Coastal Hazards and Considerations

This chapter describes the hazards associated with coastal areas and the issues that local officials must consider when they work in this environment. The chapter enlightens the reader on the flood and wind hazards associated with coastal areas and provides a brief summary of other hazards that could potentially impact construction methods at the end of the chapter.

2.1 Flood Hazards: General Design Considerations

This section introduces the physical nature and characteristics of coastal floods. It also describes the types of flood damage that can result when buildings are located within coastal flood hazard areas.

2.1.1 The Nature of Flooding

Flooding is the most common natural hazard to occur in the United States, affecting more than 20,000 local jurisdictions covered under the National Flood Insurance Program (NFIP) and representing more than 70 percent of presidential disaster declarations. Flooding is a natural process that may occur in a variety of forms. This guide focuses on coastal flooding from hurricanes and tropical storms. Increased development along our nation's coastlines creates potentially life-threatening situations and renders property vulnerable to serious damage or destruction.

Flooding along shorelines is usually the result of coastal storms that generate storm surge or waves. Several factors can affect the frequency and severity of damage that ensues as a result of coastal flooding:

- Erosion of shorelines, often resulting in significant losses of soil with a single event
- Rising sea levels
- Deposition of sediment from receded waves or water, or sediment that is carried inland by wave action
- Land subsidence, which increases flood depths
- Failure of levees that may result in the sudden flooding of areas behind levees

NOTE

Flood frequency analyses are performed using historical records and hydrological analysis, and the results are influenced by the length of the record. Such analyses do not account for recent changes to the land (such as shifting of barrier islands due to storms) or future changes (including development, greater subsidence, or climatic variations).

Coastal flooding has distinct characteristics that should be considered in the selection of building sites, design of new buildings, and substantial repair or modification of existing floodprone buildings.

Coastal flooding occurs along the Atlantic, Gulf, and Pacific coasts and many large lakes, including the Great Lakes. Coastal flooding is influenced by storm surges associated with tropical cyclonic weather systems (e.g., hurricanes, tropical storms, tropical depressions, and typhoons), extratropical systems (i.e., nor'easters), and tsunamis (which are surges induced by seismic activity). Coastal flooding is primarily characterized by wind-driven waves. Along the reaches of the Great Lakes, winds blowing across broad expanses of water can generate waves rivaling those of ocean shorelines. Figure 2-1 is a schematic of a generic coastal floodplain. Section 2.1.3.1 provides additional information on depth of flooding in mapped areas.

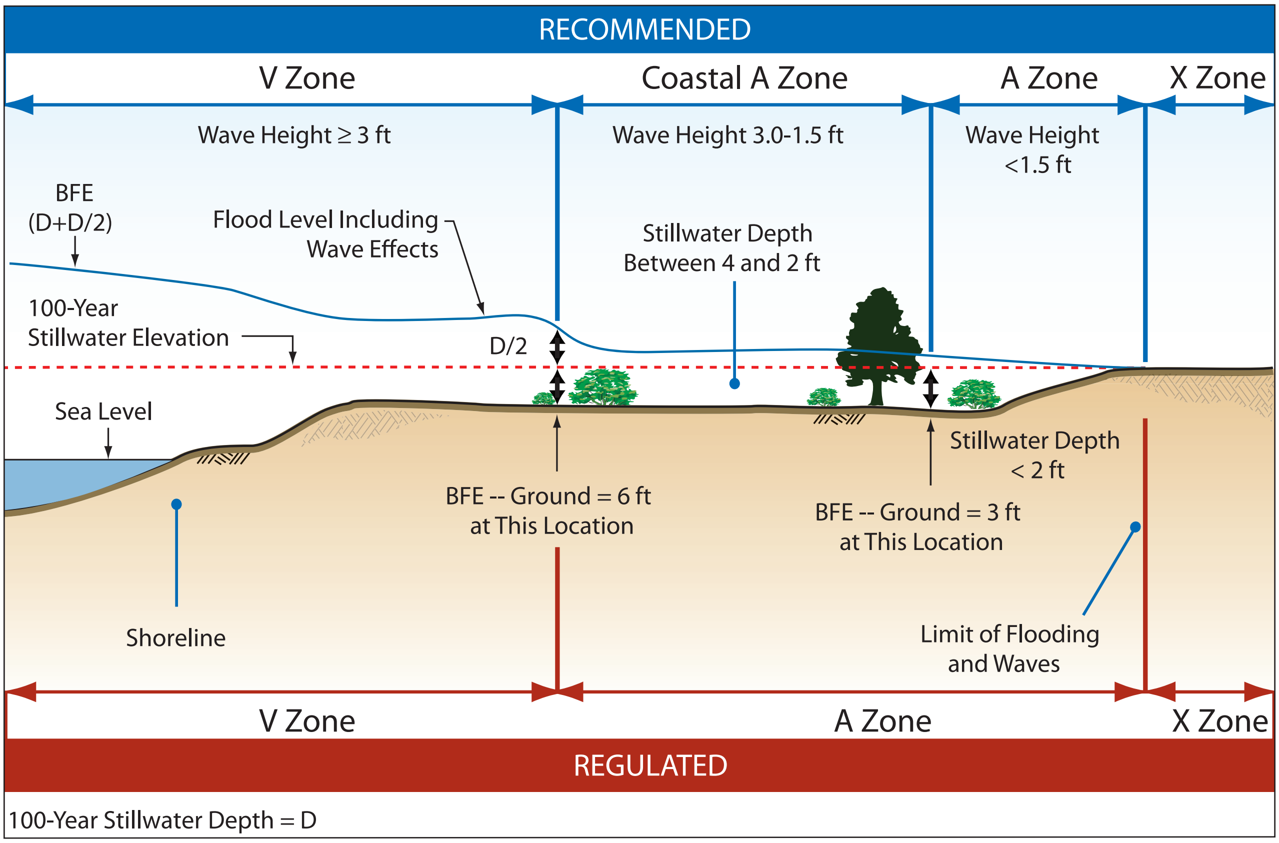


Figure 2-1.
Floodplain along an open coast. (Flood zones identified in this figure are discussed in Subsection 2.1.4.3 of this guide.)

2.1.2 Flood Characteristics and Loads

Characteristics associated with coastal flooding are important in the analysis of sites for buildings and in the determination of flood loads that must be considered as part of the architectural and engineering design. These characteristics are described below.

Depth. The most noticeable characteristic of any flood is water depth. The depth of coastal flooding is influenced by such factors as storm strength, tidal cycle, storm duration, land elevation, and the presence of waves. Depth is a critical factor in building design because the flood forces acting upon a vertical surface (such as a foundation wall, column, post, pier, or pile) are directly related to depth. Costs associated with protecting buildings from flooding typically increase with depth. Under certain conditions, hurricanes

Figure 2-2.
LONG BEACH, MISSISSIPPI: Aerial photo of apartment complex and surrounding area after Hurricane Katrina. (Source: FEMA 549)

can produce storm-surge flooding that is 20 to 30 feet above mean sea level or, in extreme cases along the Gulf Coast, as much as 35 feet above mean sea level (see Figure 2-2). These storm-surge events can result in significant water depths within low-lying coastal areas.

Duration. Duration is defined as the recorded length of time of above normal water levels. Most coastal flooding is influenced by the normal tidal cycle as well as how fast coastal storms move through that particular region. Areas subject to coastal flooding can experience long-duration flooding in which drainage is poor or slow as a result of topography or the presence of flood control structures. For example, there may be depressions in the land that could hold water or situations in which water could be trapped behind a floodwall or levee with inadequate drainage. More commonly, coastal flooding is of shorter duration—usually 12 to 24 hours—especially if storms move rapidly. For building design, duration is important because it affects access, building usability, saturation and stability of soils, and selection of building materials. In the mid-Atlantic and New England states, however, nor'easters can result in flooding that lasts for more than 3 days.

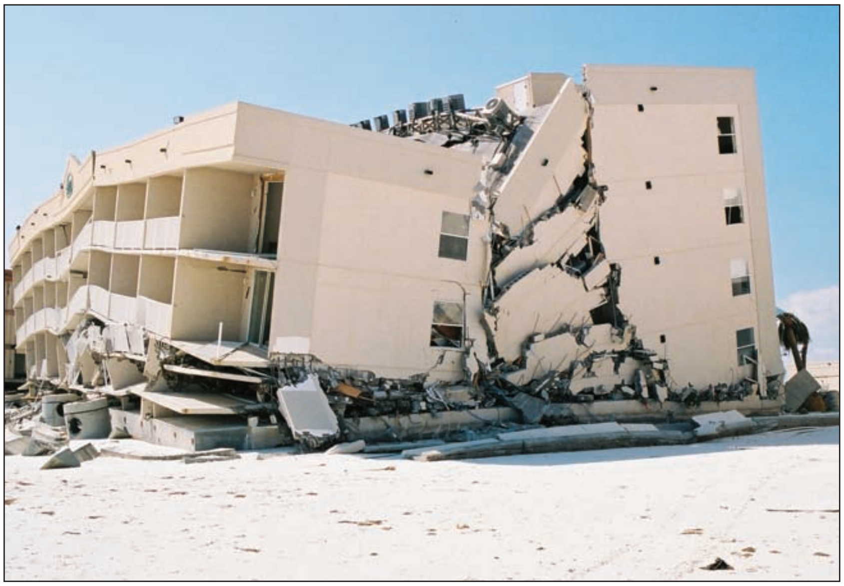
Velocity. Floodwater velocity ranges from extremely high (associated with storm surges of 10 feet per second or more) to very low or nearly stagnant (in backwater areas and expansive floodplains). In this context, velocity refers not to the motion associated with breaking waves but to the speed of the mass movement of floodwater across an area. Velocity is important in site planning because of the potential for erosion. In structural design, velocity is a factor in determining the hydrodynamic (i.e., moving water) loads and impact loads (which is the force of moving water or the force of floodborne debris hitting a building).

Wave action. Waves contribute not only to erosion and scour but also add significantly to the loads exerted on buildings. The magnitude of wave forces can be 10 to more than 100 times greater than wind and other design loads and thus may control many design parameters. Waves must be considered in site planning along coastal shorelines; waves must also be considered in flood hazard areas that are inland of open coasts and other locations where waves occur, including areas with sufficient open spaces that winds can generate waves (such as lakes and expansive riverine floodplains). Waves on top of storm surges may be as much as 50 percent higher than the depth of the surge. Figures 2-3, 2-4, 2-5, and 2-6 illustrate the power of wave action on structures.

Impacts from debris. Floating debris contributes to the loads that must be considered in the structure design. The methods and models used to predict and delineate flood hazard areas do not specifically incorporate the effects of debris. Few sources, other than past observations and engineering judgment, are available to determine the potential effects of debris impact loads. More recent model building codes require that foundations be designed to resist a representative impact from floodborne debris.

Figures 2-3 and 2-4.
GULF SHORES, WEST BEACH, ALABAMA: Insufficient pile embedment contributed to the displacement of houses. (Source: FEMA 489)

Erosion and scour. In coastal areas, *erosion* refers either to the lowering of the ground surface as a result of a flood event or the gradual recession of a shoreline as a result of long-term coastal processes. *Scour* refers to a localized lowering of the ground surface due to the interaction of currents and/or waves with structural elements (such as pilings). Soil characteristics influence an area's susceptibility to scour. Erosion and scour may affect foundation stability and the maintaining of filled areas by removing all support from beneath a foundation, resulting in possible structural damage or building collapse.

