads and buildings and marshes (see Figure 3-34)
- Breaching low-lying coastal barrier islands exposing structures on the mainland to increased flood and wave effects (see Figures 3-35 and 3-36)
- Eroding coastal bluffs that provide support to buildings outside the floodplain itself (see Figure 3-37)

Sand that is moved during erosional events can create overwash and sediment burial issues. Further, the potential for landslides and ground failures must also be considered.

Figure 3-31.
Dune erosion in Ocean City, NJ, caused by the remnants of Hurricane Ida (2009) and a previous nor'easter

Figure 3-32.
Erosion and seawall damage in New Smyrna Beach, FL, following Hurricane Jeanne in 2007

Figure 3-33.
Erosion undermining a coastal residence in Oak Island, NC, caused by Hurricane Floyd in 1999

Figure 3-34. Overwash on Topsail Island, NC, after Hurricane Bonnie in 1998

SOURCE: USGS

Figure 3-35. A January 1987 nor'easter cut a breach across Nauset Spit on Cape Cod, MA; the breach grew from an initial width of approximately 20 feet to over a mile within 2 years, exposing the previously sheltered shoreline of Chatham to ocean waves and erosion

SOURCE: JIM O'CONNELL, USED WITH PERMISSION

Figure 3-36.
Undermined house at Chatham, MA, in 1988; nine houses were lost as a result of the formation of the new tidal inlet shown in Figure 3-35

SOURCE: JIM O'CONNELL, USED WITH PERMISSION

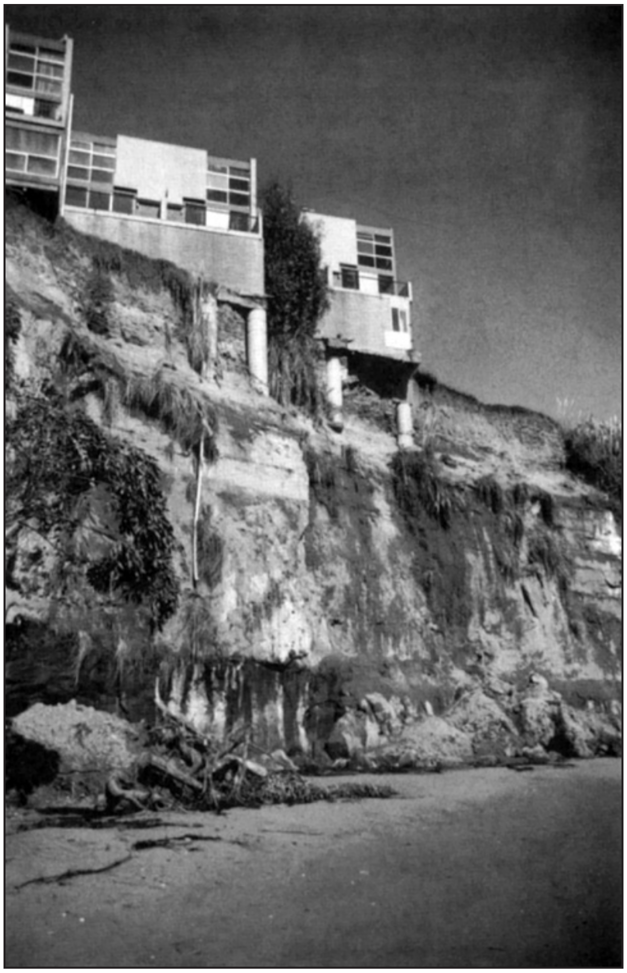


Figure 3-37.
Bluff failure by a combination of marine, terrestrial, and seismic processes led to progressive undercutting of blufftop apartments at Capitola, CA, where six of the units were demolished after the 1989 Loma Prieta earthquake

SOURCE: GRIGGS 1994, *JOURNAL OF COASTAL RESEARCH*, USED WITH PERMISSION

3.5.1 Describing and Measuring Erosion

Erosion should be considered part of the larger process of shoreline change. When more sediment leaves a shoreline segment than moves into it, ***erosion*** results; when more sediment moves into a shoreline segment than leaves it, ***accretion*** results; and when the amounts of sediment moving into and leaving a shoreline segment balance, the shoreline is said to be ***stable***.

Care must be exercised in classifying a particular shoreline as erosional, accretional, or stable. A shoreline classified as erosional may experience periods of stability or accretion. Likewise, a shoreline classified as stable or accretional may be subject to periods of erosion. Observed shoreline behavior depends on the time period of analysis and on prevailing and extreme coastal processes during that period.

NOTE

Most owners and designers worry only about erosion. However, sediment deposition and burial can also be a problem if dunes and windblown sand migrate inland.

NOTE

Short-term erosion rates can exceed long-term rates by a factor of 10 or more.

For these reasons, shoreline changes are classified as short-term changes and long-term changes. Short-term changes occur over periods ranging from a few days to a few years and can be highly variable in direction and magnitude. Long-term changes occur over a period of decades, during which short-term changes tend to average out to the underlying erosion or accretion trend. Both short-term and long-term shoreline changes should be considered in siting and design of coastal residential construction.

Erosion is usually expressed as a rate, in terms of:

- Linear retreat (e.g., feet of shoreline recession per year)
- Volumetric loss (e.g., cubic yards of eroded sediment per foot of shoreline frontage per year)

The convention used in this Manual is to cite erosion rates as positive numbers, with corresponding shoreline change rates as negative numbers (e.g., an erosion rate of 2 feet per year is equivalent to a shoreline change rate of -2 feet per year). Likewise, accretion rates are listed as positive numbers, with corresponding shoreline change rates as positive numbers (e.g., an accretion rate of 2 feet per year is equivalent to a shoreline change rate of 2 feet per year).

Shoreline erosion rates are usually computed and cited as long-term, average annual rates. However, erosion rates are not uniform in time or space. Erosion rates can vary substantially from one location along the shoreline to another, even when the two locations are only a short distance apart.

A study by Zhang (1998) examined long-term erosion rates along the east coast of the United States. Results showed the dominant trend along the east coast of the United States is

WARNING

Proper planning, siting, and design of coastal residential buildings require: (1) a basic understanding of shoreline erosion processes, (2) erosion rate information from the community, State, or other sources, (3) appreciation for the uncertainty associated with the prediction of future shoreline positions, and (4) knowledge that siting a building immediately landward of a regulatory coastal setback line does not guarantee the building will be safe from erosion. Owners and designers should also be aware that shore changes and modifications near to or updrift of a building site can affect the site.

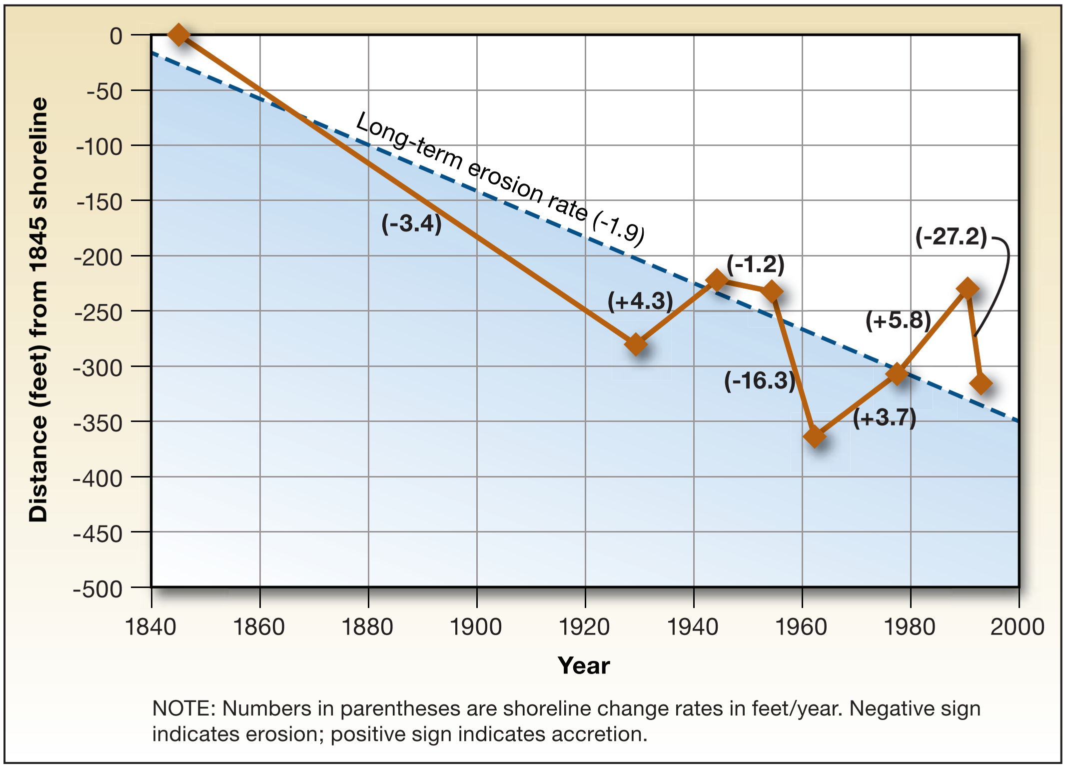
one of erosion (72 percent of the stations examined experienced long-term erosion), with shoreline change rates averaging -3.0 feet per year (i.e., 3.0 feet per year of erosion). However, variability along the shoreline is considerable, with a few locations experiencing more than 20 feet per year of erosion, and over one-fourth of the stations experiencing accretion. A study of the Pacific County, WA, coastline found erosion rates as high as 150 feet per year, and accretion rates as high as 18 feet per year (Kaminsky et al. 1999).

Erosion rates can also vary over time at a single location. For example, Figure 3-38 illustrates the shoreline history over a period of 160 years for the region approximately 1.5 miles south of Indian River Inlet, DE. Although the long-term, average annual shoreline change rate is approximately -2 feet per year, short-term shoreline change rates vary from -27 feet per year (erosion resulting from severe storms) to +6 feet per year (accretion associated with post-storm recovery of the shoreline). This conclusion—that erosion rates can vary widely over time—has also been demonstrated by other studies (e.g., Douglas, et al., 1998).

Designers should also be aware that some shorelines experience large seasonal fluctuations in beach width and elevation. These changes are a result of seasonal variations in wave conditions and water levels, and should not be taken as indicators of long-term shoreline changes. For this reason, shoreline change calculations at beaches subject to large seasonal fluctuations should be based on shoreline measurements taken at approximately the same time of year.

NOTE

Apparent erosion or accretion resulting from seasonal fluctuations of the shoreline is not an indication of true shoreline change.



NOTE: Numbers in parentheses are shoreline change rates in feet/year. Negative sign indicates erosion; positive sign indicates accretion.

Figure 3-38.
Shoreline changes through time at a location approximately 1.5 miles south of Indian River Inlet, DE
DATA SOURCES: NOAA AND THE STATE OF DELAWARE

Erosion rates have been calculated by many States and communities to establish regulatory construction setback lines. These rates are typically calculated from measurements made with aerial photographs, historical charts, or beach profiles. However, a number of potential errors are associated with measurements and calculations using each of the data sources, particularly the older data. Some studies have estimated that errors in computed erosion rates can range up to 1 foot or more per year. Therefore, even if published erosion rates are less than 1 foot per year ***this Manual recommends siting coastal residential structures based on the larger of the published erosion rate, or 1 foot per year***, unless there is compelling evidence to support a smaller erosion rate. Basing design on erosion rates of less than 1 foot per year can lead to significant underestimation of the future shoreline and inadequate setback to protect the building from long-term erosion.

