UNIT VI: IDENTIFYING HAZARDS (PART I)

IDENTIFYING HAZARDS (PART I)

INTRODUCTION

In coastal areas, proper siting and design require an accurate assessment of the vulnerability of any proposed structure. That assessment must include the nature and extent of coastal hazards. Failure to properly identify and design against coastal hazards can lead to severe consequences—most often building damage or destruction.

This unit is the first of two units presenting a broad array of information on hazard identification. In this unit, you will learn about:

- **Hazard-producing events** that strike coastal areas, including tropical cyclones, coastal storms, and tsunamis.
- **Natural hazards** that affect coastal residential buildings and building sites, including:
    - Coastal flooding.
    - High winds.

  In the next unit, you will learn more about natural hazards, including:
    - Erosion.
    - Earthquakes.
    - Other hazards.

  The next unit will also present information about coastal hazard zones and procedures for translating hazard information into practice.

UNIT OBJECTIVES

After completing this unit, you should be able to:

6.1 Identify hazard-producing events and their potential effects on U.S. coastal areas.
6.2 Describe the potential effects of coastal flooding on coastal residential structures.
6.3 Describe the potential effects of high winds on coastal residential structures.

NATURAL HAZARDS AFFECTING COASTAL AREAS

To assess the risk associated with building in a given coastal area, we must understand the types of hazards that may impact coastal areas and the effects these hazards may produce.

The most significant natural hazards that affect the coastlines of the United States and its territories can be divided into five general categories:

- Coastal flooding.
- High winds.
- Erosion.
- Earthquakes.
- Other hazards.

Before we discuss each of these natural hazards, let's begin with a brief look at three types of events that are significant sources of several of these hazards:

- Tropical cyclones.
- Other coastal storms.
- Tsunamis.

TROPICAL CYCLONES AND COASTAL STORMS

Tropical cyclones and coastal storms include all storms associated with circulation around an area of atmospheric low pressure. When the storm origin is **tropical** in nature and when the **circulation is closed**, tropical storms, hurricanes, or typhoons result.

Tropical cyclones and coastal storms are capable of generating a wide array of effects (see Fig. 6-1):

- High winds.
- Coastal flooding.
- High-velocity flows.
- Damaging waves.
- Significant erosion.
- Intense rainfall.
- Large quantities of waterborne sediments and floating debris.

Consequently, the risk to improperly sited, designed, or constructed coastal buildings can be great.

Figure 6-1. Hurricane Frederic (1979). Storm surge and waves overtopping a coastal barrier island in Alabama.

Classification

Tropical storms have sustained winds averaging 39–74 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).

- Hurricanes are divided into five classes according to the Saffir-Simpson hurricane scale (see Table 6.1), which uses wind speed and central pressure as the principal parameters to categorize storm damage potential.

- Typhoons are divided into two categories: ***typhoons*** (sustained winds less than 150 mph) and ***super typhoons*** (sustained winds 150 mph or greater).

NOTE

One parameter that is not taken into account in these storm classifications—**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 effects of the storm are magnified by the higher water levels upon which they are added.

Table 6.1 Saffir-Simpson Hurricane Scale

Scale Number (Category)	Central Pressure (in) [mb]	Wind Speed (mph) Sustained & (3-sec Gust)	Surge Height (ft)	Property Damage	Recent Examples
1	≥ 28.94 [≥980]	74 – 95 (93 – 119)	4 – 5	**Minimal**	**Agnes** (1972 – FL; NE U.S.) **Juan** (1985 – LA) **Earl** (1998 – FL)
2	28.49 – 28.93 [965 – 979]	96 – 110 (120 – 138)	6 – 8	**Moderate**	**Bob** (1991 – MA) **Marilyn** (1995 – U.S. Virgin Is.)
3	27.90 – 28.48 [945 – 964]	111 – 130 (139 – 163)	9 – 12	**Extensive**	**Frederic** (1979 – AL) **Alicia** (1983 – TX) **Fran** (1996 – NC)
4	27.17 – 27.89 [920 – 944]	131 – 155 (164 – 194)	13 – 18	**Extreme**	**Hugo** (1989 – SC) **Andrew** (1992 – FL)
5	< 27.17 [< 920]	>155 (> 194)	> 18	**Catastrophic**	**FL Keys** (1935) **Camille** (1969 – MS)

NOTE

The Saffir-Simpson scale is a generalization, and **classification of actual storms may be inconsistent.** For example, the classification of a hurricane based on wind speed may differ from the classification based on storm surge or central pressure.

Tropical Cyclone Landfall

Approximately one in four named storms (tropical storms and hurricanes) in the North Atlantic basin makes landfall along the Atlantic or Gulf of Mexico coast of the United States (approximately 2.6 landfalling storms per year).

However, landfalls are not evenly distributed on a geographic basis. In fact, there is a wide variation in the incidence of landfalls—as illustrated in Figure 6-2. The figure shows the total number of direct and indirect impacts of landfalling hurricanes between 1900 and 1994. (Generally speaking, a ***direct impact*** occurs when the eye makes landfall in the county of interest, and an ***indirect impact*** occurs when the eye makes landfall in an adjacent county.)