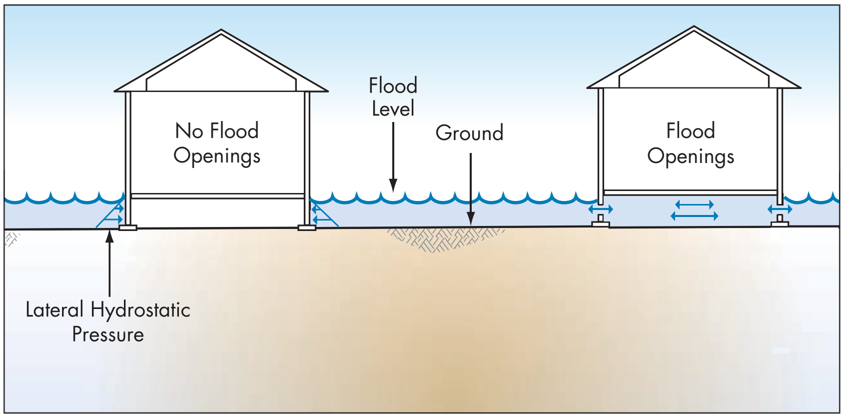


Figures 2-5 and 2-6.
ORANGE BEACH, ALABAMA: Collapse of five-story, multi-family buildings on shallow foundations. (Source: FEMA 489)

2.1.2.1 Hydrostatic Loads

Hydrostatic loads occur when water comes into contact with a building or building component, both above and below the ground level. These loads may act as lateral pressure or as upward vertical pressure (buoyancy).

Lateral hydrostatic loads are a direct function of water depth (see Figure 2-7). These loads can cause severe deflection or displacement of buildings or building components if there is a substantial difference in water levels on opposite sides of the component (such as the interior and exterior of a building). Hydrostatic loads are balanced on the foundation elements of elevated buildings, such as piers and columns, because the element is surrounded by water. To reduce excessive pressure from standing water, minimum NFIP requirements in A Zones require the use of flood openings along continuous foundations, as well as for enclosed areas below the flood elevation.



NOTE

Flood openings are recommended to relieve most foundation hydrostatic loads. The number of openings required is related to the size of those openings and the size of the footprint of the structure. Properly designed flood openings will allow the water level to rise equally on either side of enclosed foundation walls.

Figure 2-7. Hydrostatic loads on buildings.

Buoyancy forces resulting from the displacement of water is also a matter of concern, especially for basements, dry swimming pools, and aboveground and underground tanks. Buoyancy forces are resisted by the dead load of the building or the weight of the tank. When determining resistance to buoyancy forces, the weights of occupants or other live loads are not considered. If the building or tank does not weigh enough when empty, additional stabilizing measures must be taken to prevent flotation. Further, when combining loads in the design process, typically only 60 percent of the building s dead load may be used to resist flood-related loading; this becomes a significant consideration for designs intended to dry floodproof a building. It should be noted that buoyancy force is slightly greater in saltwater because saltwater is more dense than fresh water.

2.1.2.2 Hydrodynamic Loads

Water flowing around a building or a structural element that extends below the flood level imposes hydrodynamic loads. The loads, which are a function of flow velocity and structure geometry, include frontal impact on the upstream face, drag along the sides, and suction on the downstream side (see Figure 2-8).

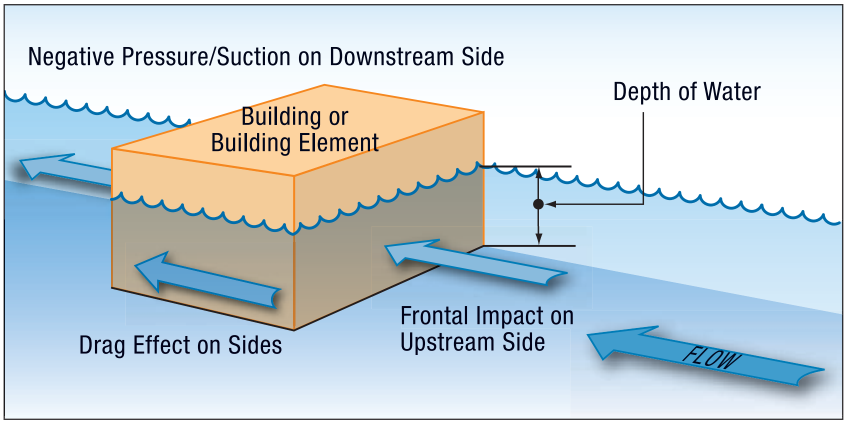


Figure 2-8.
Hydrodynamic loads on a building or building element. (Source: FEMA 543)

The computation methods for hydrodynamic loads are outlined in the design standard ASCE 7-05. Those methods assume that the flood velocity is constant (i.e., steady state flow) and that the dynamic load imposed by floodwaters moving at less than 10 feet per second can be converted to the equivalent hydrostatic load. According to ASCE 7-05, hydrodynamic loads become important when flow rate exceeds 5 feet per second; for velocities less than 5 feet per second, the standard allows the load to be calculated as a hydrostatic load, as outlined in ASCE 7-05 Section 5.4.2

NOTE

Drag coefficients for common building elements, such as columns and piers, can be found in a number of sources. ASCE 7-05 and FEMA 55 recommend some drag-coefficient values.

2.1.2.3 Wave Loads

When waves strike building elements, the force can be 10 to 100 or more times higher than wind and other forces. Forces of this magnitude can be significant, even when acting over the relatively small surface area of the open foundation of an elevated building. Post-storm damage inspections show that breaking wave loads overwhelm nearly all wood-frame and unreinforced masonry walls below the wave crest elevation. Only engineered and massive structural elements are capable of withstanding breaking wave loads.

NOTE

While Coastal A Zones are not formally shown on Flood Insurance Rate Maps (FIRM), in A Zones where wave heights exceed 1.5 feet (such as Coastal A Zones), FEMA recommends using open foundations.

Therefore, in most residential structure design, the preferred method of addressing hydrodynamic loads is to raise the structure above the expected depth of flooding (including waves). The hydrodynamic loads can be so high that it is not possible to resist them in a cost-effective manner. The magnitude of wave forces is the rationale behind the floodplain management requirement for the bottom of the lowest horizontal structural member of the lowest floor to be positioned at or above the design flood elevation in environments where waves are predicted to be 3 feet high or higher (i.e., V Zones). Based upon these factors, the NFIP requires an open foundation design be used within V Zones.

The magnitude of wave loads depends upon the wave height. Equations for wave height are based upon the assumption that waves are depth-limited (on the order of 78 percent of stillwater depth in shallow water break areas) and that waves propagating into shallow water break when the wave height reaches a certain proportion of the underlying stillwater depth. FEMA uses these assumptions to define coastal high-hazard areas (i.e., V Zones) where breaking waves are predicted to be 3 feet high or higher. At any given site, wave heights may be modified by other factors. Designers should refer to ASCE 7-05 for a detailed discussion and computation procedures. As described in ASCE 7-05, "…design and construction of buildings and other structures subject to wave loads shall account for the following loads: waves breaking on any portion of the building or structure; uplift forces caused by shoaling waves beneath a building or structure, or portion thereof; wave run up striking any portion of the building or structure; wave-induced drag and inertia forces; and wave-induced scour at the base of a building or structure, or its foundation."

NOTE

Waves only 1.5 feet high can impose considerable loads and damage. A 1.5-foot-high wave can catastrophically fail the wall of a wood-frame (2 by 4) structure. As a result, there is a growing awareness of the value of considering waves in areas referred to as Coastal A Zones (see Subsection 2.1.4.3 of this guide).

Breaking wave loads on vertical walls or supporting structural members reach a maximum when the direction of wave approach is perpendicular. It is common to assume that the direction of approach will be perpendicular to the shoreline, in which case the orientation of the wall to the shoreline will influence the direction of approach used in load calculations. ASCE 7-05 provides a method for reducing breaking-wave loads on vertical walls for waves that approach a building from a direction other than straight-on.

2.1.2.4 Debris Impact Loads

Debris impact loads are imposed on a building or building element by objects carried by moving water. Objects commonly carried by floodwaters include trees, dislodged tanks, and remnants of structures such as docks and buildings, as shown in Figures 2-9, 2-10, 2-11, and 2-12. Extreme impact loads result from less common sources, such as shipping containers, boats, and barges. The magnitude of these loads is difficult to predict, yet some reasonable allowance is required during the design process if model codes are in effect.

Figure 2-9.
GULFPORT, MISSISSIPPI:
Floodborne debris, including shipping containers and sections of destroyed buildings. (Source: FEMA 549)

Figure 2-10.
Example of surge, wave, and debris damage.
(Source: FEMA 549)

Figure 2-11.
Example of surge, wave, and debris damage.
(Source: FEMA 489)

Figure 2-12.
BIG LAGOON, ALABAMA: Buildings constructed on piles and elevated several feet above the base flood elevation (BFE) sustained less flood damage than adjacent buildings at lower elevations. (Source: FEMA 489)

The location of a building within the potential debris stream influences impact loads. The potential for debris impacts is significant if a building is located immediately adjacent to (or downstream from) other buildings, among closely spaced buildings, or downstream from large floatable objects. Debris impacts those buildings that are located on the open coast and shorelines of back bays.

Debris may impact not only the first row of buildings, but also buildings several rows back.The basic equation to estimate the magnitude of impact loads depends upon designer-selected variables such as coefficients, building or building-element stiffness, debris weight, debris velocity, and duration of impact. The latter three variables (which are described in detail in ASCE 7-05) are briefly described below.

When reviewing plans, the inclusion of debris loads should consider impacts on foundation elements from debris weighing at least 1,000 pounds. Based upon regional conditions, this number could increase in some areas. Chapter C5 of ASCE 7-05 provides some background on impact loads and the assumptions made in calculating them. Standard assumptions are made for most coastal and riverine areas. Special provisions are outlined for areas such as the Pacific Northwest, where large trees and logs are common. The chapter also addresses situations where loads less than the standard 1,000-pound impact force should be considered. Other factors to be considered in the calculation of debris impact loads include the debris velocity, which is the velocity of debris when it strikes a building, and the duration that it takes the debris to stop once it impacts the building.

2.1.2.5 Erosion and Local Scour

Erosion and scour can significantly impact building performance and should therefore be considered during the site evaluation and design. In coastal areas, erosion may affect the ground surface and may cause a short- or long-term recession of the shoreline. In areas subject to gradual erosion of the ground surface, additional foundation-embedment depth can mitigate the effects. Where shoreline erosion is significant, however, engineered solutions are unlikely to prove effective. Avoidance of sites in areas subject to active erosion usually is a safe and cost-effective solution. Although every building site is important, local officials should evaluate areas of known long-term shoreline recession and ensure that elected officials are aware of the potential impacts of poorly sited structures within these areas.