3.5.2 Causes of Erosion

Erosion can be caused by a variety of natural or manmade actions, including:

- Storms and coastal flood events, usually rapid and dramatic (also called storm-induced erosion)
- Natural changes associated with tidal inlets, river outlets, and entrances to bays (e.g., interruption of littoral transport by jetties and channels, migration or fluctuation of channels and shoals, formation of new inlets)
- Construction of manmade structures and human activities (e.g., certain shore protection structures; damming of rivers; dredging or mining sand from beaches and dunes; and alteration of vegetation, surface drainage, or groundwater at coastal bluffs)
- Long-term erosion that occurs over a period of decades, due to the cumulative effects of many factors, including changes in water level, sediment supply, and those factors mentioned above
- Local scour around structural elements, including piles and foundation elements

CROSS REFERENCE

Chapters 12 and 13 provide information about designing and constructing sound pile and column foundations.

Erosion can affect all coastal landforms except highly resistant geologic formations. Low-lying beaches and dunes are vulnerable to erosion, as are most coastal bluffs, banks, and cliffs. Improperly sited buildings—even those situated atop coastal bluffs and outside the floodplain—and buildings with inadequate foundation support are especially vulnerable to the effects of erosion.

3.5.2.1 Erosion During Storms

Erosion during storms can be dramatic and damaging. Although storm-induced erosion is usually short-lived (usually occurring over a few hours in the case of hurricanes and typhoons, or over a few tidal cycles or days in the case of nor'easters and other coastal storms), the resulting erosion can be equivalent to decades of long-term erosion. During severe storms or coastal flood events, large dunes may be eroded 25 to 75 feet or more (see Figure 3-31) and small dunes may be completely destroyed.

Erosion during storms sometimes occurs despite the presence of erosion control devices such as seawalls, revetments, and toe protection. Storm waves frequently overtop, damage, or destroy poorly designed, constructed, or maintained erosion control devices. Lands and buildings situated behind an erosion control device are not necessarily safe from coastal flood forces and storm-induced erosion.

Narrow sand spits, barrier islands and low-lying coastal lands can be breached by tidal channels and inlets—often originating from the buildup of water on the back side (see Figure 3-39)—or washed away entirely (see Figure 3-40). Storm-induced erosion damage to unconsolidated cliffs and bluffs typically takes the form of large-scale collapse, slumping, and landslides, with concurrent recession of the top of the bluff.

CROSS REFERENCE

FIRMs incorporate the effects of dune and bluff erosion during storms (see Section 3.6.7).

Figure 3-39.
Breach through barrier island at Pine Beach, AL, before Hurricane Ivan (2001) and after (2004)
SOURCE: USGS

Figure 3-40.
Cape San Blas, Gulf County, FL, in November 1984, before and after storm-induced erosion

Storm-induced erosion can take place along open-coast shorelines (Atlantic, Pacific, Gulf of Mexico, and Great Lakes shorelines) and along shorelines of smaller enclosed or semi-enclosed bodies of water. If a body of water is subject to increases in water levels and generation of damaging wave action during storms, storm-induced erosion can occur.

3.5.2.2 Erosion Near Tidal Inlets, Harbor, Bay, and River Entrances

Many miles of coastal shoreline are situated on or adjacent to connections between two bodies of water. These connections can take the form of tidal inlets (short, narrow hydraulic connections between oceans and inland waters), harbor entrances, bay entrances, and river entrances. The size, location, and adjacent shoreline stability of these connections are usually governed by six factors:

- Tidal and freshwater flows through the connection
- Wave climate
- Sediment supply
- Local geology
- Jetties or stabilization structures
- Channel dredging

WARNING

The location of a tidal inlet, harbor entrance, bay entrance, or river entrance can be stabilized by jetties or other structures, but the shorelines in the vicinity can still fluctuate in response to storms, waves, and other factors.

Temporary or permanent changes in any of these governing factors can cause the connections to migrate, change size, or change configuration, and can cause sediment transport patterns in the vicinity of the inlet to change, thereby altering flood hazards in nearby areas.

Construction of jetties or similar structures at a tidal inlet or a bay, harbor, or river entrance often results in accretion on one side and erosion on the other, with a substantial shoreline offset. This offset results from the jetties trapping the ***littoral drift*** (wave-driven sediment moving along the shoreline) and preventing it from moving to the downdrift side. Figure 3-41 shows such a situation at Ocean City Inlet, MD, where formation

Figure 3-41.
Ocean City Inlet, MD, was opened by a hurricane in 1933 and stabilized by jetties in 1934–35 that have resulted in extreme shoreline offset and downdrift erosion (1992 photograph)

of the inlet in 1933 by a hurricane and construction of inlet jetties in 1934–1935 led to approximately 800 feet of accretion against the north jetty at Ocean City and approximately 1,700 feet of erosion on the south side of the inlet along Assateague Island as of 1977 (Dean and Perlin 1977). Between 1976 and 1980, shoreline change rates on Assateague Island averaged from 49 feet per year and -33 feet per year (USACE 2009b). In 2004, USACE began the "Long-Term Sand Management" project to restore Assateague Island.

Erosion and accretion patterns at stabilized inlets and entrances sometimes differ from the classic pattern occurring at the Ocean City Inlet. In some instances, accretion occurs immediately adjacent to both jetties, with erosion beyond. In some instances, erosion and accretion patterns near a stabilized inlet change over time. Figure 3-42 shows buildings at Ocean Shores, WA, that were threatened by shore erosion shortly after their construction, despite the fact that the buildings were located near an inlet jetty on a beach that was historically viewed as accretional.

Development in the vicinity of a tidal inlet or bay, harbor, or river entrance is often affected by lateral migration of the channel and associated changes in sand bars (which may focus waves and erosion on particular shoreline areas). Often, these changes are cyclic in nature and can be identified and forecast through a review of historical aerial photographs and bathymetric data. Those considering a building site near a tidal inlet or a bay, harbor, or river entrance should investigate the history of the connection, associated shoreline fluctuations, migration trends, and impacts of any stabilization structures. Failure to do so could result in increased building vulnerability or building loss to future shoreline changes.

NOTE

Cursory characterizations of shoreline behavior in the vicinity of a stabilized inlet, harbor, or bay entrance should be rejected in favor of a more detailed evaluation of shoreline changes and trends.

WARNING

Many State and local siting regulations allow residential development in areas where erosion is likely to occur. Designers should not assume that a building sited in compliance with minimum State and local requirements is safe from future erosion. See Chapter 4.

Figure 3-42.
Buildings threatened by erosion at Ocean Shores, WA, in 1998. The rock revetments were built in response to shore erosion along an area adjacent to a jetty and thought to be accretional

Shoreline changes in the vicinity of one of the more notable regulatory takings cases illustrate this point. The upper image in Figure 3-43 is a 1989 photograph of one of the two vacant lots owned by David Lucas, which became the subject of the *Lucas vs. South Carolina Coastal Council* case when Lucas challenged the State's prohibition of construction on the lots. By December 1997, the case had been decided in favor of Lucas, the State of South Carolina had purchased the lots from Lucas, the State had resold the lots, and a home had been constructed on one of the lots (Jones et al. 1998). The lower image in Figure 3-43 shows a December 1997 photograph of the same area, with erosion undermining the home built on the former Lucas lot (left side of photograph) and an adjacent house (also present in 1989 in upper image).

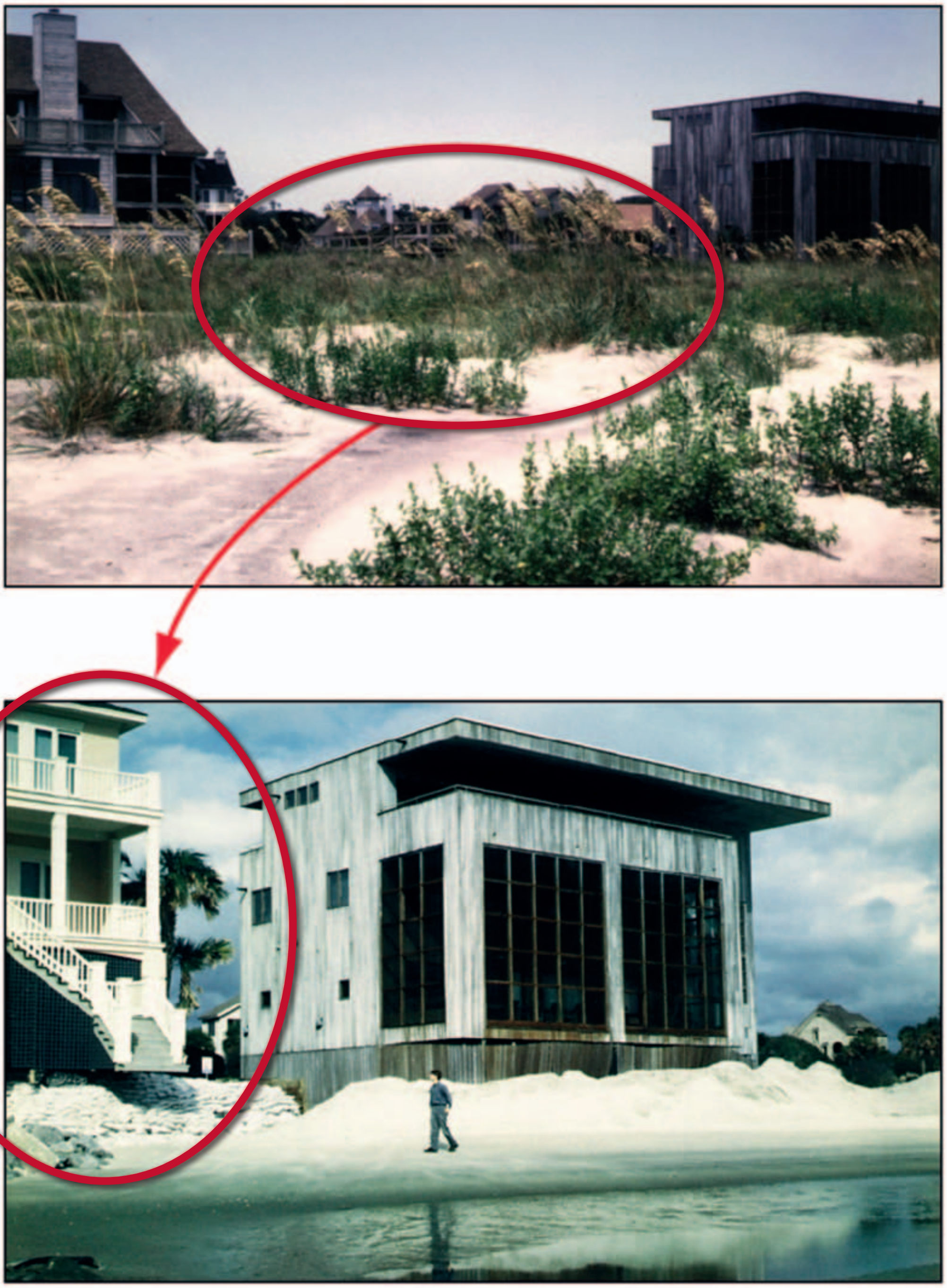


Figure 3-43. July 1989 photograph of vacant lot owned by Lucas, Isle of Palms, SC (top) and photograph taken in December 1997 of lot with new home (bottom)

3.5.2.3 Erosion Due to Manmade Structures and Human Activities

Human actions along the shoreline can both reduce and increase flood hazards. In some instances, structures built or actions taken to facilitate navigation cause erosion elsewhere. In other cases, structures built or actions taken to halt erosion and reduce flood hazards at one site increase erosion and flood hazards at nearby sites. For this reason, evaluation of a potential coastal building site requires consideration of natural and human-caused shoreline changes.