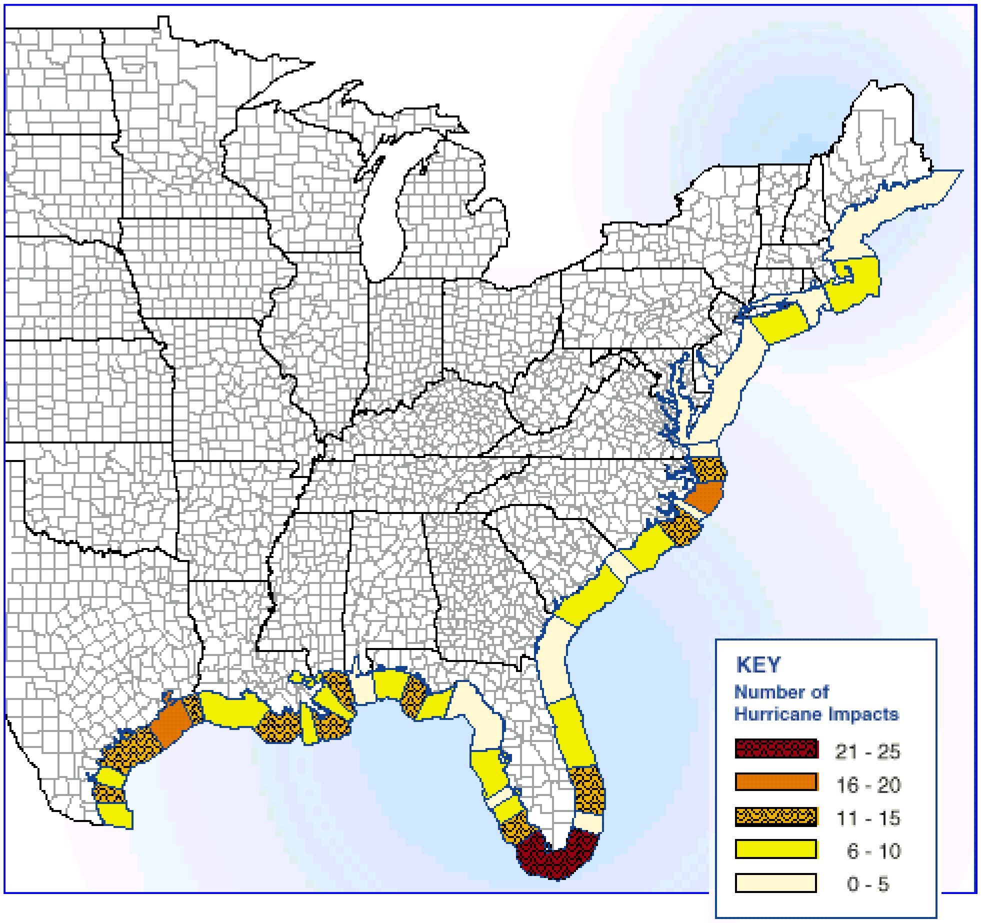


Figure 6-2. Landfalling Hurricanes. Total number of direct and indirect impacts by landfalling hurricanes for coastal counties from Texas to Maine, 1900–1994.

Mean Return Period

Table 6.2 shows the ***mean return period***—the average time (in years) between landfall or nearby passage of a tropical storm or hurricane.

Over short periods of time, the actual number and timing of tropical cyclone passage or 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 feel the effects of a tropical cyclone for years or decades, and then be affected by several storms in a single year.

Table 6.2. Mean Return Periods for Landfall or Nearby Passage of Tropical Cyclones

Mean Return Period (years)			
Area	**Passage of All Tropical Cyclones Within 50 Miles[a]**	**Landfall of All Hurricanes (Category 1–5)[b]**	**Landfall of All Major Hurricanes (Category 3–5)[b]**
U.S. (Texas to Maine)	–	0.6	1.5
Texas	1.4	2.7	6.5
South	–	7.5	16
Central	–	16	49
North	–	5.7	14
Louisiana	1.6	39	8.1
Mississippi	2.7	12	16
Alabama	2.7	9.7	19
Florida	0.8	1.7	4.0
Northwest	–	4.0	14
Southwest	–	5.4	11
Southeast	–	3.7	8.8
Northeast	–	11	#
Georgia	2.0	19	#
South Carolina	2.3	6.9	24
North Carolina	1.7	3.9	8.8
Virginia	4.0	24	97
Maryland	4.2	97	#
Delaware	4.7	#	#
New Jersey	4.7	97	#
New York	3.7	11	19
Connecticut	4.2	19	32
Rhode Island	4.2	19	32
Massachusetts	3.7	16	49
New Hampshire	7.8	49	#
Maine	7.2	19	#
Virgin Islands[a]	2.0	~	~
Puerto Rico[a]	2.4	8	~
Hawaii[a]	7.1	~	~
Guam[a]	1.0	~	~

[a] Based on National Weather Service (NWS) data for period 1899–1992, from FEMA Hurricane Program, 1994.