Local scour results from turbulence at the ground level around foundation elements. Determining potential scour is critical in the design of foundations to ensure that failure during and after flooding does not occur as a result of the loss in either bearing capacity or anchoring resistance around the posts, piles, piers, columns, footings, or walls. Scour can also impact a building's lateral stability. A loss of lateral stability can often overstress pile connections with the structure, resulting in the failure of weak or improperly designed connections. In many instances, deeper foundations are recommended to account for significant losses in soil and scour. Figures 2-13, 2-14, and 2-15 show the dramatic impacts of erosion on structures.

At some locations, soil at or below the ground surface can be resistant to local scour, and calculated scour depths based upon unconsolidated surface soils below may be considered excessive. In instances where the local official believes the underlying soil at a site will be scour-resistant, the official should recommend the assistance of a geotechnical engineer or geologist.

Figure 2-13.
ORANGE BEACH, ALABAMA: Significant erosion caused a non-structural parking slab to fail and the structure to lean due to insufficient pile embedment. (Source: FEMA 489)

Figures 2-14 and 2-15.
GULF SHORES, ALABAMA: House on pile foundation, adjacent to breach in the barrier island that experienced erosion and significant non-structural damage below the lowest floor. (Source: FEMA 489)

2.1.3 Design Parameters

Flood hazards and flooding characteristics must be identified to evaluate the impact of site development, determine design parameters necessary to calculate flood loads, design floodproofing measures, and identify and prioritize retrofit measures for existing buildings.

2.1.3.1 Flood Depth

Because nearly every other flood-load calculation depends directly or indirectly upon it, flood depth is the most important factor required to compute loads exerted by flooding. The first step in determining flood depth at a specific site is to identify the flood that is specified (i.e., the design event), which will either be stated in applicable regulations or mandated by the governing authority. The most common flood used for design is the base flood (see Subsection 2.1.4 of this guide). Base flood elevations (BFE) are determined in V and A Zones as the design stillwater flood depth plus the additional wave crest height, which is an additional 55 percent of the stillwater depth. The second step is to determine the ground elevation at the site. Because these pieces of data are usually obtained from different sources, it is important to determine whether they are based on the same vertical datum. If they are not, standard corrections must be applied.

NOTE

When evaluating flood depths or elevations as related to house elevations, it is important to consider which vertical datum is being used. Newer FIRMs use the NAVD88 (while older maps use the NGVD29). This information, which is listed on the FIRM, is considered by the surveyor when structure elevations are taken.

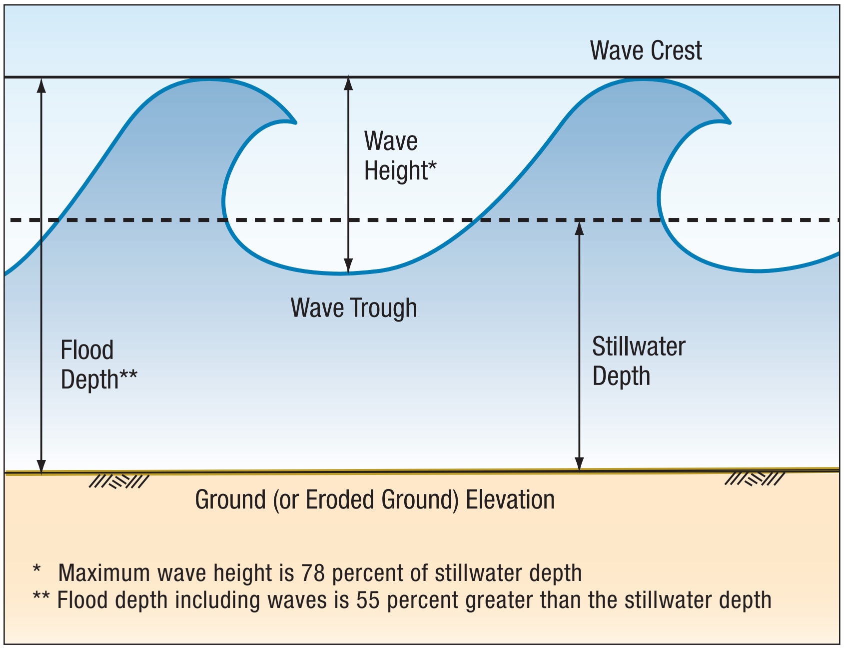


Figure 2-16. Coastal wave height and stillwater depth. (Source: FEMA 543)

NOTE

Waves and storm-induced erosion are most common in coastal areas. However, wide rivers and lakes may experience wind-driven waves, and erodible soils are found throughout the United States. For information about waves and erosion, see FEMA 55, Coastal Construction Manual.

In coastal areas, the flood elevations shown on Flood Insurance Rate Maps (FIRMs) include the depth of waves only if the predicted wave heights are greater than 3 feet. In these areas, shown as V Zones on FIRMs (see Subsection 3.1.4.3 of this guide), the flood depth is composed of a “stillwater” depth plus the expected height of waves (see Figure 2-16).

The FIRMs also delineate flood hazard areas shown as A Zones; these zones are inland of V Zones or located along shorelines where predicted wave heights are less than 3 feet. When the ground elevation is subtracted from the flood elevation, the result is the stillwater depth. Where waves are expected to range in height from 1.5 feet to 3 feet (i.e., in the Coastal A Zone, as explained in Subsection 2.1.4.3 of this guide), the loading from the waves should be included in the load calculations. Use of only the stillwater depth to determine the flood loads will result in an underestimate of the loads. The relationship shown on Figure 2-16 should be used to estimate wave heights as a function of stillwater depth.

In areas with erodible soils, local officials must consider the effects of erosion where floodwaters lower the ground surface or cause local scour around foundation elements. The flood depth determined using flood elevation and ground elevation should be increased to account for changes in conditions during a flood event. Lowering the ground surface effectively results not only in deeper water against the foundation; it may also remove supporting soil from the foundation, which must be accounted for in the foundation design. While flood maps and the resulting BFEs account for the erosion that occurs during a base flood event, they do not consider long-term erosion. In addition, the maps do not account for site-specific, foundation-specific scour, which should be considered in the design process.

2.1.3.2 Flood Velocity

Estimating flood velocities in coastal flood hazard areas involves considerable uncertainty, and little reliable historical information or data from actual coastal flood events is available. The direction and velocity of floodwaters can vary significantly throughout a coastal flood event. Floodwaters can approach a site from one direction as a storm approaches and then shift to another direction (or several directions) as the storm moves through the area. Floodwaters can inundate some low-lying coastal sites from both the front (e.g., ocean) and the back (e.g., bay, sound, or river). Similarly, at any given site, flow velocities can vary from close to zero to more than 10 feet per second. For these reasons, when determining flood loads for building design, velocities should be estimated conservatively, and it should be assumed that floodwaters can approach from the most design-critical direction.

Despite the uncertainties, there are methods to estimate approximate coastal flood velocities. One common method is based on the stillwater depth (i.e., the flood depth without waves). Local officials should verify that designers considered the topography, distance from the flooding source, and proximity to other buildings and obstructions before selecting the flood velocity for design. Those factors can direct and confine floodwaters, with a resulting acceleration of velocities. This increase in velocities is described as the “expected upper bound.” “Expected lower bound” velocities are experienced in areas where those factors are not expected to influence the direction and velocity of floodwaters.

2.1.4 Flood Hazard Maps and Zones

NOTE

As of 2007, 60.3 percent of the U.S. population had digital geographic information system (GIS) flood data. It is projected that by the end of 2009, 92 percent of the population will have digital GIS flood data.

FIRMs identify areas subject to flooding. These locations include the Special Flood Hazard Area (SFHA) representing the land within the floodplain with a 1 percent annual chance of flooding. The flood event that produces the 1 percent annual flood is often called the 100-year flood. FIRMs also include areas between the 100- and 500-year floods and those areas outside those flood extents. NFIP-prepared maps are the minimum basis of state and local floodplain regulatory programs. FIRMs are part of the program to regulate development within the floodplain; in return, property owners are offered insurance protection against losses from flooding. Some communities base their regulations on a flood of record or a historically significant flood that exceeds the base flood shown on NFIP maps.

The FIRMs used by the authority having jurisdiction (AHJ) should be consulted during planning and site selection, site design, and architectural and engineering design (whether for the design of new buildings or the rehabilitation of existing buildings). Regardless of the flood hazard data required for regulatory purposes, additional research should be conducted on past major floods and other factors that could lead to more severe flooding, and hence impact the flood risk at a particular site.

2.1.4.1 The 100-year Flood

The recurrence interval of a flood is an expression of frequency based on probabilities. This could be defined as the likelihood that an event (in this case, a flood) of a certain magnitude will occur within a given period. The flooding event commonly referred to in the NFIP is the 100-year flood. This designation can be deceptive and give the impression that this type of event will occur only once every 100 years. When calculated, the 100-year flood has a 1 percent chance of occurring or being exceeded within a year. Due to this number being a percent-annual chance, it is possible that a comparable flood could occur at the same location during the next year, or could occur even multiple times during a single year. The laws of probability suggest that as time passes, the chance of one of these events occurring will increase, as shown in Figure 2-17. Note that during the 30-year life of a typical mortgage, there is a 26 percent chance of experiencing a base flood for buildings located in a floodplain.

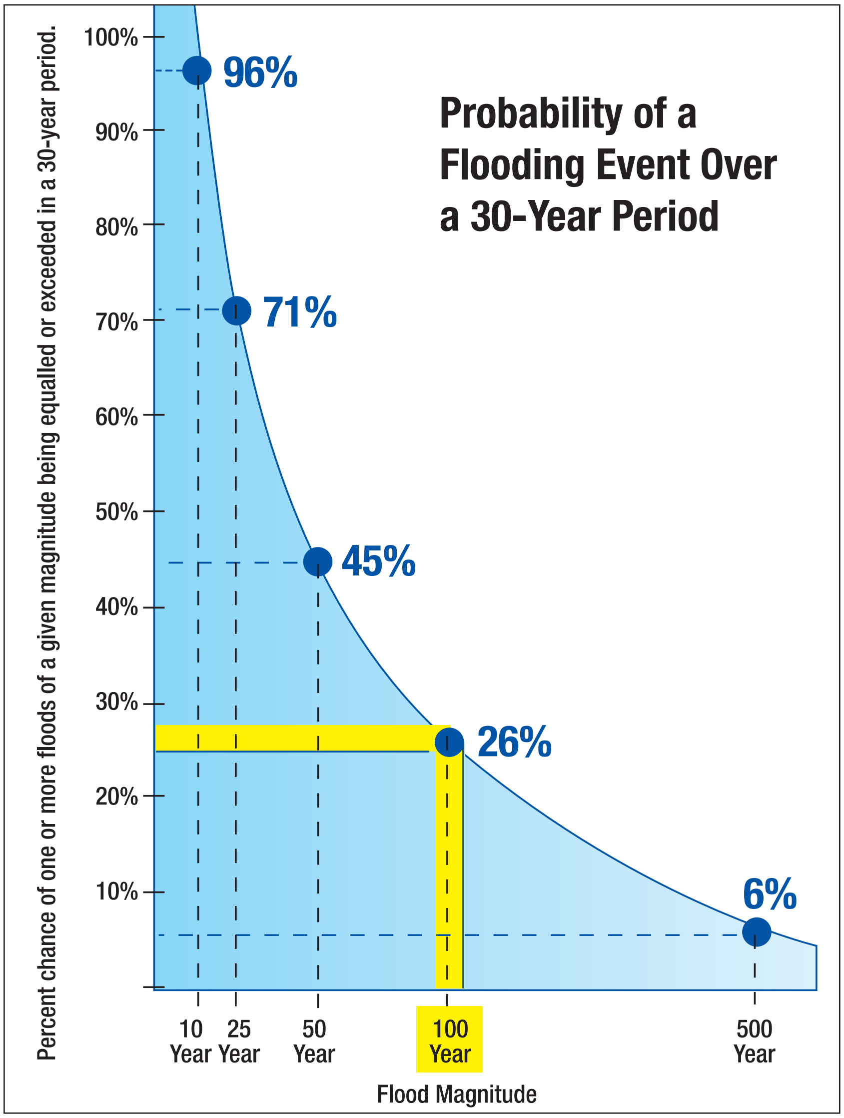


Figure 2-17.
Flood probability chart.
(Source: U.S. Geological Survey, Guidelines for Determining Flood Flow Frequency, Bulletin 17B (Appendix D)).