NOTE

More information on beach nourishment is provided at http://www.csc.noaa.gov/beachnourishment.

Effects of Shore Protection Structures

CROSS REFERENCE

Adverse impacts of erosion control structures can sometimes be mitigated through beach nourishment. See Section 4.7.

In performing their intended function, shore protection structures can lead to or increase erosion on nearby properties. This statement should not be taken as an indictment of all erosion control structures, because many provide protection against erosion and flood hazards. Rather, this Manual simply recognizes the potential for adverse impacts of these structures on nearby properties and offers some siting guidance for residential buildings relative to erosion control structures (see Section 4.6), where permitted by States and communities. These potential impacts vary from site to site and structure to structure and can sometimes be mitigated by ***beach nourishment***—the placement of additional sediment on the beach—in the vicinity of the erosion control structure.

Groins (such as those shown in Figure 2-12, in Chapter 2) are short, shore-perpendicular structures designed to trap available littoral sediments. They can cause erosion to downdrift beaches if the groin compartments are not filled with sand and maintained in a full condition.

Likewise, ***offshore breakwaters*** (see Figure 3-44) can trap available littoral sediments and reduce the sediment supply to nearby beaches. This adverse effect should be mitigated by combining breakwater construction with beach nourishment—design guidance for offshore breakwater projects typically calls for the inclusion of beach nourishment (Chasten et al. 1993).

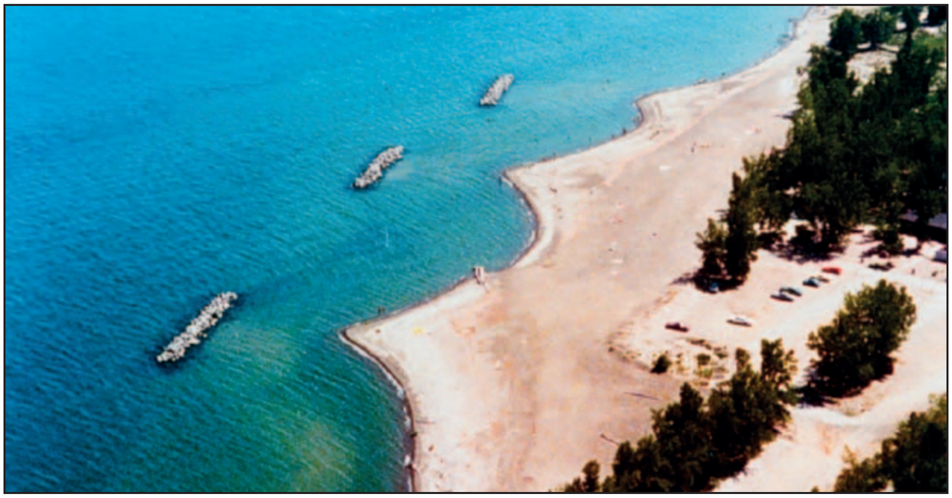


Figure 3-44. Example of littoral sediments being trapped behind offshore breakwaters on Lake Erie, Presque Isle, PA

SOURCE: USACE

Seawalls, ***bulkheads***, and ***revetments*** are shore-parallel structures built, usually along the shoreline or at the base of a bluff, to act as retaining walls and to provide some degree of protection against high water levels, waves, and erosion. The degree of protection they afford depends on their design, construction, and maintenance. They do not prevent erosion of the beach, and in fact, can exacerbate ongoing erosion of the beach. The structures can impound upland sediments that would otherwise erode and nourish the beach, lead to ***passive erosion*** (eventual loss of the beach as a structure prevents landward migration of the beach profile), and lead to active erosion (localized scour waterward of the structure and on unprotected property at the ends of the structure).

Post-storm inspections show that the vast majority of privately financed seawalls, revetments, and erosion control devices fail during 1-percent-annual-chance, or lesser, events (i.e., are heavily damaged or destroyed, or withstand the storm, but fail to prevent flood damage to lands and buildings they are intended to protect—see Figures 3-32 and 3-45). Reliance on these devices to protect inland sites and residential buildings is not a good substitute for proper siting and foundation design. Guidance on evaluating the ability of existing seawalls and similar structures to withstand a 1-percent-annual-chance coastal flood event can be found in Walton et al. (1989).

Finally, some communities distinguish between erosion control structures constructed to protect existing development and those constructed to create a buildable area on an otherwise unbuildable site. Designers should investigate any local or State regulations and requirements pertaining to erosion control structures before selecting a site and undertaking building design.

Effects of Alteration of Vegetation, Drainage, or Groundwater

Alteration of vegetation, drainage, or groundwater can sometimes make a site more vulnerable to coastal storm or flood events. For example, removal of vegetation (grasses, ground covers, trees, mangroves) at a site can render the soil more prone to erosion by wind, rain, and flood forces. Alteration of natural drainage patterns

WARNING

NFIP regulations require that communities protect mangrove stands in Zone V from any human-caused alteration that would increase potential flood damage.

Figure 3-45. Failure of seawall in Bay County, FL, led to undermining and collapse of the building behind the wall (Hurricane Opal, 1995)

and groundwater flow can lead to increased erosion potential, especially on steep slopes and coastal bluffs. Irrigation and septic systems often contribute to bluff instability problems by elevating groundwater levels and decreasing soil strength.

3.5.2.4 Long-Term Erosion

Observed long-term erosion at a site represents the net effect of a combination of factors. The factors that contribute to long-term erosion can include:

- Sea level rise or subsidence of uplands
- Lake level rise or lakebed erosion along the Great Lakes (Figure 3-46)
- Reduced sediment supply to the coast
- Construction of jetties, other structures, or dredged channels that impede littoral transport of sediments along the shoreline
- Increased incidence or intensity of storms
- Alteration of upland vegetation, drainage, or groundwater flows (especially in coastal bluff areas)

WARNING

Coastal FIRMs (even recently published coastal FIRMs) do not incorporate the effects of long-term erosion. Users are cautioned that mapped Zone V and Zone A areas subject to long-term erosion underestimate the extent and magnitude of actual flood hazards that a coastal building may experience over its lifetime.

Regardless of the cause, long-term shore erosion can increase the vulnerability of coastal construction in a number of ways, depending on local shoreline characteristics, construction setbacks, and structure design. Figure 3-47 shows an entire block of buildings that are dangerously close to the shoreline and vulnerable to storm damage due to the effects of long-term erosion.

Figure 3-46.
Long-term erosion of the bluff along the Lake Michigan shoreline in Ozaukee County, WI, increases the threat to residential buildings outside the floodplain (1996 photograph)

Figure 3-47.
Long-term erosion at South Bethany Beach, DE, has lowered ground elevations beneath buildings and left them more vulnerable to storm damage

SOURCE: CHRIS JONES 1992, USED WITH PERMISSION

In essence, ***long-term erosion acts to shift flood hazard zones landward.*** For example, a site mapped accurately as Zone A may become exposed to Zone V conditions; a site accurately mapped as outside the 100-year floodplain may become exposed to Zone A or Zone V conditions.

Despite the fact that FIRMs do not incorporate long-term erosion, other sources of long-term erosion data are available for much of the country's shorelines. These data usually take the form of historical shoreline maps or erosion rates published by individual States or specific reports (from Federal or State agencies, universities, or consultants) pertaining to counties or other small shoreline reaches.

Designers should be aware that more than one source of long-term erosion rate data may be available for a given site and that the different sources may report different erosion rates. Differences in rates may be a result of different study periods, different data sources (e.g., aerial photographs, maps, ground surveys), or different study methods. When multiple sources and long-term erosion rates exist for a given site, designers should use the highest long-term erosion rate in their siting decisions, unless they conduct a detailed review of the erosion rate studies and conclude that a lower erosion rate is more appropriate for forecasting future shoreline positions.

3.5.2.5 Localized Scour

Localized scour can occur when water flows at high velocities past an object embedded in or resting on erodible soil (localized scour can also be caused or exacerbated by waves interacting with the object). The scour is not caused by the flood or storm event, per se, but by the distortion of the flow field by the object; localized scour occurs only around the object itself and is in addition to storm- or flood-induced erosion that occurs in the general area.

CROSS REFERENCE

Refer to Section 8.5 for additional discussion on scour.

Flow moving past a fixed object must accelerate, often forming eddies or vortices and scouring loose sediment from the immediate vicinity of the object. Localized scour around individual piles and similar objects (see Figure 3-48) is generally limited to small, cone-shaped depressions (less than 2 feet deep and several feet in diameter). Localized scour is capable of undermining slabs and grade-supported structures. However, in severe cases, the depth and lateral extent of localized scour can be much greater, and will jeopardize foundations and may lead to structural failure. Figure 3-49 shows severe local scour that occurred around residential foundations on Bolivar Peninsula, TX, after Hurricane Ike in 2008. This type of scour was widespread during Hurricane Ike. Although some structures were able to withstand the scour and associated flood forces, others were not.

Designers should consider potential effects of localized scour when calculating foundation size, depth, or embedment requirements.

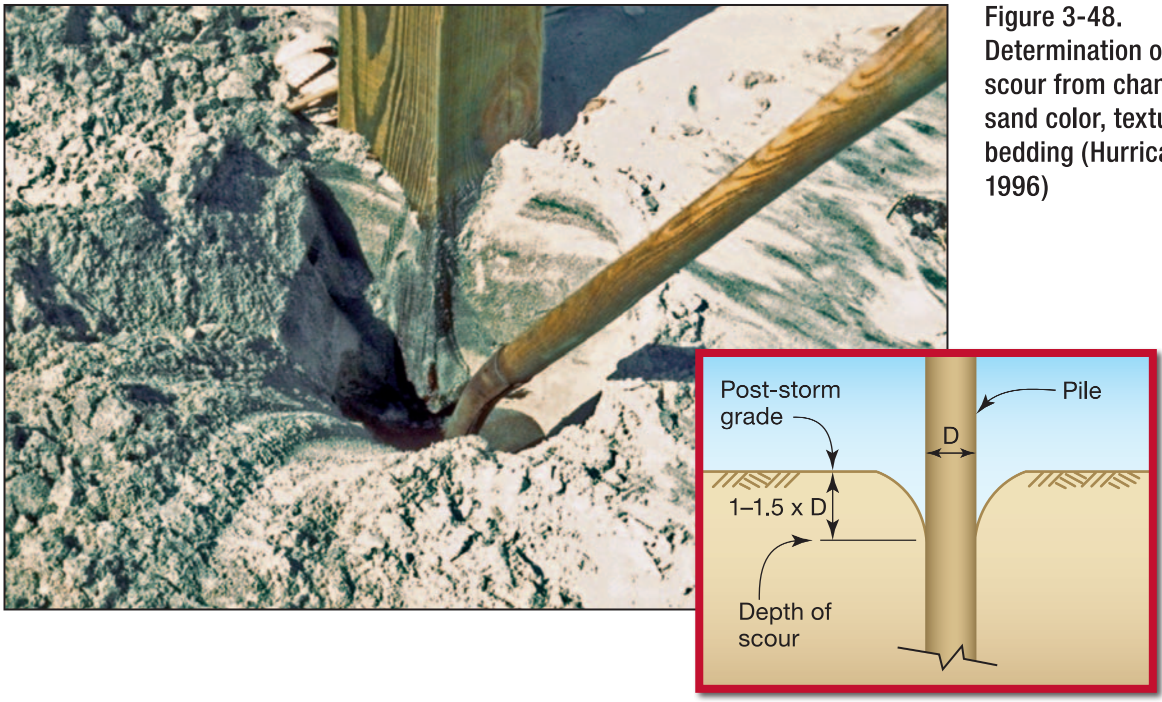


Figure 3-48. Determination of localized scour from changes in sand color, texture, and bedding (Hurricane Fran, 1996)