NOTE

Flood maps are available at the FEMA Map Store (http://www.fema.gov). For a fee, copies may be ordered online or by calling (800) 358-9616. The Flood Insurance Study (FIS) and engineering analysis used to determine the flood hazard area may be ordered through the FEMA Web site. This information can also be viewed online or downloaded.

NOTE

The assigned frequency of a flood (e.g., 100-year) is independent of the number of years between actual occurrences. Hurricane Camille hit the Mississippi coast in 1969 with storm surge flooding that far exceeded previous events, and Hurricane Katrina affected much of the same area. Although just 36 years apart, both storms produced flood levels significantly higher than the predicted “100-year flood.”

For coastal areas, both historical storms and simulated storm surge models can be used to predict the probability that floodwaters will rise to a certain level and be accompanied by waves of certain heights. Many coastal storms will produce storm surge flooding that, depending on local topography, may extend inland significantly farther than anticipated for the 100-year flood and may result in flood depths greater than the 100-year flood. Statistically, such extreme storm surges occur less frequently than the 100-year floods, but their consequences can be catastrophic.

Local officials should ensure that planners, designers, and builders understand the relationships between the flood levels for different frequency events and extreme events, especially in hurricane-prone communities. The difference in flood levels may be extreme in some situations, depending on local conditions and the source of flooding. In other areas, the lower probability flood depths may not be much higher than the 100-year flood.

The NFIP uses the 100-year flood as the basis for mapping flood hazards on regulatory maps, for setting insurance rates, and for applying regulations to minimize future flood damage (referred to on the flood maps as the BFE). The extent of the 100-year flood (or BFE) is given one of several designations or zones on the FIRM and collectively are referred to as SFHAs. The SFHAs show the extent of the anticipated 100-year flood while the individual zones provide specific or general information with regard to the expected elevation of flooding. The extent of the SFHA is also used as the standard for examination of older buildings to determine which measures to apply to reduce future damage.

2.1.4.2 Flood Maps

The NFIP produces FIRMs for more than 20,000 communities nationwide. The current effective maps are typically available for viewing in community planning or permit offices. It is important to use the most recent flood hazard map when determining site-specific flood hazard characteristics. Although many FIRMs are more than 15 years old, often one or more panels or portions of a map panel have been revised and republished. Communities must adopt revised maps to continue participating in the NFIP.

Some FIRMs do not show the 0.2-percent-annual-chance flood hazard area (500-year floodplain), and many FIRMs do not provide detailed information about predicted flood elevations along every body of water. When this information is not available, the Flood Insurance Study (FIS) produced to support the FIRMs (by community) should be used. If both the FIRM and FIS data are insufficient, additional statistical methods and engineering analyses may be needed to determine the floodprone areas and the appropriate characteristics of flooding required for site layout and building design.

WARNING

Flood Insurance Rate Maps are used for insurance rating purposes; they are not comprehensive tools to identify all hazards associated with floods and the probabilities of occurrence at a particular risk site.

NOTE

Some areas have adopted a Design Flood Elevation (DFE). This is additional elevation, known as freeboard, above the Base Flood Elevation to account for variables and changes to future flood maps. Buildings in these jurisdictions may need to be built to a DFE, which will exceed the 100-year flood elevation.

If a proposed building site or existing building is affected by flooding, a site-specific topographic survey is critical to delineate the land that is below the flood elevation used for planning purposes. If detailed flood elevation information is not available, a floodplain study may be required to identify the important flood characteristics and data required for sound design.

Having flood hazard areas delineated on a FIRM should not oversimplify the process of understanding the hazard. Flood maps have limitations that should be considered, especially during site selection and design. Some well-known limitations are identified below.

- Flood hazard areas are approximations based on probabilities; the flood elevations shown and the areas delineated should not be taken as absolutes, in part because they are based on numerical approximations of the real world.
- Especially for older maps, the topography used to delineate the flood boundary may have had contour intervals of 5, 10, or even 20 feet (versus 1 or 2 feet), which significantly affects the precision with which the boundary is determined. The actual elevation of the ground relative to the flood elevation is critical, as opposed to whether an area is shown as being in or out of the mapped flood hazard area.
- The scale of maps may impede precise determinations (many older maps are 1 inch = 2,000 feet).
- Flooding characteristics may have been altered by development, sometimes by local modifications that have altered the shape of the land surface of the floodplain (such as fills or levees).
- Local conditions are not reflected, especially conditions that change regularly, such as shoreline erosion.
- Areas exposed to very low probability flooding are not shown, such as flooding from extreme hurricane storm surges, extreme riverine flooding, dam failures, or overtopping (or failure) of levees.

While FIRMs consider storm-induced erosion associated with a single 100-year flood, they do not capture erosion potential at a site. They also do not consider the potential for waterborne debris or subsidence.

Regardless of their limitations, flood maps are valuable tools; however, additional data should be considered when evaluating the hazard. Evaluating hazards associated with flood maps is just one component of effectively mitigating the hazard posed by floodwaters.

NOTE

A Flood Insurance Study (FIS) is an examination, evaluation, and determination of flood hazards and, if appropriate, the corresponding water-surface elevations. This information is used to develop FIRMs.

Digital Flood Insurance Rate Maps (DFIRMs) are the current format in which FIRMs are being produced. This new digital format utilizes a geographic information system environment and will replace the existing manually produced FIRMs. This new format provides a more interactive format that will be associated with databases that will allow additional information to be accessed. This information will include the FIS data including the hydrologic and hydraulic models used to produce the study. Additional data such as benchmarks, structure related data and aerial photograph overlays will provide the user with more information in a more expeditious manner.

2.1.4.3 NFIP Flood Zones

NFIP-prepared FIRMs show different flood zones to delineate different floodplain characteristics (see Figure 2-18). The flood zones shown on the FIRMs, and some other designations, are described below. Figure 2-19 shows the relationships of flood zones to each other.

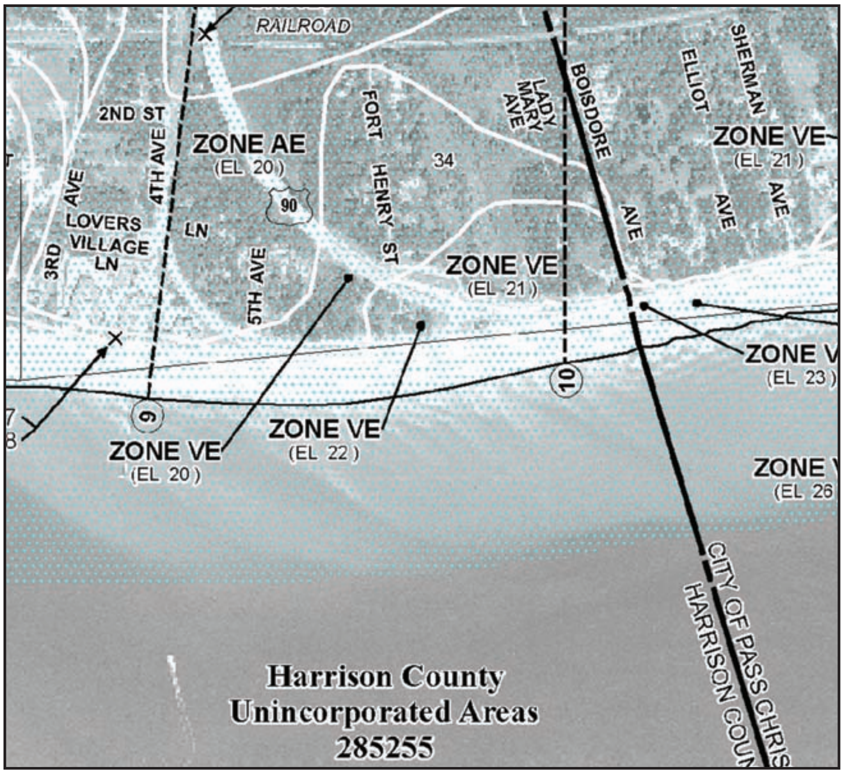


Figure 2-18.
Example of a Digital Flood Insurance Rate Map (DFIRM).

NOTE

Advisory Base Flood Elevations (ABFE) are sometimes developed after a specific event. These maps are based on surveyed high-water marks and inundation limits, but not the 500-year flood hazard area. Upon the issuance of a Recovery Advisory, these may be used in lieu of existing BFEs.

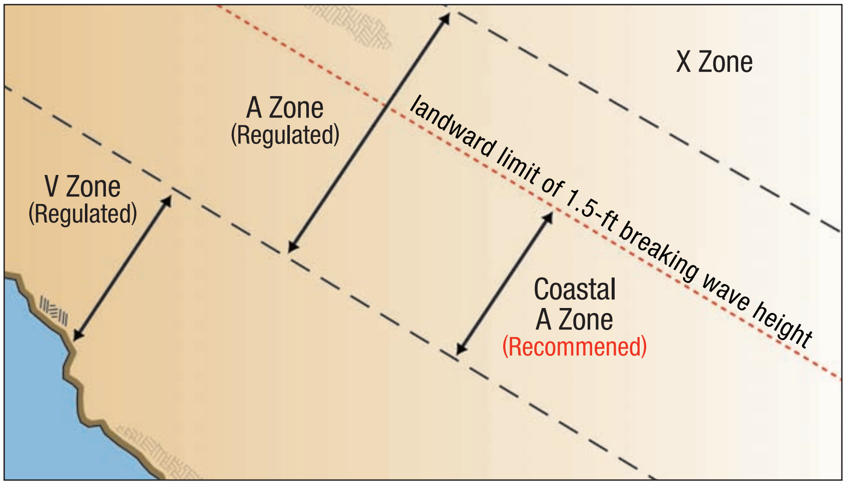


Figure 2-19.
Coastal flood hazard areas.

NOTE
Current editions of the building codes refer to ASCE 7-05 and ASCE 24-05; both design standards include requirements for Coastal A Zones (see Chapter 3 of this guide).

V Zones. Also known as coastal high-hazard areas, these SFHAs are subject to high-velocity wave action. V Zones are relatively narrow areas along open coastlines and some large lake shores that are subject to high-velocity wave action from storms or seismic sources. V Zones extend from offshore to the inland limit of a primary frontal dune or to an inland limit where the predicted height of breaking waves drops below 3 feet or a wave run-up depth of less than 3 feet.

VE and V1-V30. Also called numbered V Zones, these designations are used for SFHAs where engineering analyses have produced detailed flood elevations and boundaries for the base flood (1-percent-annual-chance flood). BFEs are provided.

A Zones. Also called unnumbered A Zones or approximate A Zones, this designation is used for SFHAs where engineering analyses have not been performed to develop detailed flood elevations. BFEs are not provided. Additional engineering analyses and site-specific assessments usually are required to determine the BFE.

AE Zones or A1-A30 Zones. Also called numbered A Zones, these designations are used for SFHAs where engineering analyses have produced detailed flood elevations and boundaries for the base flood (1-percent-annual-chance flood). BFEs are provided for riverine waterways within these zones. An FIS will include longitudinal profiles showing water surface elevations for different frequency flood events.

AO and AH Zones. These zones include areas of shallow flooding and are generally shown where the flood depth averages from 1 to 3 feet, a clearly defined channel does not exist, the path of flooding is unpredictable, and velocity flow may be evident. These zones are characterized by ponding or sheetflow. BFEs may be provided for AH Zones; flood depths may be specified in AO Zones. In coastal areas, AO Zones are most common on the landward side of dunes.

Coastal A Zones. These zones are not noted on FIRMs; however, they have been noted as being clearly defined zones where breaking waves are between 3 feet and 1.5 feet. The indication of the Limit of Moderate Wave Action (LiMWA) on many of the recent FIRMs is a good indication of the location of a Coastal A Zone. A LiMWA is the approximate landward limit of the 1.5 feet breaking wave. Because Coastal A Zones are not delineated on FIRMs, it is necessary to determine whether the required conditions are likely to occur at a site. The use of Coastal A Zones is either by local adoption or at the discretion of the AHJ.

Shaded X (or B) Zones. These zones show areas of the 500-year flood (0.2 percent-annual-chance flood) or areas protected by flood control levees. These zones are not shown on many NFIP maps; however, their absence does not imply that flooding of this frequency will not occur. With map modernization projects underway, the B Zone designation will not be used after 2010.

Unshaded X (or C) Zones. These zones are all land areas not mapped as flood hazard areas; they are outside of the floodplain that is designated for the purposes of regulating development pursuant to the NFIP. With map modernization projects underway, the C Zone designation will not be used after 2010.

Levee Certification. Special attention should be paid to the FIRM in areas with structures behind a levee. When reviewing areas behind levees, the status of the levee should be considered. The “Notes to Users” section on the FIRM explains the levee status at the time of map publication. Additional information on the levee certification process is in FEMA Procedure Memorandum No. 43, *Guidelines for Identifying Provisionally Accredited Levees.*

2.2 Wind Hazards: General Design Considerations

Even a well-designed, constructed, and maintained building may be damaged in a wind event stronger than the design wind speed. Most damage occurs because building elements have limited wind resistance due to inadequate design, poor installation, or material deterioration. Although the magnitude and frequency of strong windstorms vary by locale, all buildings should be designed, constructed, and maintained to minimize and resist wind damage.

Numerous examples of best practices pertaining to new and existing buildings are presented in this guide as recommended design and construction guidelines. Incorporating those practices applicable to specific projects will result in greater wind resistance reliability and will therefore decrease expenditures for repair of wind-damaged buildings and provide enhanced protection for occupants.

2.2.1 Primary Storm Types

A variety of windstorm events occurs in coastal areas of the United States. Characteristics of storm types that can affect the site should be considered by the designer. Primary storm types are described below.

Straight-line wind. This wind type is normally generated by thunderstorms. Straight-line wind intensities can be similar to those of a tornado. In contrast to a tornado, which produces winds in a rotating motion, straight-line winds push in one direction. High winds associated with intense low pressure can last for approximately a day at a given location. Although it is more common in some areas, straight-line winds can occur anywhere throughout the United States and its territories.[1]

Thunderstorm. Thunderstorms can form rapidly and produce high wind speeds. Approximately 10,000 severe thunderstorms occur in the United States each year, typically in the spring and summer, and they are most common in the Southeast and Midwest. In addition to producing high winds, they often create heavy rain and sometimes spawn tornadoes and hailstorms. Thunderstorms commonly move through an area rapidly, causing high winds for only a few minutes at a given location. They can also stall and become virtually stationary.

Downburst. Also known as a microburst, this is a powerful downdraft associated with a thunderstorm. When the downdraft reaches the ground, it spreads out horizontally and may form one or more horizontal vortex rings around the downdraft. The outflow is typically 6,000 to 12,000 feet across, and the vortex ring may rise 2,000 feet above the ground. The life cycle of a downburst is usually 15 to 20 minutes. Observations suggest that approximately 5 percent of all thunderstorms produce downbursts, which can result in significant damage in localized areas. It is not uncommon for the untrained observer to mistake downburst damage as tornado damage.

Nor'easter (northeaster). A nor'easter is a cyclonic storm occurring off the east coast of North America. These weather events (typically occurring in the winter season) are notorious for producing heavy snow, rain, high waves, and wind. A nor'easter gets its name from the continuously strong northeasterly winds blowing in from the ocean ahead of the storm and over the coastal areas. These storms may last for several days.

[1] U.S. territories include American Samoa, Guam, Northern Mariana Islands, Puerto Rico, and the U.S. Virgin Islands. ASCE 7-05 provides basic wind speed criteria for all but Northern Mariana Islands.

Tornado. Tornadoes are violently rotating columns of air extending from the base of a thunderstorm to the ground. Although the wind speed at a given building site might not be great, a building on the periphery could still be impacted by many large pieces of windborne debris. Tornadoes are responsible for the greatest number of the nation's wind-related deaths each year. However, tornado frequency, occurrence, and wind speeds **are not** considered by the wind maps of the IBC, IRC, and ASCE used to identify the basic (design) wind speed at a particular site.

Buildings that are well-designed, well-constructed, and well-maintained should have little if any damage from weak tornadoes, except for window breakage. However, weak tornadoes often cause building envelope damage because many buildings have inherent vulnerabilities to wind and windborne debris. Most buildings experience significant damage if they are in the path of a strong or violent tornado because they typically are not designed for this storm type. As of February 2007, tornadoes are now classified by the Enhanced Fujita Scale shown in Table 2-1.

NOTE

ASCE 7-05 defines "Special Wind Region" as an area where the basic wind speed shall be increased where records or experience indicate that the wind speeds are higher than normal. These regions consist of mountainous terrain, gorges, and other special topographic features.

Table 2-1. Enhanced Fujita Scale.

EF-SCALE	DAMAGE LEVEL	WIND SPEED (3-SEC GUST)	TYPE OF DAMAGE DONE
EF0	Light	65–85 mph	Peels surface off of some roofs; some damage to gutters or siding; branches broken off trees; shallow-rooted trees pushed over.
EF1	Moderate	86–110 mph	Roofs severely stripped; mobile homes overturned or badly damaged; loss of exterior doors; windows and other glass broken.
EF2	Considerable	111–135 mph	Roofs torn off well-constructed houses; foundations of frame homes shifted; mobile homes completely destroyed; large trees snapped or uprooted; light-object missiles generated; cars lifted off ground.
EF3	Severe	136–165 mph	Entire stories of well-constructed houses destroyed; severe damage to large buildings such as shopping malls; trains overturned; trees debarked; heavy cars lifted off the ground and thrown; structures with weak foundations blown away some distance.
EF4	Devastating	166–200 mph	Well-constructed houses and entire frame houses completely leveled; cars thrown and small missiles generated.
EF5	Incredible	>200 mph	Strong frame houses leveled off foundations and swept away; automobile-sized missiles fly through the air in excess of 100 yards; high-rise buildings have significant structural deformation; incredible phenomena occurs.

Source: National Oceanic and Atmospheric Administration

Hurricane. A hurricane is a system of spiraling winds converging with increasing speed toward the storm's center (the eye of the hurricane). Hurricanes form over warm ocean waters. The diameter of the storm varies from 50 miles to 600 miles. A hurricane's forward movement (translational speed) can vary between approximately 5 mph to more than 25 mph. Besides being capable of delivering extremely strong winds for several hours and moderately strong winds for a day or more, many hurricanes also bring heavy rainfall. Hurricanes can also spawn tornadoes.

Of all the storm types, hurricanes have the greatest potential for devastating a large geographical area and, hence, affecting the greatest number of people. The terms hurricane, cyclone, and typhoon describe the same type of storm. The term used depends on the region of the world where the storm occurs. Figure 2-20 shows hurricane-prone regions of the United States. Table 2-2 presents the Saffir-Simpson scale used to classify hurricane intensity. The table shows wind speeds for the different categories as both sustained winds and gust speeds. Hurricane frequency, occurrence, and wind speeds **are** considered by the IBC, IRC, and ASCE when producing wind maps that identify the basic (design) wind speed at a given site. Additional information is provided in Section 2.2.1.3.

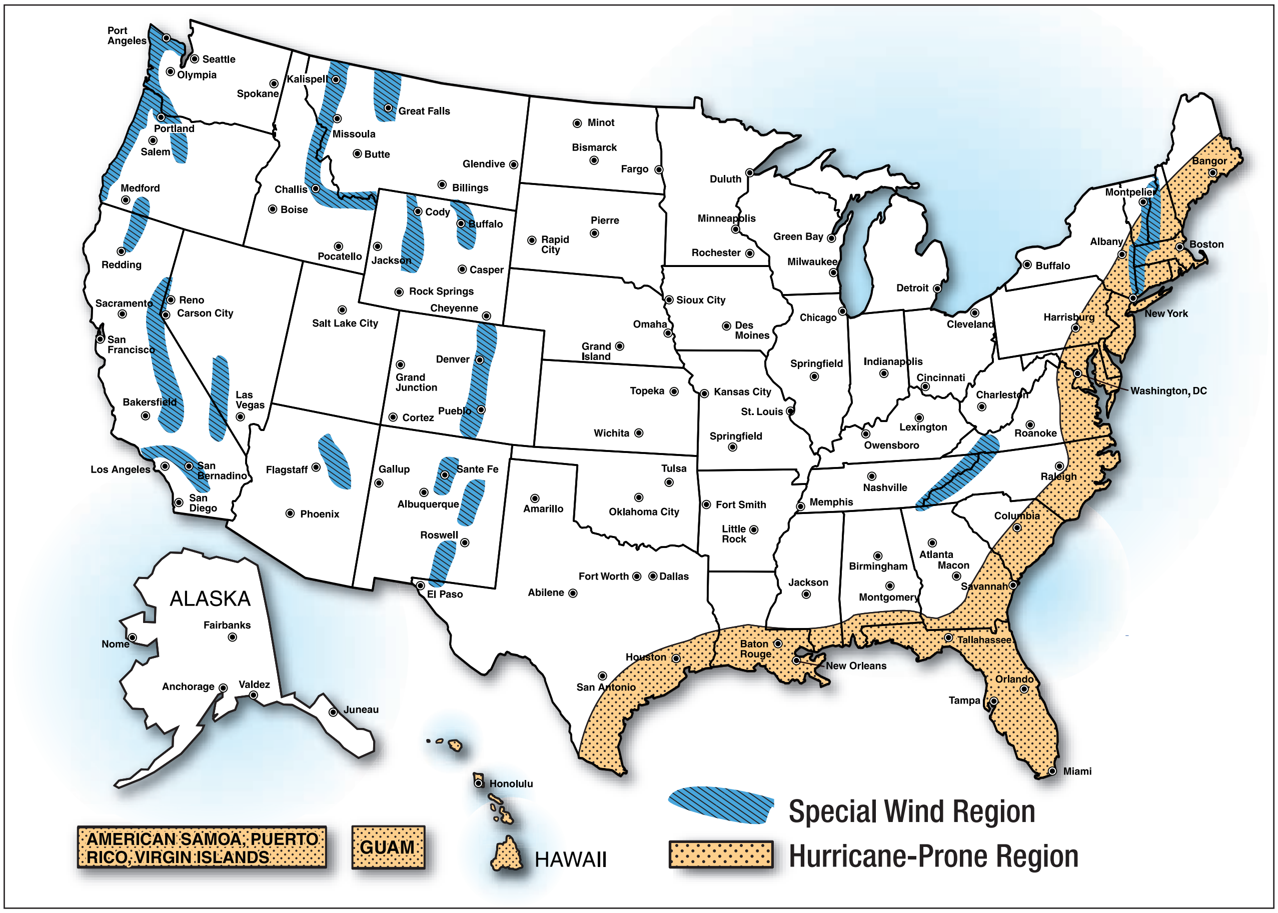


Figure 2-20.
Hurricane-prone regions and special wind regions. (Source: Adapted from ASCE 7-05)