Figure 3-49.
Residential foundation that suffered severe scour on Bolivar Peninsula, TX (Hurricane Ike, 2008)

3.5.3 Overwash and Sediment Burial

Sediment eroded during a coastal storm event must travel to one of the following locations: offshore to deeper water, along the shoreline, or inland. Overwash occurs when low-lying coastal lands are overtopped and eroded by storm surge and waves, such that the eroded sediments are carried landward by floodwaters, burying uplands, roads, and at-grade structures (see Figure 3-50). Depths of overwash deposits can reach 3 to 5 feet, or more, near the shoreline, but gradually decrease with increasing distance from the shoreline. Overwash deposits can extend several hundred feet inland following a severe storm (see Figure 3-34), especially in the vicinity of shore-perpendicular roads. Post-storm aerial photographs and/or videos can be used to identify likely future overwash locations.

NOTE

Most owners and designers worry only about erosion. However, sediment deposition and burial can also be a problem.

The physical processes required to create significant overwash deposits (i.e., waves capable of suspending sediments in the water column and flow velocities generally in excess of 3 feet per second) are also capable of damaging buildings. Thus, existing coastal buildings located in Zone A (particularly the seaward portions of Zone A) and built on slab or crawlspace foundations should be considered vulnerable to damage from overwash, high-velocity flows, and waves.

3.5.4 Landslides and Ground Failures

Landslides occur when slopes become unstable and loose material slides or flows under the influence of gravity. Often, landslides are triggered by other events such as erosion at the toe of a steep slope, earthquakes, floods, or heavy rains, but can be worsened by human actions such as destruction of vegetation or uncontrolled pedestrian access on steep slopes (see Figure 3-51). An extreme example is Hurricane Mitch in 1998, where heavy rainfall led to flash flooding, numerous landslides, and an estimated 10,000 deaths in Nicaragua.

Figure 3-50.
Overwash from Hurricane Opal (1995) at Pensacola Beach, FL, moved sand landward from the beach and buried the road, adjacent lots, and some at-grade buildings to a depth of 3 to 4 feet

Figure 3-51.
Unstable coastal bluff at Beacon's Beach, San Diego, CA

SOURCE: LESLEY EWING, USED WITH PERMISSION

Designers should seek and use landslide information and data from State geological survey agencies and USGS (http://landslides.usgs.gov/). Designers should also be aware that coastal bluff failures can be induced by seismic activity. Griggs and Scholar (1997) detail bluff failures and damage to residential buildings resulting from several earthquakes, including the March 1964 Alaska earthquake and the October 1989 Loma Prieta earthquake (see Figure 3-37). Coastal bluff failures were documented as far away as 50 miles from the Loma Prieta epicenter and 125 miles from the Alaska earthquake epicenter. In both instances, houses and infrastructure were damaged and destroyed as a result of these failures.

3.6 NFIP Flood Hazard Zones

Understanding the methods and assumptions underlying Flood Insurance Study (FIS) reports and FIRMs is useful to the designer, especially in the case where the effective FIRM is more than a few years old, and where an updated flood hazard determination is desired.

FEMA determines flood hazards at a given site based on the following factors:

- Anticipated flood conditions (stillwater elevation, wave setup, wave runup and overtopping, and wave propagation) during the base flood event (based on the flood level that has a 1-percent chance of being equaled or exceeded in any given year)
- Potential for storm-induced erosion of the primary dune during the base flood event
- Physical characteristics of the floodplain, such as vegetation and existing development
- Topographic and bathymetric information
- Computer models are used to calculate flood hazards and water surface elevations. FEMA uses the results of these analyses to map BFEs and flood hazard zones.

NOTE

A detailed discussion of the methodology for computing stillwater elevations, wave heights, and wave runup is beyond the scope of this Manual. Refer to *Guidelines and Specifications for Flood Hazard Mapping Partners* (FEMA 2003) for more information.

3.6.1 Base Flood Elevations

To determine BFEs for areas affected by coastal flooding, FEMA computes 100-year ***stillwater elevations*** and ***wave setup***, and then determines the maximum 100-year ***wave heights*** and, in some areas, the maximum 100-year ***wave runup***, associated with those stillwater elevations. Wave heights are the heights, above the wave trough, of the crests of wind-driven waves. Wave runup is the rush of wave water up a slope or structure. Stillwater elevations are the elevations of the water surface resulting solely from storm surge (i.e., the rise in the surface of the ocean due to the action of wind and the drop in atmospheric pressure associated with hurricanes and other storms).

NOTE

Note that rounding of coastal BFEs means that it is possible for the wave crest or wave runup elevation to be up to 0.5 foot above the lowest floor elevation. This is another reason to incorporate freeboard into design.

The stillwater elevation plus wave setup equals the ***mean water elevation***, which serves as the surface across which waves propagate. Several factors can contribute to the 100-year mean water elevation in a coastal area. The most important factors include offshore bathymetry, astronomical tide, wind setup (rise in water surface as strong winds blow water toward the shore), pressure setup (rise in water surface due to low atmospheric pressure), wave setup (rise in water surface inside the surf zone due to the presence of breaking waves), and, in the case of the Great Lakes, seiches and variations in lake levels.

The BFEs shown for coastal flood hazard areas on FIRMs are established not at the stillwater elevation, but at the elevation of either the wave crest or the wave runup (rounded to the nearest foot), whichever is greater. Whether the wave crest elevation or the wave runup elevation is greater depends primarily on upland topography. In general, wave crest elevations are greater where the upland topography is gentle, such as along most of the Gulf, southern Atlantic, and middle-Atlantic coasts, while wave runup elevations are greater where the topography is steeper, such as along portions of the Great Lakes, northern Atlantic, and Pacific coasts.

3.6.2 Flood Insurance Zones

The insurance zone designations shown on FIRMs indicate the magnitude and severity of flood hazards. The zone designations that apply to coastal flood hazard areas are listed below, in decreasing order of magnitude and severity.

NOTE

Zones AE, VE, and X appear on FIRMs produced since the mid-1980s. On older FIRMs, the corresponding zones are A1–A30, V1–V30, and B or C, respectively.

Zones VE, V1–V30, and V. These zones, collectively referred to as Zone V, identify the Coastal High Hazard Area, which is the portion of the SFHA that extends from offshore to the inland limit of a ***primary frontal dune*** along an open coast and any other portion of the SFHA that is subject to high-velocity wave action from storms or seismic sources. The boundary of Zone V is generally based on wave heights (3 feet or greater) or wave runup depths (3 feet or greater). Zone V can also be mapped based on the ***wave overtopping*** rate (when waves run up and over a dune or barrier).

Zones AE, A1–A30, AO, and A. These zones, collectively referred to as Zone A or AE, identify portions of the SFHA that are not within the Coastal High Hazard Area. Zones AE, A1–A30, AO, and A are used to designate both coastal and non-coastal SFHAs. Regulatory requirements of the NFIP for buildings located in Zone A are the same for both coastal and riverine flooding hazards.

Limit of Moderate Wave Action (LiMWA). Zone AE in coastal areas is divided by the LiMWA. The LiMWA represents the landward limit of the 1.5-foot wave. The area between the LiMWA and the Zone V limit is known as the ***Coastal A Zone*** for building code and standard purposes and as the ***Moderate Wave Action (MoWA)*** area by FEMA flood mappers. This area is subject to wave heights between 1.5 and 3 feet during the base flood. The area between the LiMWA and the landward limit of Zone A due to coastal flooding is known as the ***Minimal Wave Action*** (***MiWA***) area, and is subject to wave heights less than 1.5 feet during the base flood.

NOTE

The LiMWA is now included on preliminary DFIRMs provided to communities; however, if a community does not want to delineate the LiMWA on its final DFIRM, it can provide a written request to FEMA, with justification, to remove it.

There presently are no NFIP floodplain management requirements or special insurance ratings associated with the designation of the LiMWA. However, in areas designated with a LiMWA, there are requirements imposed by the I-Codes. Aside from I-Code requirements, communities are encouraged to adopt Zone V requirements rather than the minimum NFIP requirements in these areas to address the increased risks associated with waves and velocity action.

The Community Rating System (CRS) awards credit points to communities that extend Zone V design and construction requirements to the LiMWA, and additional points to communities that extend Zone V requirements landward of the LiMWA.

Zones X, B, and C. These zones identify areas outside the SFHA. Zone B and shaded Zone X-500 identify areas subject to inundation by the flood that has a 0.2-percent chance of being equaled or exceeded during any given year, often referred to as the 500-year flood. Zone C and unshaded Zone X identify areas outside the 500-year floodplain. Areas protected by accredited levee systems are mapped as shaded Zone X.

TERMINOLOGY

SPECIAL FLOOD HAZARD AREA (SFHA) defines an area with a 1-percent chance, or greater, of flooding in any given year. This is commonly referred to as the extent of the 100-year floodplain.

COASTAL SFHA is the portion of the SFHA where the source of flooding is coastal surge or inundation. It includes Zone VE and Coastal A Zone.

ZONE VE is that portion of the coastal SFHA where base flood wave heights are 3 feet or greater, or where other damaging base flood wave effects have been identified, or where the primary frontal dune has been identified.

COASTAL A ZONE (MoWA AREA) is that portion of the coastal SFHA referenced by building codes and standards, where base flood wave heights are between 1.5 and 3 feet, and where wave characteristics are deemed sufficient to damage many NFIP-compliant structures on shallow or solid wall foundations.

MiWA AREA is that portion of the Coastal SFHA where base flood wave heights are less than 1.5 feet.

LiMWA is the boundary between the MoWA and the MiWA.

RIVERINE SFHA is that portion of the SFHA mapped as Zone AE and where the source of flooding is riverine, not coastal.

ZONE AE is the portion of the SFHA not mapped as Zone VE. It includes the MoWA, the MiWA, and the Riverine SFHA.

3.6.3 FIRMs, DFIRMs, and FISs

Figure 3-52 shows a typical paper FIRM that a designer might encounter for some coastal areas. Three flood hazard zones are shown on this FIRM: Zone V, Zone A, and Zone X. Figure 3-53 shows an example of a transect perpendicular to the shoreline.

Since the early 2000s, FEMA has been preparing Digital FIRMs (DFIRMs) to replace the paper maps. Figure 3-54 shows a typical DFIRM that a designer is likely to encounter in many coastal areas. The DFIRM uses a photographic base and shows either the results of a recent FIS or the results of a digitized paper FIRM (possibly with a datum conversion from National Geodetic Vertical Datum [NGVD] to North American Vertical Datum [NAVD]). The flood hazard zones and BFEs on a DFIRM are delineated in a manner consistent with those on a paper FIRM, although they may reflect updated flood hazard calculation procedures.