Table 2-2. Saffir-Simpson Hurricane Scale

Strength	Sustained Wind Speed (mph) 1 minute sustained wind over water	Gust Wind Speed (mph) 3 second gust over open water	Gust Wind Speed (mph) 3 second gust over open ground	Pressure (millibar)	Description
Cat 1	74–95	91–116	82–108	>979	Storm surge 4 to 5 feet above normal; no real building damage; unanchored mobile homes damaged.
Cat 2	96–110	117–140	109–130	965–979	Storm surge 6 to 8 feet above normal; some roofing, door, and window damage; considerable damage to mobile homes.
Cat 3	111–130	141–165	131–156	945–964	Storm surge 9 to 12 feet above normal; some structural damage to small residences and utility buildings with minor curtain wall damage; mobile homes destroyed.
Cat 4	131–155	166–195	157–191	920–944	More extensive curtainwall failures with some complete roof structure failures on small residences; complete destruction of mobile homes.
Cat 5	>155	>195	>191	<920	Complete roof failure on many residences and industrial buildings; some complete building failures with small utility buildings blown over or away; complete destruction of mobile homes.

NOTE

The Saffir-Simpson Hurricane Scale categorizes hurricanes based on sustained wind speeds. Storm surge is not always correlated with the category because other factors influence surge elevations, notably forward speed of the storm, tide cycle, offshore bathymetry, and land topography.

2.2.1.1 Windborne Debris

During any large wind event heavy objects can become airborne. These objects pose significant hazards to the surrounding buildings. Design criteria in the current model building codes take these hazards into account by requiring protection systems for glazed openings developed to resist small (rocks, roofing material, and small branches) and large (trees, signs, and posts) impacts from windborne debris (commonly referred to as missiles). These objects typically impact all portions of a building and cause damage to doors, glazing, exterior siding, and roofs. Construction methods that do not account for missile impacts can result in a breach of the building envelope and subsequently cause additional damage to the structure due to wind loading. Protection of glazing from windborne debris impact is required based upon your proximity to the coast and the basic wind speed at a site. Additional information is provided in Chapter 10.

2.2.1.2 Rainfall Penetration

High winds impact buildings in many ways. In addition to loading from the wind and windborne debris, when they are coupled with rain events, significant water intrusion problems can occur. Portions of the building envelope that have been designed to shed rain may be compromised by wind-driven rain.

2.2.1.3 Wind/Building Interactions

When wind interacts with a building, both positive and negative pressures occur simultaneously (see Figure 2-21). To prevent wind-induced building failure, buildings must have sufficient strength to resist the applied loads from these pressures. Loads exerted on the building envelope are transferred to the structural system, where they in turn must be transferred through the foundation into the ground, or building damage may result. Chapter 5 of this guide has a detailed discussion of load paths and the importance of load path continuity. The magnitude of the pressure is a function of several primary factors: exposure, basic wind speed, topography, building height, building shape, and internal pressure classification.

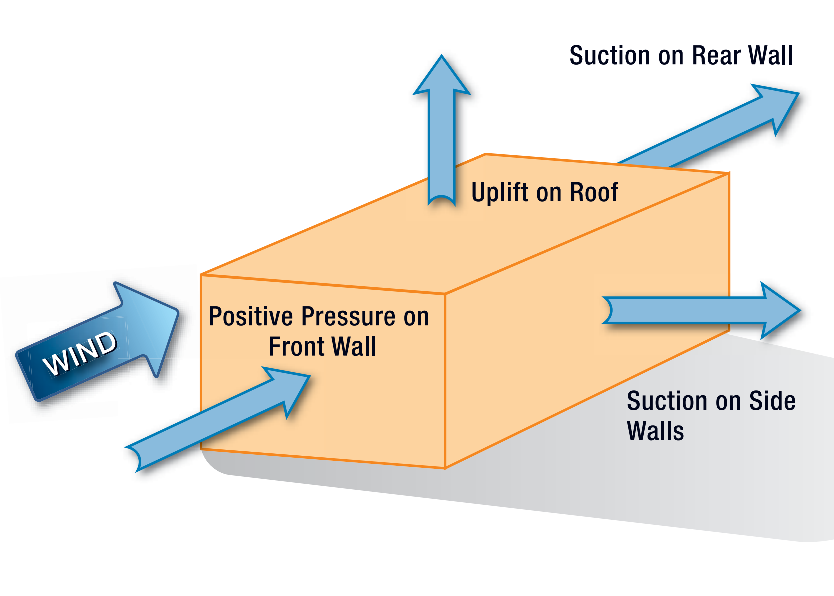


Figure 2-21.
Wind-induced pressures on a building. (Source: FEMA 543)

NOTE

For information on exposure, see ASCE 7-05, Chapter 6 Commentary, which includes aerial photographs of the different terrain conditions associated with Exposures B, C, and D.

Basic wind speed. ASCE 7-05 specifies the basic (design) wind speed for determining design wind loads at a building site. The basic wind speed is mapped for the continental U.S. and provided for other islands and U.S. territories at 33 feet above grade in Exposure C (flat open terrain). If a building is located in an Exposure B or D area, rather than a C area, an adjustment for the actual exposure is made in the ASCE 7-05 calculation procedure when wind pressures are calculated.

Since the 1995 edition of ASCE 7, the basic wind speed measurement has been a 3-second gust speed. Before 1995, the basic wind speed was a fastest-mile speed (i.e., the speed averaged over the time required for a mile-long column of air to pass a fixed point)[2]. Most of the United States has a basic wind speed of 90 mph[3], but much higher speeds occur in Alaska and in hurricane-prone regions. The highest basic wind speed specified on the ASCE 7-05 map—170 mph—is in Guam. Hurricane-prone regions are defined in ASCE 7-05 to be the Atlantic and Gulf coastal areas where the basic wind speed is greater than 90 mph, Hawaii, and the U.S. territories in the Caribbean and South Pacific (see Figure 2-20).

Basic Wind Speed. The design values used to begin the wind load calculations using ASCE 7-05. This wind speed value is measured at a height of 33 feet (10 meters) above grade and for an Exposure C. ASCE 7-05 requires that the building be designed to sustain this basic wind speed from any direction.

3-second gust. The measurement of wind speed averaged over a 3 second period. The short duration of the average is why it is referred to as a gust.

Fastest mile. The average speed for a 1-mile-long column of air to pass an anemometer. (Now an obsolete term and no longer used by the National Weather Service.)

The Saffir-Simpson Hurricane Scale (Table 2-2) measures sustained winds that are averaged over 1 minute. Therefore, these wind speeds are not equivalent to fastest mile or 3-second gust wind speeds used by the codes. The measurements are taken over open water. To convert this information into a 3-second gust, a conversion must be made to the sustained winds over land and then further converted to the 3-second gust using the Durst curve (see ASCE 7-05). ASCE 7-05, Commentary C6, explains the conversion of sustained wind over water to sustained wind over land.

In the formulas used to determine wind pressures, the basic wind speed is squared. Therefore, as the wind speed increases, the pressures acting on a building are exponentially increased, as shown in Figure 2-22. Figure 2-22 also illustrates the relative difference in pressures exerted on the Main Wind Force Resisting System (MWFRS) and the components and cladding (C&C) elements of buildings. Higher winds can produce vortices creating very high local pressures on C&C. These pressures on roofing, roof sheathing and sidings are localized and much greater than that on the main framing members. Drawings should provide specific detailing and fastening of roofing, roof sheathing, and siding in these areas.

Exposure. Terrain characteristics (i.e., ground roughness and surface irregularities in the vicinity of a building) influence wind loading. ASCE 7-05 defines three exposure categories: Exposures B, C, and D, with Exposure B being the roughest terrain category and Exposure D being the smoothest.

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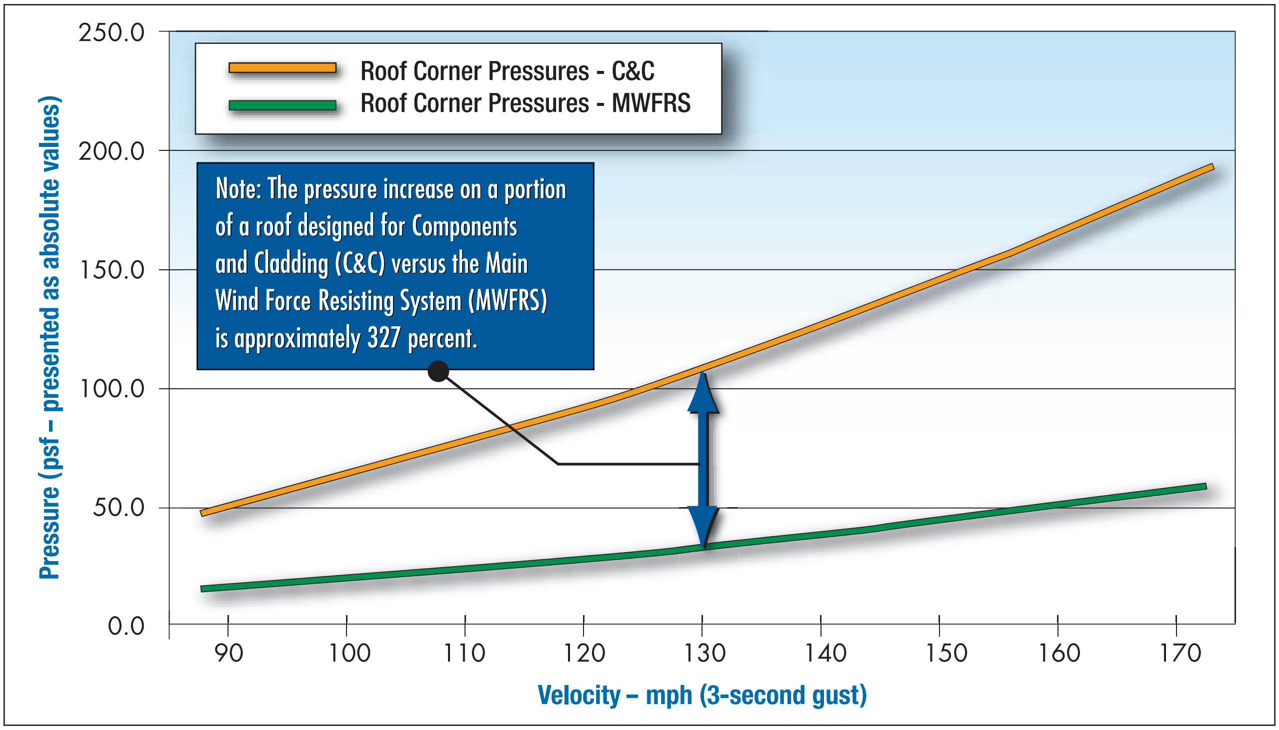
[2] Gust speeds are about 15 mph to 20 mph higher than fastest-mile speeds (e.g., a 90 mph peak basic wind speed is equivalent to a 76 mph fastest-mile wind speed). International Building Code, Chapter 16, has a table of equivalent basic wind speeds.