CROSS REFERENCE

See Section 3.3 for a brief discussion of coastal flood hazards and FIRMs.

NOTE

Additional information about FIRMs is available in FEMA's 2006 booklet *How to Use a Flood Map to Protect Your Property,* FEMA 258 (FEMA 2006b).

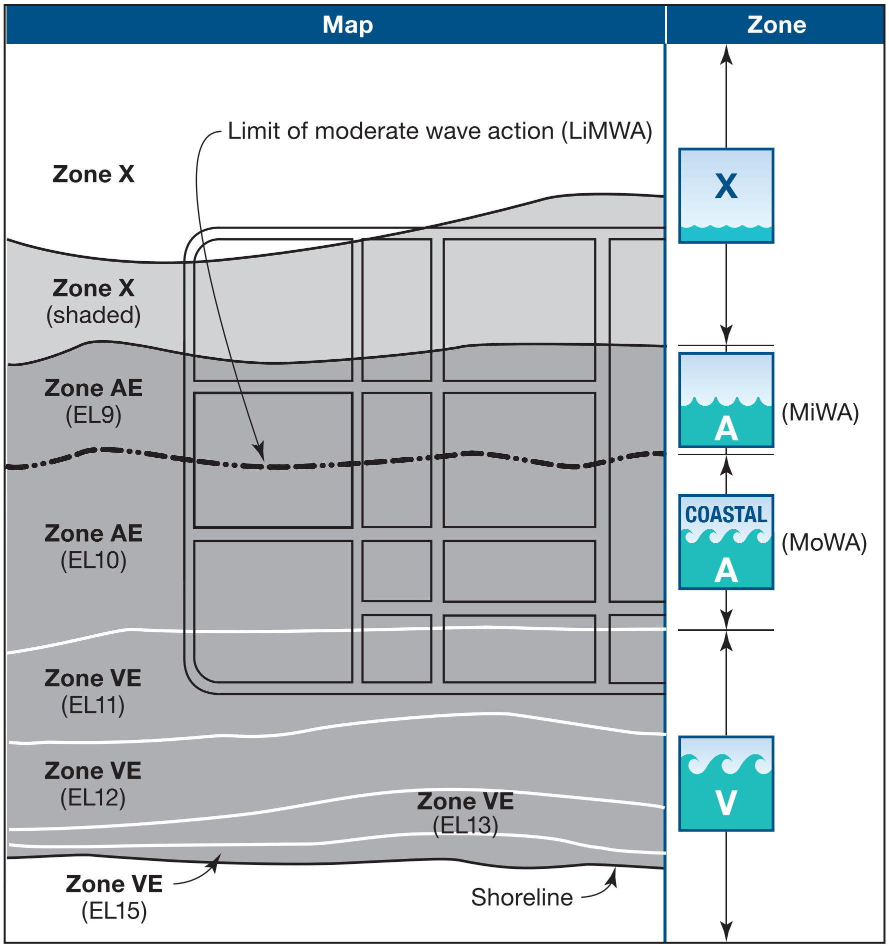


Figure 3-52.
Portion of a paper FIRM showing coastal flood insurance rate zones. The icons on the right indicate the associated flood hazard zones for design and construction purposes. The LiMWA is not shown on older FIRMs, but is shown on newer FIRMs and DFIRMs

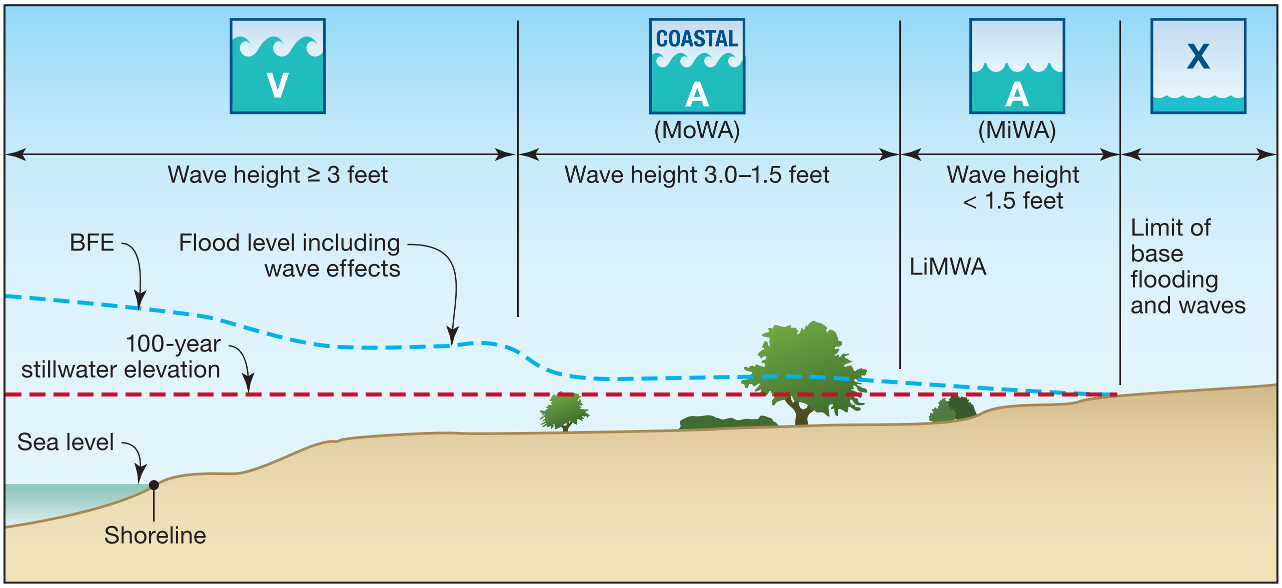
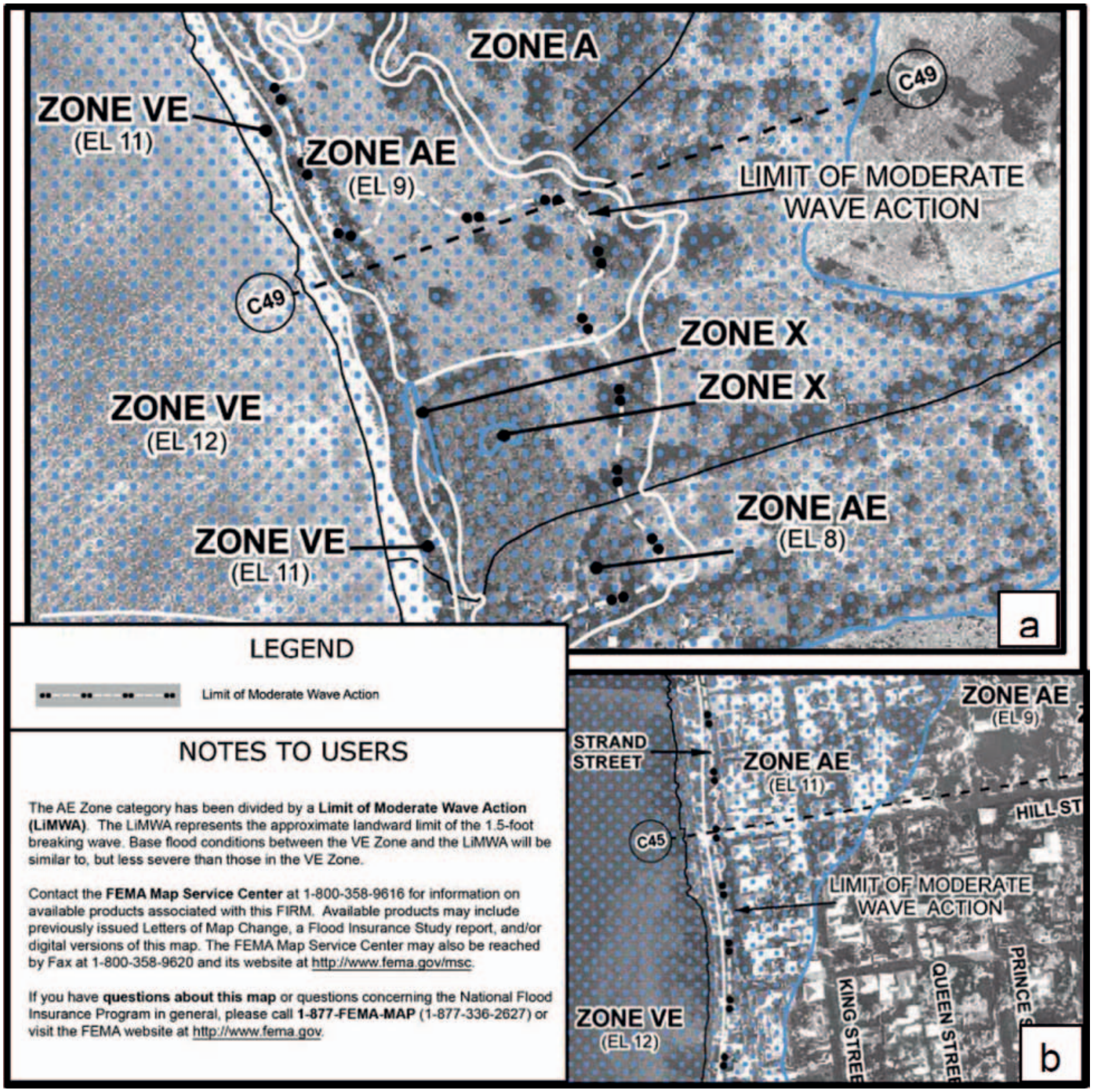


Figure 3-53.
Typical shoreline-perpendicular transect showing stillwater and wave crest elevations and associated flood zones



NOTES TO USERS

The AE Zone category has been divided by a **Limit of Moderate Wave Action (LiMWA)**. The LiMWA represents the approximate landward limit of the 1.5-foot breaking wave. Base flood conditions between the VE Zone and the LiMWA will be similar to, but less severe than those in the VE Zone.

Contact the **FEMA Map Service Center** at 1-800-358-9616 for information on available products associated with this FIRM. Available products may include previously issued Letters of Map Change, a Flood Insurance Study report, and/or digital versions of this map. The FEMA Map Service Center may also be reached by Fax at 1-800-358-9620 and its website at http://www.fema.gov/msc.

If you have **questions about this map** or questions concerning the National Flood Insurance Program in general, please call **1-877-FEMA-MAP** (1-877-336-2627) or visit the FEMA website at http://www.fema.gov.

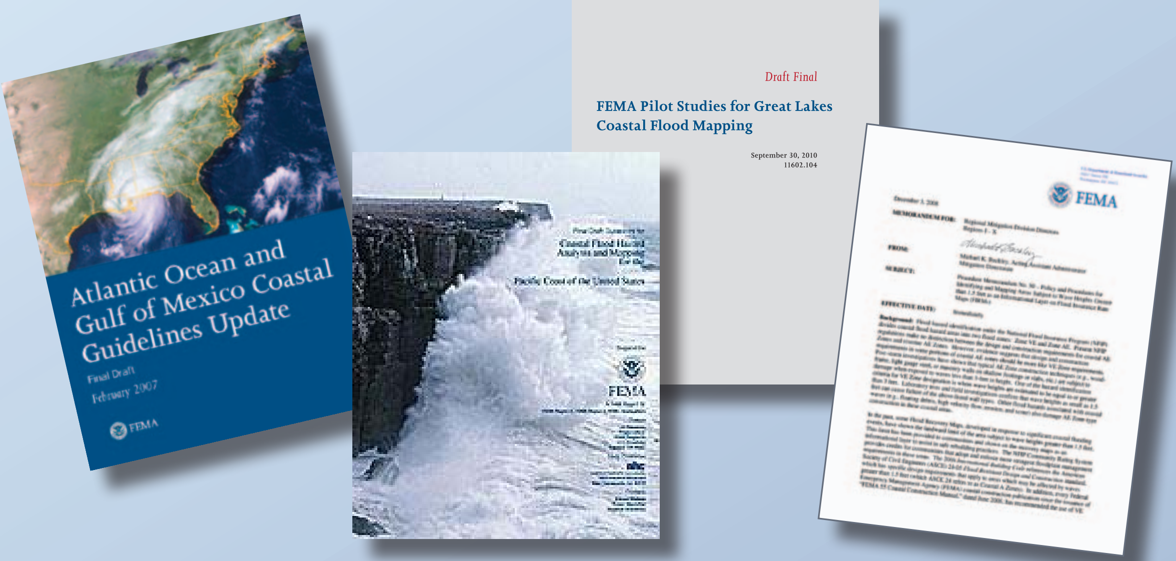
Figure 3-54.
Example DFIRM for a coastal area that shows the LiMWA
SOURCE: FEMA 2008c

A coastal FIS is completed with FEMA-specified techniques and procedures (see FEMA 2007) to determine mean water levels (stillwater elevation plus wave setup) and wave elevations along transects drawn perpendicular to the shoreline (see Figure 3-53). The determination of the 100-year mean water elevation (and elevations associated with other return intervals) is usually accomplished through the statistical analysis of historical tide and water level data, and/or by the use of numerical storm surge and wave models. Wave heights and elevations on land are computed from mean water level and topographic data with established procedures and models that account for wave dissipation by obstructions (e.g., sand dunes, buildings, vegetation) and wave regeneration across overland fetches.

Building codes and standards—and FEMA building science publications—refer to the Coastal A Zone and have specific requirements or recommendations for design and construction in this zone. Post-disaster damage inspections consistently show the need for such a distinction. Figure 3-53 shows how the Coastal A Zone can be inferred from FIS transects and maps.

NOTE

Detailed FEMA coastal mapping guidance is contained in Appendix D of *Guidelines and Specifications for Flood Hazard Mapping Partners* (FEMA 2003). Designers need not be familiar with all of these guidelines, but they may be useful on occasion. Appendix D is divided into several documents, one for the Atlantic and Gulf of Mexico coasts, one for the Pacific coast, and one for the Great Lakes coast. These documents have been and continue to be updated and revised, so designers should refer to the FEMA mapping Web site for the latest versions: http://www.fema.gov/plan/prevent/fhm/dl_vzn.shtm#3. Guidance on mapping the LiMWA is contained in *Procedure Memorandum No. 50* at http://www.fema.gov/library/viewRecord.do?id=3481.



3.6.4 Wave Heights and Wave Crest Elevations

FEMA's primary means of establishing BFEs and distinguishing between Zone V, Zone A, and Zone X is ***wave height***. Wave height is simply the vertical distance between the crest and trough of a wave propagating over the water surface. BFEs in coastal areas are usually set at the elevation of the crest of the wave as it propagates inland.

The maximum wave crest elevation (used to establish the BFE) is determined by the maximum wave height, which depends

TERMINOLOGY: WAVE HEIGHT

Wave height is the vertical distance between the wave crest and wave trough (see Figure 3-55). Wave crest elevation is the elevation of the crest of a wave, referenced to the NGVD, NAVD, or other datum.

largely on the 100-year stillwater depth (d_{100}). This depth is the difference between the 100-year stillwater elevation (E_{100}) (including wave setup) and the ground elevation (noted as *GS* in Figure 3-55). Note that ground elevation in this use is ***not*** the existing ground elevation, but is the ground elevation that will result from the erosion expected to occur during the base flood (or in some cases, it may be appropriate to take it as the eroded ground elevation expected over the life of a building).

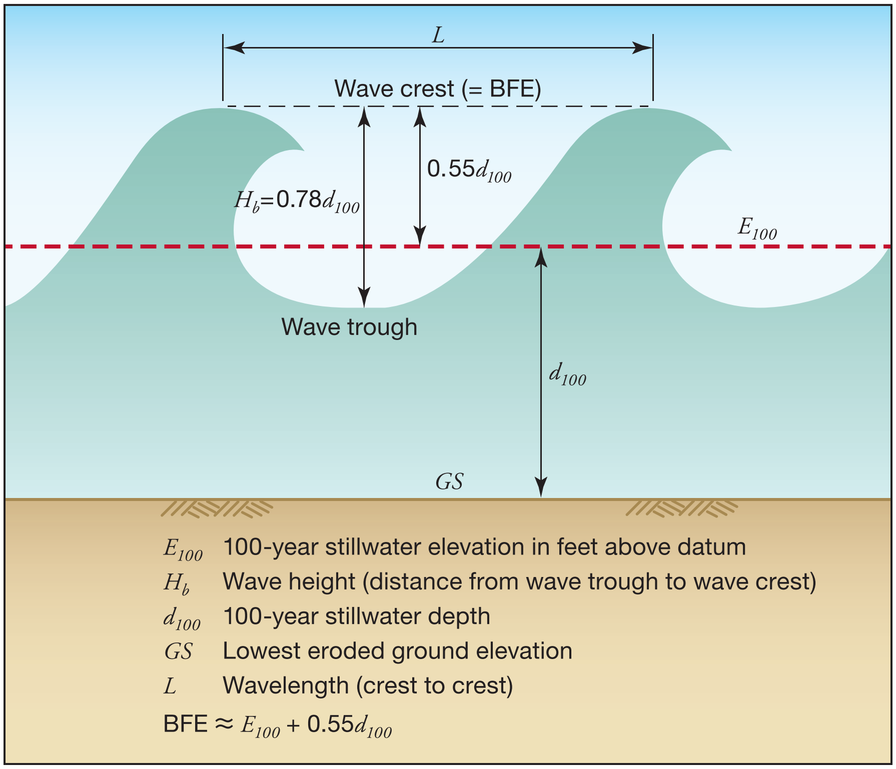
In shallow waters the maximum height of a breaking wave (H_b) is usually taken to be 78 percent of the stillwater depth d_s, and determined by the equation $H_b = 0.78d_s$. However, designers should be aware that where steep slopes exist immediately seaward of a building, wave heights can exceed $0.78d_{sw}$ (and a reasonable alternative is to set $H_b = 1.00d_s$ in such instances).

CROSS REFERENCE

See Equation 8.1 and Example 8.1 for calculations pertaining to stillwater depth (d_s).

The wave form in shallow water is distorted so that the crest and trough are not equidistant from the stillwater level; for NFIP flood mapping purposes, the wave crest lies at 70 percent of the wave height above the stillwater elevation (the wave trough lies a distance equal to 30 percent of the wave height, below the stillwater elevation). Thus, the maximum elevation of a breaking wave crest above the stillwater elevation is equal to $0.55d_s$. In the case of the 1-percent-annual-chance (base) flood, $H_b = 0.78d_{100}$ and the maximum height of a breaking wave above the 100-year stillwater elevation = $0.55d_{100}$ (see Figure 3-55). Note that for wind-driven waves, water depth is only one of three parameters that determine the actual wave height at a particular site (wind speed and fetch length are the other two). In some instances, actual wave heights may be below the depth-limited maximum height.

Figure 3-55.
BFE determination for coastal flood hazard areas where wave crest elevations exceed wave runup elevations (Zones A and V)



For a coastal flood hazard area where the ground slopes up gently from the shoreline, and there are few obstructions such as houses and vegetation, the BFE shown on the FIRM is approximately equal to the ground elevation plus the 100-year stillwater depth (d_{100}) plus 0.55d_{100}. For example, where the ground elevation is 4 feet NAVD and d_{100} is 6 feet, the BFE is equal to 4 feet plus 6 feet plus 3.3 feet, or 13.3 feet NAVD, rounded to 13 feet NAVD.

NOTE

FEMA maps Zone V based on ***wave heights*** where the wave height (vertical distance between wave crest and wave trough) is greater than or equal to 3 feet.

3.6.5 Wave Runup

On steeply sloped shorelines, the rush of water up the surface of the natural beach (including dunes and bluffs) or the surface of a manmade structure (such as a revetment or vertical wall) can result in flood elevations higher than those of the crests of wind-driven waves. For a coastal flood hazard area where this situation occurs, the BFE shown on the FIRM is equal to the highest elevation reached by the water (see Figure 3-56).

NOTE

FEMA maps Zone V based on ***wave runup*** where the vertical distance between the runup elevation and the ground (the runup "depth") is greater than or equal to 3 feet.

3.6.6 Primary Frontal Dune

The NFIP has other parameters used to establish Zone V delineations besides wave heights and wave runup depths. In some cases, the landward limit of the primary frontal dune will determine the landward limit of Zone V. This Zone V designation is based on dune morphology, as opposed to base flood conditions. Consult the *Guidelines and Specifications for Flood Hazard Mapping Partners* (FEMA 2003) for details regarding the NFIP primary frontal dune delineation. Note that some States and communities may have different dune definitions, but these will not be used by the NFIP to map Zone V.

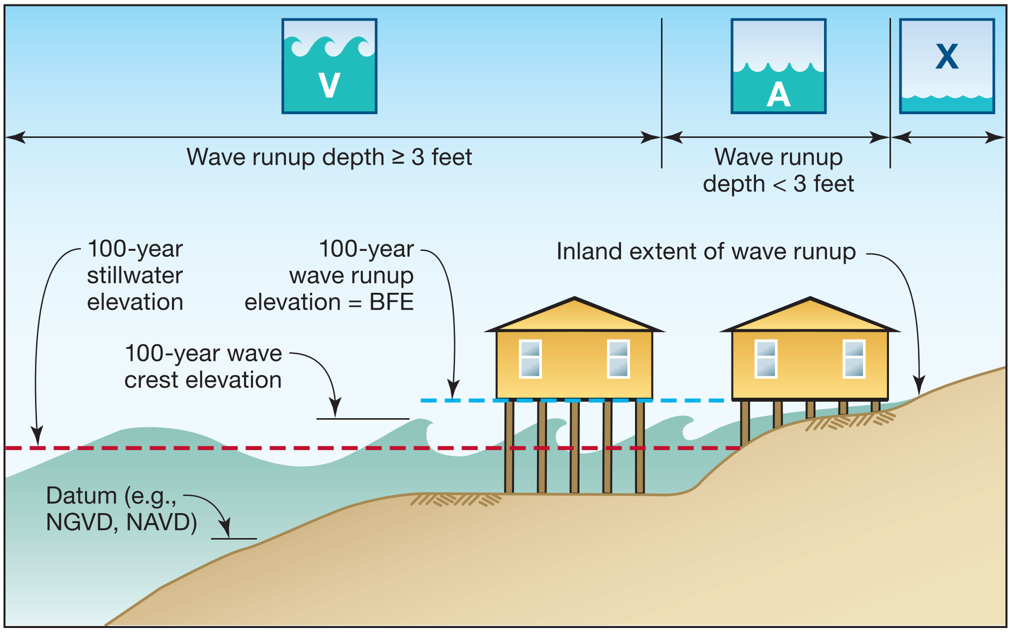


Figure 3-56. Where wave runup elevations exceed wave crest elevations, the BFE is equal to the runup elevation

TERMINOLOGY

WAVE RUNUP is the rush of water up a slope or structure.