[3] Unless otherwise noted, wind speeds in this guide are presented as 3-second gust wind speeds with exposure C at 33 feet above grade.



Note: The pressure increase on a portion of a roof designed for Components and Cladding (C&C) versus the Main Wind Force Resisting System (MWFRS) is approximately 327 percent.

Figure 2-22.
Wind pressure as a function of wind speed. (Source: FEMA 543)

Exposure B includes urban, suburban, and wooded areas. Exposure C includes flat, open terrain with scattered obstructions and areas adjacent to water surfaces in hurricane-prone regions (which are defined above under "basic wind speed"). Exposure D includes areas adjacent to water surfaces outside hurricane-prone regions, mud flats, salt flats, and unbroken ice. Because of the wave conditions generated by hurricanes, areas adjacent to water surfaces in hurricane-prone regions are considered to be Exposure C rather than the smoother Exposure D. The smoother the terrain, the greater the wind pressure; therefore, buildings in Exposure C areas would receive higher wind loads than those in Exposure B areas, at the same basic wind speed.

Topography. Abrupt changes in topography, such as isolated hills, ridges, and escarpments, cause wind to speed up. A building located near a ridge would receive higher wind pressures than a building located on relatively flat land; in some cases, the wind pressures may be twice those on flat areas. ASCE 7-05 has a procedure to account for topographic influences.

Building height. Wind speed at a particular site increases with height above ground. Taller buildings are exposed to higher wind speeds and greater wind pressures. ASCE 7-05 contains a procedure to account for building height during the calculation of wind pressures.

For buildings of lower heights (such as those found in coastal areas), elevating or raising the building to account for flood hazards will increase the wind pressures acting on the building. However, this increase is relatively small. Tables 2-3 and 2-4 provide wind pressure information for five locations on a hypothetical building located on a site with a basic wind speed of 120 mph. The wind pressures were determined using the prescriptive tables from ASCE 7-05 for low-rise buildings (ASCE 7-05, Figures 6-2 and 6-3).

Table 2-3. Wind Pressure Example for Exposure B

Mean roof height	**MWFRS**		**C&C**		
above grade in Exp B	Wall	Roof	Wall Zone 5	Roof Zone 1	Roof Zone 3
(feet)	(psf)*	(psf)	(psf)	(psf)	(psf)
15	21.10	-19.10	-34.70	-23.70	-61.00
20	21.10	-19.10	-34.70	-23.70	-61.00
25	21.10	-19.10	-34.70	-23.70	-61.00
30	21.10	-19.10	-34.70	-23.70	-61.00
35	22.16	-20.06	-36.44	-24.89	-64.05
40	23.00	-20.82	-37.82	-25.83	-66.49
45	23.63	-21.39	-38.64	-26.54	-68.32

Table Notes (applicable for each table)
1. Wind pressures calculated for a square building, approximately 20 ft by 20 ft
2. Roof slope = 20 degrees (assumed)
3. Effective wind area = 10 sf (for C&C wind pressures)
4. The highest elevation provided is for a mean roof height of 45 feet above grade. The tables were ended at this height as that is a common zoning limit used for the height of residential structures in coastal areas.
* (psf) pounds per square foot

Specifically, for homes sited where the terrain surrounding the building is considered Exposure B (see ASCE 7-05), Table 2-3 shows there is no change to the wind pressures if the mean roof height is increased from an elevation 15 feet above ground to 30 feet above ground. In general, as the building height increases in any 5-foot increment (from 30 feet to 35 feet, from 35 feet to 40 feet, or from 40 feet to 45 feet), the increase in pressures is approximately 5 percent. If the elevation increase was a change of 10 feet, the increase in pressures is approximately 8 percent, while an increase in 30 feet would result in a change in pressures of approximately 10 percent. Considering that even the largest pressure increase associated with a 30-foot elevation change results only in an increase of 7 psf, the impact to the building design and cost would be minimal for connectors or members to withstand these new wind pressures.

Similarly, Table 2-4 provides the same comparison for a building sited in Exposure C. The primary difference is that wind pressures will begin to increase as the mean roof height is increased from 15 feet to 20 feet (approximately 6 percent). However, after this initial increase, the increase in pressures for elevation changes of 5 feet and 10 feet are less than those in Table 2-3 for Exposure B conditions, approximately 3.5 percent and 6 percent, respectively. Although the total increase in wind pressure for some building components may increase 20 percent if the building elevation is increased 30 feet, this is not a probable scenario. In most cases, the building may be elevated 10 or 15 feet higher than it was originally constructed. The increase in wind pressures from 15 to 30 feet above grade would only be 13.5 percent. Again, as connectors and large members would be required to carry the loads for the basic wind speed at the site, an increase in pressure of 5 to 12 psf for select building components would have minimal impact on the building design or cost because connectors and other fasteners would have been required for the building at this site regardless of height.

These tables also highlight the differences between wind loads in Exposure B and C areas. If a site is improperly classified as Exposure B, the building may be underdesigned by as much as 30 to 40 percent (based on comparative C&C loads.)

Table 2-4. Wind Pressure Example for Exposure C

Mean roof height	**MWFRS**		**C&C**		
above grade in Exp C	Wall	Roof	Wall Zone 5	Roof Zone 1	Roof Zone 3
(feet)	(psf)*	(psf)	(psf)	(psf)	(psf)
15	25.53	-23.11	-41.90	-28.68	-73.81
20	27.22	-24.64	-44.76	-30.57	-78.69
25	28.49	-25.79	-46.85	-32.00	-82.35
30	29.54	-26.74	-48.58	-33.18	-85.40
35	30.60	-27.70	-50.32	-34.37	-88.45
40	31.44	-28.46	-51.70	-35.31	-90.80
45	32.28	-29.22	-53.09	-36.26	-93.33

Table Notes (applicable for each table)
1. Wind pressures calculated for a square building, approximately 20 ft by 20 ft
2. Roof slope = 20 degrees (assumed)
3. Effective wind area = 10 sf (for C&C wind pressures)
4. The highest elevation provided is for a mean roof height of 45 feet above grade. The tables were ended at this height as that is a common zoning limit used for the height of residential structures in coastal areas.
* (psf) pounds per square foot

Building shape. As wind flows over and around a building, the resultant pressures acting on it are a function of the building shape and its orientation to the wind. Exterior walls typically have lower loads than the roof. The ends (edges) of walls have higher suction loads than the portion of wall between the ends. However, when the wall is loaded with positive pressure, the entire wall is uniformly loaded. Figure 2-23 shows these aerodynamic influences. The negative values shown on Figure 2-24 indicate suction pressure acting upward from the roof surface and outward from the wall surface. Positive values indicate positive pressure acting inward on the wall surface. Positive coefficients represent a positive (inward acting) pressure, and negative coefficients represent negative (outward acting [suction]) pressure. Building irregularities, such as entryways, corners, bay window projections, stair towers projecting from main walls, dormers, and chimneys can all cause localized turbulence. Turbulence causes wind to speed up, which increases the wind loads in the vicinity of the building irregularity. Simply stated, it can be assumed that at locations where building geometry changes, pressures will increase. These areas may include wall corners, roof edges, corners, and overhangs.

Internal pressure (building pressurization/depressurization). The building portion that keeps the elements away from building occupants is typically referred to as the building envelope. Openings through the building envelope, in combination with wind interacting with a building, can cause either an increase in the pressure within the building (i.e., positive internal pressure) or a decrease in the pressure (i.e., negative internal pressure). Gaps or disconnects in the building envelope typically occur around openings such as doors and window frames, and by air infiltration through walls that are not completely airtight. A door or window left open, or glazing that is broken during a storm, can greatly influence the magnitude of the internal pressure and may expose the building to wind forces it was not designed to resist.