WAVE RUNUP DEPTH at any point is equal to the maximum wave runup elevation minus the lowest eroded ground elevation at that point.

WAVE RUNUP ELEVATION is the elevation reached by wave runup, referenced to NGVD or other datum.

WAVE SETUP is an increase in the stillwater surface elevation near the shoreline, due to the presence of breaking waves. Wave setup typically adds 1.5 to 2.5 feet to the 100-year stillwater flood elevation.

MEAN WATER ELEVATION is the sum of the stillwater elevation and wave setup.

3.6.7 Erosion Considerations and Flood Hazard Mapping

Proper design requires two types of erosion to be considered: dune and bluff erosion during the base flood event, and long-term erosion. Newer FIRMs account for the former, but no FIRMs account for the latter.

Dune/Bluff Erosion. Current FIS procedures account for the potential loss of protective dunes and bluffs during the 100-year flood. However, this factor was not considered in coastal FIRMs prepared prior to May 1988, which delineated Zone V without any consideration for storm-induced erosion. Zone V boundaries were drawn at the crest of the dune solely on the basis of the elevation of the ground and without regard for the erosion that would occur during a storm.

Long-Term Erosion. Designers, property owners, and floodplain managers should be careful not to assume that flood hazard zones shown on FIRMs accurately reflect current flood hazards, especially if there has been a significant natural hazard event since the FIRM was published. For example, flood hazard restudies completed after Hurricane Opal (1995, Florida Panhandle) and Fran (1996, Topsail Island, NC) have produced FIRMs that are dramatically different from the FIRMs in effect prior to the hurricanes.

Figure 3-57 provides an example of the effects of both dune erosion and long-term erosion changes. The figure compares pre- and post-storm FIRMs for Surf City, NC. The map changes are attributable to two factors: (1) pre-storm FIRMs did not show the effects of erosion that occurred after the FIRMs were published and did not meet technical standards currently in place, and (2) Hurricane Fran caused significant changes to the topography of the barrier island. Not all coastal FIRMs would be expected to undergo such drastic revisions after a flood restudy; however, many FIRMs may be in need of updating, and designers should be aware that FIRMs may not accurately reflect present flood hazards at a site.

3.6.8 Dune Erosion Procedures

Current Zone V mapping procedures (FEMA 2003) require that a dune have a minimum ***frontal dune reservoir*** (dune cross-section above 100-year stillwater level and seaward of dune peak) of 540 square feet in order to be considered substantial enough to withstand erosion during a base flood event. According to FEMA procedures, a frontal dune reservoir less than 540 square feet will result in dune removal (dune disintegration), while a frontal dune reservoir greater than or equal to 540 square feet generally will result in dune retreat (see Figure 3-58).

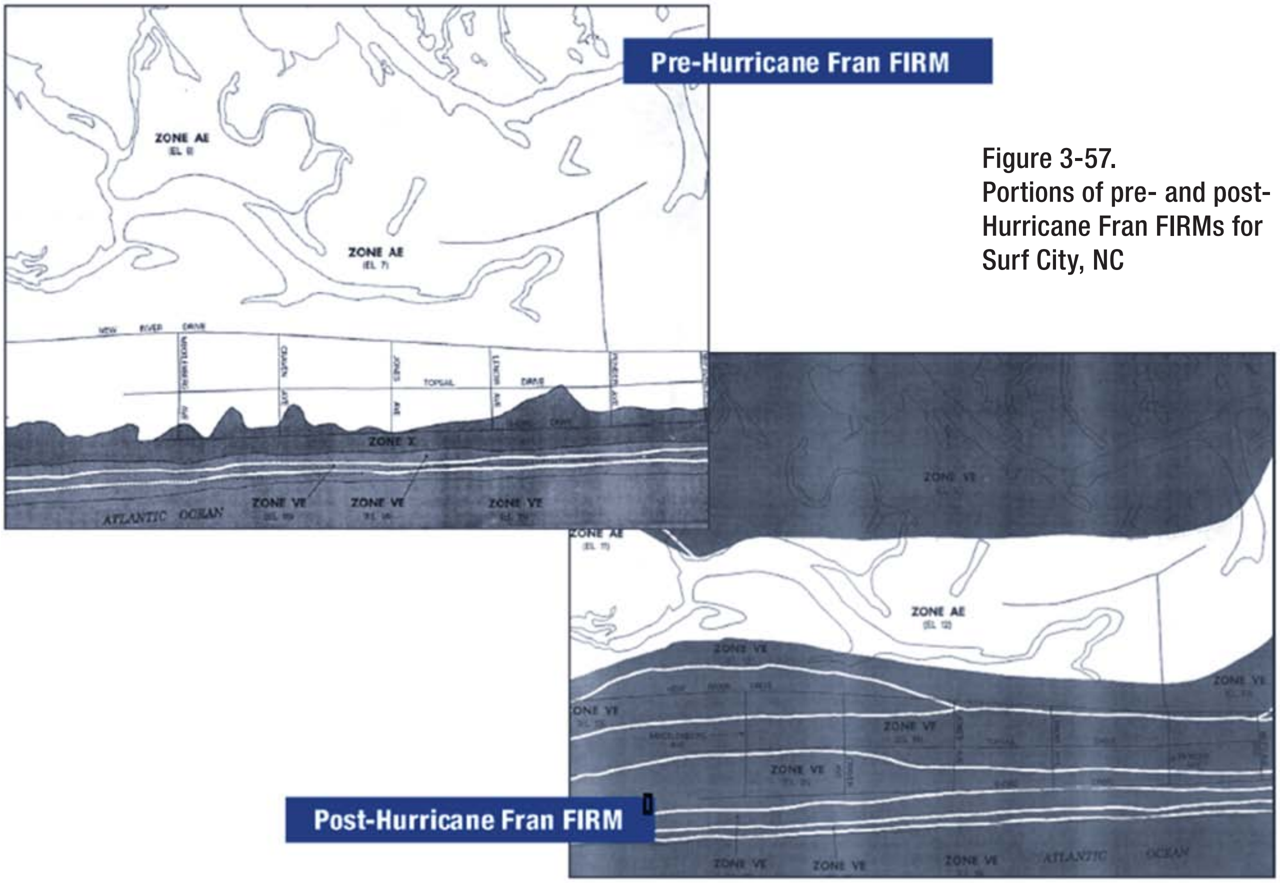


Figure 3-57.
Portions of pre- and post-Hurricane Fran FIRMs for Surf City, NC

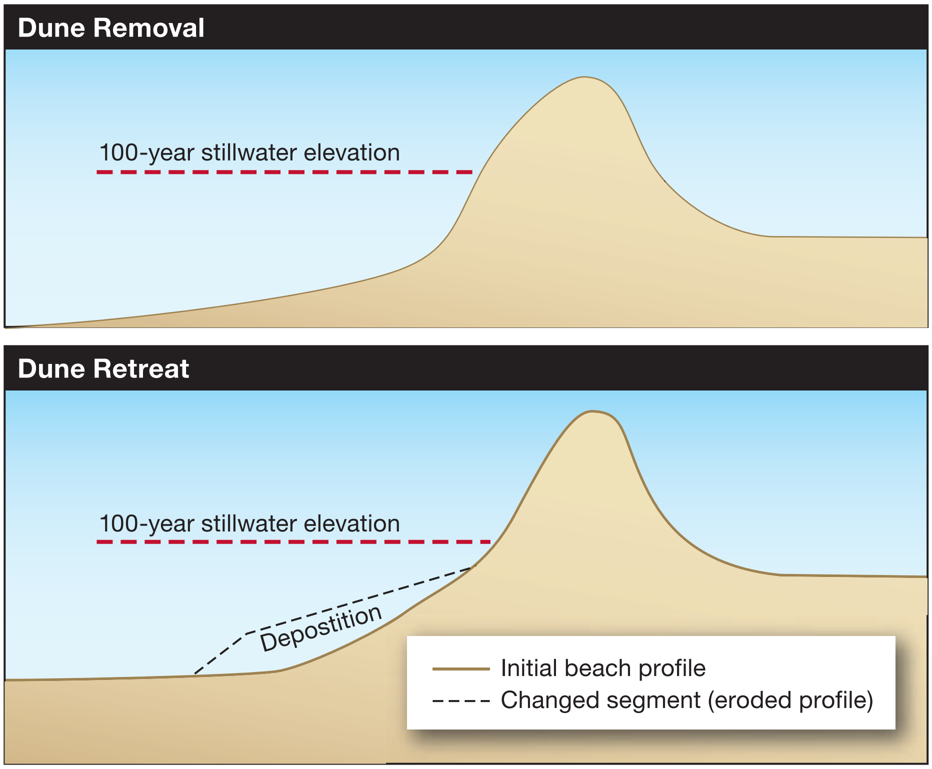


Figure 3-58.
Current FEMA treatment of dune removal and dune retreat

SOURCE: FEMA 2003

The current procedure for calculating the post-storm profile in the case of dune removal is relatively simple: a straight line is drawn from the pre-storm dune toe landward at an upward slope of 1 on 50 (vertical to horizontal) until it intersects the pre-storm topography landward of the dune. Any sediment above the line is assumed to be eroded.

This Manual recommends that the size of the frontal dune reservoir used by designers to prevent dune removal during a 100-year storm be increased to 1,100 square feet. This recommendation is made for three reasons: (1) The 540 square feet rule used by FEMA reflects dune size at the time of mapping and does not account for future conditions, when beaches and dunes may be compromised by long-term erosion; (2) The 540 square feet rule does not account for the cumulative effects of multiple storms that may occur within short periods of time, such as in 1996, when Hurricanes Bertha and Fran struck the North Carolina coast within 2 months of each other (see Figure 4-6 in Chapter 4); and (3) even absent long-term erosion and multiple storms, use of the median frontal dune reservoir underestimates dune erosion 50 percent of the time.

Dune erosion calculations at a site should also take ***dune condition*** into account. A dune that is not covered by well-established vegetation (i.e., vegetation that has been in place for two or more growing seasons) is more vulnerable to wind and flood damage than one with well-established vegetation. A dune crossed by a road or pedestrian path offers a weak point that storm waves and flooding exploit; to reduce potential weak points, elevated dune walkways are recommended. Post-storm damage inspections frequently show that dunes are breached at these weak points and structures landward of them are more vulnerable to erosion and flood damage.

3.6.9 Levees and Levee Protection

The floodplain area landward of a levee system for which the levee system provides a certain level of risk reduction is known as the ***levee-impacted area.*** Some levees include interior drainage systems that provide for conveyance of outflow of streams and runoff. Levee-impacted areas protected by accredited levees meeting NFIP requirements are mapped as Zone X (shaded) and the interior drainage areas are designated as Zone A. For levees not meeting NFIP requirements, both sides of the levee are mapped as Zone A. Levees on older FIRMs may not have been evaluated against NFIP criteria, and may not offer the designed level of protection due to deterioration, changed hydrology or channel characteristics, or partial levee failure.

CROSS REFERENCE

Section 2.6.2 provides additional detail on the risks of siting a building in a levee-impacted area.

3.7 Flood Hazard Assessments for Design Purposes

Designers may sometimes be faced with a FIRM and FIS that are several years old, or older. As such, designers should determine whether the FIRM still accurately represents flood hazards associated with the site under present day base flood conditions. If not, the designer may need to pursue updating the information in order to more accurately understand the hazard conditions at the site.

WARNING

Some sites lie outside flood hazard areas shown on FIRMs, but may be subject to current or future flood and erosion hazards. These sites, like those within mapped flood hazard areas, should be evaluated carefully.

3.7.1 Determine If Updated or More Detailed Flood Hazard Assessment is Needed

Two initial questions drive the decision to update or complete a more detailed flood hazard assessment:

1. Does the FIRM accurately depict present flood hazards at the site of interest?
2. Will expected shore erosion render the flood hazard zones shown on the FIRM obsolete during the projected life of the building or development at the site?

The first question can be answered with a brief review of the FIRM, the accompanying FIS report, and site conditions. The answer to the second question depends upon whether or not the site is experiencing long-term shore erosion. If the shoreline at the site is stable and is not experiencing long-term erosion, then the FIRM does not require revision for erosion considerations. However, because FIRMs are currently produced without regard to long-term erosion, if a shoreline fluctuates or experiences long-term erosion, the FIRM will cease to provide the best available data at some point in the future (if it has not already) and a revised flood hazard assessment will be necessary.

Updated and revised flood hazard assessments are discussed with siting and design purposes in mind, not in the context of official changes to FIRMs that have been adopted by local communities. The official FEMA map change process is a separate issue that is not addressed by this Manual. Moreover, some siting and design recommendations contained in this Manual exceed minimum NFIP requirements, and are not tied to a community's adopted FIRM and its associated requirements.

3.7.1.1 Does the FIRM Accurately Depict Present Flood Hazards?

In order to determine whether a FIRM represents current flood hazards, and whether an updated or more detailed flood hazard assessment is needed, the following steps should be carried out:

NOTE

The date of the effective (i.e., newest) FIRM for a community can be found on FEMA's Web site under the heading "Community Status Book," at http://www.fema.gov/fema/csb.shtm.

- Obtain copies of the latest FIRM and FIS report for the site of interest. If the effective date precedes the critical milestones listed in Section 3.8, an updated flood hazard assessment may be needed.
- Review the legend on the FIRM to determine the history of the panel (and revisions to it), and review the study methods described in the FIS. If the revisions and study methods are not consistent with current study methods (FEMA 2007), an updated flood hazard assessment may be needed.
- If the FIS calculated dune erosion using the 540 square feet criterion (refer to Section 3.5.8) and placed the Zone V boundary on top of the dune, check the dune cross-section to see if it has a frontal dune reservoir of at least 1,100 square feet above the 100-year stillwater elevation. If not, consider shifting the Zone V boundary to the landward limit of the dune and revising other flood hazard zones, as needed.
- Review the description in the FIS report of the storm, water level, and flood source data used to generate the 100-year stillwater elevation and BFEs. If significant storms or flood events have affected the area since the FIS report and FIRM were completed, the source data may need to be revised and an updated flood hazard assessment may be needed.

- Determine whether there have been significant physical changes to the site since the FIS and FIRM were completed (e.g., erosion of dunes, bluffs, or other features; opening of a tidal inlet; modifications to drainage, groundwater, or vegetation on coastal bluffs; construction or removal of shore protection structures; filling or excavation of the site). If there have been significant changes in the physical configuration and condition since the FIS and FIRM were completed, an updated and more detailed flood hazard assessment may be needed.
- Determine whether adjacent properties have been significantly altered since the FIS and FIRM were completed (e.g., development, construction, excavation, etc.) that could affect, concentrate, or redirect flood hazards on the site of interest. If so, an updated and more detailed flood hazard assessment may be needed.

NOTE

Where a new FIRM exists (i.e., based on the most recent FEMA study procedures and topographic data), long-term erosion considerations can be approximated by shifting all flood hazard zones landward a distance equal to the long-term annual erosion rate multiplied by the life of the building or development (use 50 years as the minimum life). The shift in the flood hazard zones results from a landward shift of the profile.

If, after following the steps above, it is determined that an updated flood hazard assessment may be needed, see Section 3.7.2 for more information on updating and revising flood hazard assessments.

3.7.1.2 Will Long-Term Erosion Render a FIRM Obsolete?

Designers should determine whether a FIRM is likely to become obsolete as a result of long-term erosion considerations, and whether a revised flood hazard assessment is needed. First, check with local or State CZM agencies for any information on long-term erosion rates or construction setback lines. If such rates have been calculated, or if construction setback lines have been established from historical shoreline changes, long-term erosion considerations may necessitate a revised flood hazard assessment.

In cases where no long-term erosion rates have been published, and where no construction setback lines have been established based on historical shoreline movements, designers should determine whether the current shoreline has remained in the same approximate location as that shown on the FIRM (e.g., has there been any significant shore erosion, accretion, or fluctuation?). If there has been significant change in the shoreline location or orientation since the FIS and FIRM were completed, a revised flood hazard assessment may be needed.

3.7.1.3 Will Sea Level Rise Render a FIRM Obsolete?

Sea level rise has two principal effects: (1) it increases storm tide elevations and allows for larger wave heights to reach a coastal site, and (2) it leads to shoreline erosion. For these reasons, designers should investigate potential sea level rise and determine whether projected sea level changes will increase flood hazards at a site. Relying on the FIRM to project future site and base flood conditions may not be adequate in many cases. The NOAA site http://tidesandcurrents.noaa.gov/sltrends/sltrends.html provides historical information that a designer can extrapolate into the future. Designers may also wish to consider whether accelerated rates of rise will occur in the future.

A USACE Engineering Circular (USACE 2009a) provides guidance on sources of sea level change data and projections, and discusses how the data and projections can be used for planning purposes. The guidance is useful for planning and designing coastal residential buildings.

3.7.2 Updating or Revising Flood Hazard Assessments

Updating or revising an existing flood hazard assessment—for siting and design purposes—can be fairly simple or highly complex, depending upon the situation. A simple change may involve shifting a Zone A or Zone X boundary, based upon topographic data that is better than those used to generate the FIRM. A complex change may involve a detailed erosion assessment and significant changes to mapped flood hazard zones.

NOTE

Coastal hazard analysis models (Erosion, Runup, WHAFIS) used by FEMA's FIS contractors are available for use by others. However, those performing updates or revising flood hazard assessments are advised to obtain the assistance of an experienced coastal professional. FEMA has also issued its Coastal Hazard Modeling Program (CHAMP) to facilitate the use of standard FEMA models for flood hazard mapping.

If an assessment requires recalculating local flood depths and wave conditions on a site, FEMA models (Erosion, Runup, and WHAFIS) can be used for the site (bearing in mind the recommended change to the required dune reservoir to prevent dune loss, described in 3.5.8).

If an assessment requires careful consideration of shore erosion, the checklist, flowchart, and diagram shown in Chapter 4 can be a guide, but a qualified coastal professional should be consulted. Much of the information and analyses described in the checklist and flowchart is likely to have already been developed and carried out previously by others, and should be available in reports about the area; designers are advised to check with the community. Cases for which information is unavailable and basic analyses have not been completed are rare.

The final result of the assessment should be a determination of the greatest flood hazards resulting from a 1-percent-annual-chance coastal flood event that the site will be exposed to over the anticipated life of a building or development. The determination should account for short- and long-term erosion, bluff stability, sea level rise, and storm-induced erosion; in other words, both chronic and catastrophic flood and erosion hazards, along with future water level conditions, should be considered.

3.8 Milestones of FEMA Coastal Flood Hazard Mapping Procedures and FIRMs

Designers are reminded that FEMA's flood hazard mapping procedures have evolved over the years (the coastal mapping site, http://www.fema.gov/plan/prevent/fhm/dl_vzn.shtm, provides links to current coastal mapping guidance and highlights many of these changes). Thus, a FIRM produced today might differ from an earlier FIRM, not only because of physical changes at the site, but also because of changes in FEMA hazard zone definitions, revised models, and updated storm data. Major milestones in the evolution of FEMA flood hazard mapping procedures, which can render early FIRMs obsolete, include:

- In approximately 1979, a FEMA storm surge model replaced NOAA tide frequency data as the source of storm tide stillwater elevations for the Atlantic and Gulf of Mexico coasts.
- In approximately 1988, coastal tide frequency data from the USACE New England District replaced earlier estimates of storm tide elevations for New England.
- In approximately 1988, return periods for Great Lakes water levels from the USACE Detroit District replaced earlier estimates of lake level return periods.
- There have been localized changes in flood elevations. For example, after Hurricane Opal (1995), a revised analysis of historical storm tide data in the Florida panhandle raised 100-year stillwater flood elevations and BFEs by several feet (Dewberry & Davis 1997).
- Prior to Hurricane Frederic in 1979, BFEs in coastal areas were set at the storm surge stillwater elevation, not at the wave crest elevation. Beginning in the early 1980s, FIRMs have been produced with Zone V, using the WHAFIS model and the 3-foot wave height as the landward limit of Zone V.
- Beginning in approximately 1980, tsunami hazard zones on the Pacific coast were mapped using procedures developed by the USACE. These procedures were revised in approximately 1995 for areas subject to both tsunami and hurricane effects.
- Before May 1988, flood hazard mapping for the Atlantic and Gulf of Mexico coasts was based solely on ground elevations and without regard for erosion that would occur during the base flood event; this practice resulted in Zone V boundaries being drawn near the crest of the primary frontal dune. Changes in mapping procedures in May 1988 accounted for storm-induced dune erosion and shifted many Zone V boundaries to the landward limit of the primary frontal dune.
- After approximately 1989, FIRMs were produced using a revised WHAFIS model, a runup model, and wave setup considerations to map flood hazard zones.
- Beginning in approximately 1989, a Great Lakes wave runup methodology (developed by the USACE Detroit District and modified by FEMA) was employed.
- Beginning in approximately 1989, a standardized procedure for evaluating coastal flood protection structures (Walton et al. 1989) was employed.
- Beginning in approximately 2005, FEMA began mapping the 2-percent exceedance wave runup elevation during the base flood instead of the mean runup elevation.
- In 2005, FEMA issued its *Final Draft Guidelines for Coastal Flood Hazard Analysis and Mapping for the Pacific Coast of the United States.*
- Beginning in 2005, FEMA began using advanced numerical storm surge (ADCIRC) and offshore wave (STWAVE and SWAN) models for Atlantic and Gulf of Mexico coastal flood insurance studies (conventional dune erosion procedures and WHAFIS are still used on land). Studies completed using these models should be considered the most accurate and reliable.
- In 2007, FEMA issued its *Atlantic Ocean and Gulf of Mexico Coastal Guidelines Update.*

- In 2007, FEMA issued guidance for mapping the 500-year (0.2-percent-annual-chance) wave envelope in coastal studies.
- In 2008, FEMA issued guidance for mapping coastal flood hazards in sheltered waters.
- In December 2008, FEMA issued mapping guidance for the LiMWA (FEMA 2008c), which delineates the 1.5-foot wave height location, and thus, defines the landward limit of the Coastal A Zone.
- In 2009, FEMA issued its *Great Lakes Coastal Guidelines Update* (FEMA 2009).

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