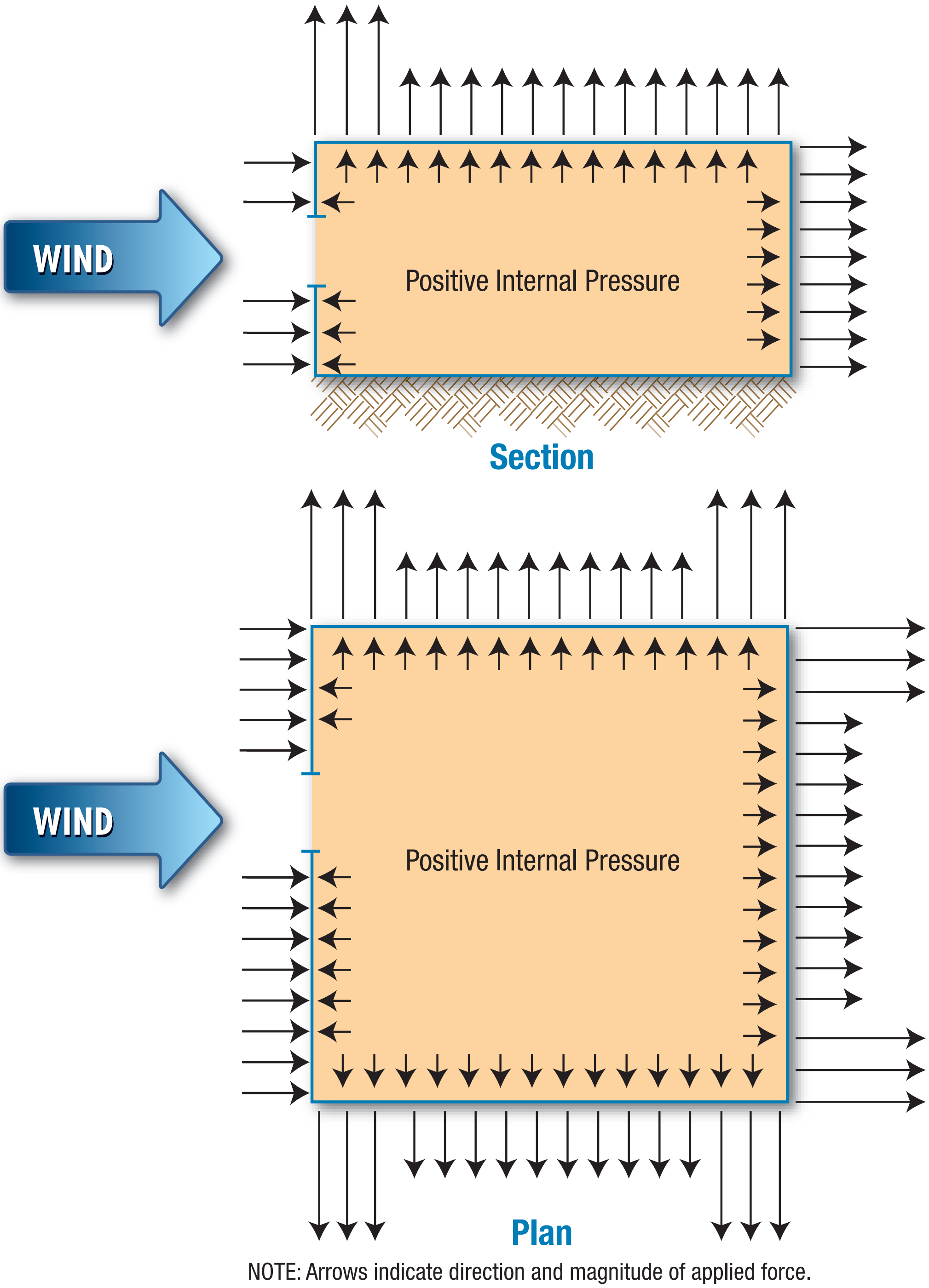
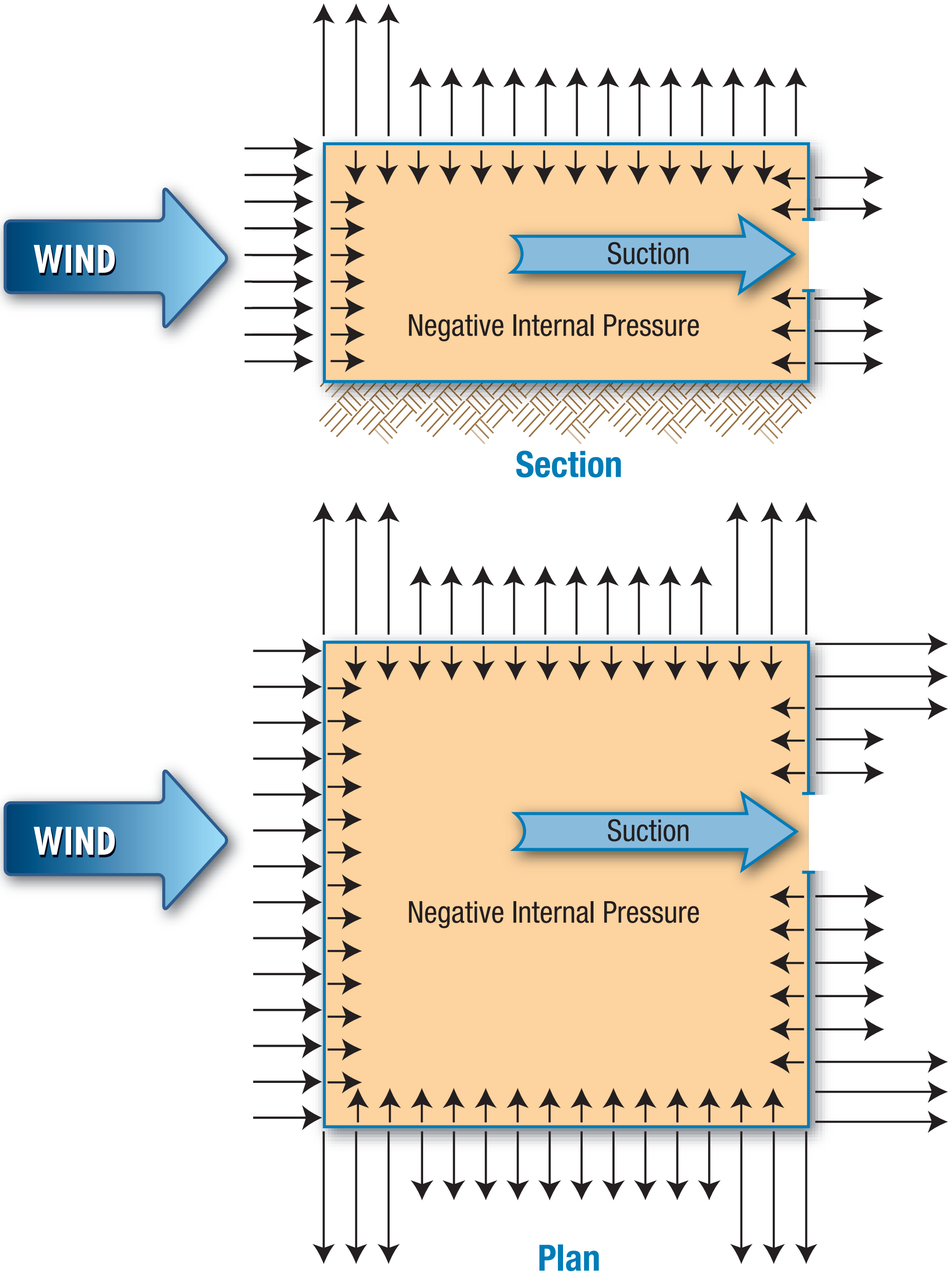


Figure 2-23.
Internal pressure condition when the dominant opening is in the windward wall. (Source: FEMA 543)



NOTE: Arrows indicate direction and magnitude of applied force.

Figure 2-24.
Internal pressure condition when the dominant opening is in the leeward wall. (Source: FEMA 543)

Wind striking exterior walls exerts a positive pressure on the wall, which forces air through unprotected openings and into the interior of the building. At the same time that the windward wall is receiving positive pressure, the side and rear walls are experiencing negative (suction) pressure from winds moving around the building. This is in part due to the lack of high-pressure air on the outside of the rear wall. As more air is forced into the building through the unprotected openings, the building begins to bulge or become pressurized. The building will continue to pressurize as the air finds areas of lower pressure and escapes on the rear (leeward) side of the building. Unprotected openings can be breached on the leeward side (opposite the wind) of buildings due to negative pressure (suction). This can cause the opposite effect, and a structure may collapse due to a lack of internal air pressure.

When a building is pressurized, the internal pressure pushes up on the roof. This push from below the roof is combined with suction on the roof from above, resulting in an increased upward wind pressure on the roof. The internal pressure also pushes on the side and rear walls. This outward push is combined with the suction on the exterior side of these walls (see Figures 2-25 and 2-26). The breaching of a small window can be sufficient to cause full pressurization of the facility's interior. When a building becomes fully pressurized (e.g., due to window breakage or soffit failure), the loads applied to the exterior walls and roof are significantly increased. The rapid build up of internal pressure can also blow down interior partitions and blow suspended ceiling panels out of their supporting grid.

When a building is depressurized, the internal pressure pulls the roof down, thus reducing the uplift exerted on the roof. The decreased internal pressure also pulls inward on the windward wall, which increases the wind loading on that wall.

The ASCE 7-05 wind design procedure accounts for the influence of internal pressure on the wall and roof loads, and it provides positive and negative internal pressure coefficients for use in load calculations. Buildings that are designed to accommodate full pressurization are referred to as partially enclosed buildings. According to the criteria in ASCE 7-05, the presence of openings (doors, windows, and vents) on exterior walls and surfaces of the building determine whether a building can be considered enclosed, partially enclosed or open. Once the appropriate designation has been selected, the building is designed for the pressures associated with the designation. Typically, buildings that are intended to experience only limited internal pressurization are referred to as enclosed buildings. Buildings that do not experience internal pressurization are referred to as open buildings (such as covered walkways and most parking garages). It should be noted, that the 2006 IBC and IRC limit the use of partially enclosed buildings without opening protection in hurricane-prone regions.

Figure 2-25.
OCEAN SPRINGS, MISSISSIPPI: Apartment complex severely damaged by wind. Although wind speeds were less than current code-specified values, widespread severe damage occurred at this development, a result of poor construction quality. (Source: FEMA 549)

Figure 2-26.
GULF SHORES, ALABAMA: Partition walls destroyed by interior pressurization due to window damage. (Source: FEMA 489)

2.3 Other Hazards

NOTE

Additional information on publications from the National Earthquake Hazard Reduction Program (NEHRP) publications are available at http://www.fema.gov/plan/prevent/index.shtm

During any storm event there exists the potential for other types of hazards. These hazards can be caused either by the storm event or be totally independent of it. In either case, their potential impacts should be considered in the design of the structure.

Earthquake and seismic events. Seismic events can occur on both the west and east coasts. Such events can cause liquefaction (soil failures), surface fault ruptures, slope failures, or spur tsunamis. Local officials in coastal areas with potential for seismic events should consider these possibilities when reviewing building plans. While most building officials in seismic areas are aware of the building considerations necessary, coastal areas present particular challenges. The need to elevate buildings to prevent waves and infiltration from floodwaters and damage from floodborne debris adds challenges to stabilize them from the movement induced by an earthquake. Model building codes and guidance from FEMA through the National Earthquake Hazard Reduction Program (NEHRP) provide code requirements and best practices in regions with seismic activity. Additional guidance on the design of residential buildings in seismic areas is provided in FEMA 232, *Homebuilders' Guide to Earthquake-Resistant Design and Construction.*

Tsunamis. Long-period water waves generated by undersea shallow-focus earthquakes or by tectonic plate movements, landslides, or volcanic activity are referred to as tsunamis. Tsunamis can travel great distances in deep water and can grow quite large when they reach shallow coastal areas. Designing for or resisting wave loads for tsunamis may be difficult and expensive.

Indoor air quality. After a storm event, mold can grow quickly and present major human health hazards. Mold and mildew are present everywhere but need excessive moisture and a food source to become problematic. Long-term power outages after storms and a lack of airflow from non-operating HVAC systems prevent moist areas inside houses from drying out. The possibility for mold propagation should be considered as a potential hazard when residential structures are rebuilt after storm events. If mold is suspected, air quality experts should be contacted to ensure that proper mitigation techniques are used. Information is available at http://www.epa.gov/mold/moldresources.html. Additional information can be found in FEMA 549, *Mitigation Assessment Team Report: Hurricane Katrina in the Gulf Coast, Building Performance Observations, Recommendations, and Technical Guidance.*

Levee failure. The United States has thousands of miles of levees. Levees can fail in three ways: a breach or break in the levee, water seeping underneath the levee and erupting on the other side (called a boil), and overtopping or floodwaters exceeding the height of the levee. Each of these failures is usually triggered by excessive rains or storm surges. Residential structures protected by levees should be evaluated for their susceptibility to levee failure because most areas have been mapped (to show flood zones), assuming the levees remain intact and functional. Levee failures can often be worse than standard storm surge or rain flooding due to the water being trapped or contained. An example of the devastating effects of levee failure is shown in Figure 2-27.

Figure 2-27.
NEW ORLEANS, LOUISIANA: Neighborhood with homes flooded and cars covered. In the background is a breached levee with water entering the area. (Source: FEMA 549)