[b] For period 1900–1996, from National Oceanic Atmospheric Administration (NOAA) Technical Memorandum NWS TPC-1, February 1997.

– No intrastate breakdown by FEMA Hurricane Program.

Number not computed (no storms of specified intensity made landfall during 1900–1996).

~ Island; landfall statistics alone may understate hazard.

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 Pacific coast, the Great Lakes coast, the Gulf of Mexico coast, or the Atlantic coast. Along the Atlantic coast, these storms are known as ***extratropical storms*** or ***northeasters***.

Classification

Table 6.3 presents a classification scheme for northeasters, based on storm characteristics and typical damage to beaches, dunes, and property.

Table 6.3 Classification for Northeasters

Storm Class	Storm Description	Storm Duration	Storm Impacts on Beaches and Dunes	Property Damage
1	**Weak**	1 tidal cycle	Minor beach erosion	Little or none
2	**Moderate**	2 to 3 tidal cycles	Moderate beach erosion; dune scarping begins; minor flooding and shallow overwash in low areas, especially street ends	Undermining of seaward ends of dune walkovers; undermining of slab foundations on or near the active beach; some damage to erosion-control structures
3	**Significant**	3 to 4 tidal cycles	Significant beach erosion; dune scarping with complete loss of small dunes; increased depth of flooding and overwash in low areas	Widespread damage to dune walkovers and boardwalks; increased damage to erosion-control structures; undermining of beachfront slab foundations and shallow post or pile foundations; burial of roads and inland property by overwash
4	**Severe**	4 to 5 tidal cycles	Severe beach erosion and dune scarping; widespread dune breaching in vulnerable areas; coalescing of overwash fans; occasional inlet formation	Damage to poorly sited, elevated, or constructed coastal buildings is common; frequent damage to erosion-control structures; floodborne debris loads increase; overwash burial depths increase
5	**Extreme**	> 5 tidal cycles	Widespread and severe beach and dune loss; widespread flooding of low-lying areas; massive overwash; inlet formation is common	Widespread damage to buildings with inadequate elevations or foundations, and to buildings with inadequate setbacks from the shoreline or inlets; widespread damage to low-lying roads and infrastructure

Pacific Coast

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 Nino Southern Oscillation (ENSO)—a climatic anomaly resulting in above-normal ocean temperatures and elevated sea levels along the U.S. Pacific coast. During El Nino 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 results of these effects are:

- Increased storm-induced erosion.
- Changes in longshore sediment transport (because of changes in the direction of wave approach) which results in changes in erosion or deposition patterns along the shoreline.
- Increased incidence of rainfall and landslides in coastal regions.

Great Lakes

Storms on the Great Lakes are usually associated with the passage of low-pressure systems or cold fronts. Storm effects (i.e., 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 be limited to less than 2 feet, except in embayments (2–4 feet) and on Lake Erie, where storm surges can reach 8 feet near the east and west ends of the lake.

TSUNAMIS

Tsunamis are long-period water waves generated by undersea shallow-focus earthquakes or by undersea crustal displacements, 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 Fig. 6-3). Tsunamis have been known to damage some structures hundreds of feet inland and over 50 feet above sea level.

Figure 6-3. Hilo, Hawaii—damage from the 1960 tsunami

Coastal construction in tsunami hazard zones must consider the effects of:

- Tsunami runup.
- Flooding.
- Erosion.
- Debris loads.
- "Rundown" (return of water to the sea), which can damage the landward sides of structures that withstood the initial runup.

Tsunami Effects

Tsunami effects at a particular site will be determined by four basic factors, described in Table 6.4.

Table 6.4. Factors that Determine Tsunami Effects

Factor	Description
Magnitude	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. 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.
Location	The location of the triggering event has two important consequences: (1) The distance between the point of tsunami generation and the shoreline determines the maximum available warning time. Tsunamis generated at a remote source will take longer to reach a given shoreline than locally generated tsunamis. (2) The point of generation will determine 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.
Configuration	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 Topography	Upland elevations and topography will also determine tsunami impacts at a site. Low-lying tsunami-prone coastal sites will be more susceptible to inundation, tsunami runup, and damage than sites at higher elevations.

Areas Subject to Tsunamis

Table 6.5 lists areas that are subject to tsunami events, and the sources of those events.

Table 6.5. Areas Subject to Tsunami Events

	Principal Source of Tsunamis	
Area	**Locally Generated Events**[a]	**Remote-Source Earthquakes**
Alaska		
North Pacific coast	x	
Aleutian Islands	x	x
Gulf of Alaska coast	x	x
Bering Sea coast[b]		
Hawaii		x
American Samoa		x
Oregon	x	x
Washington	x	x
California	x	x
Puerto Rico	x	
U.S. Virgin Islands	x	

[a] Landslides, subduction, submarine landslides, volcanic activity.
[b] Not considered threatened by tsunamis.

SELF-CHECK REVIEW: NATURAL HAZARD EVENTS

Instructions: Answer the following questions. Then turn the page to check your answers. If you answered any items incorrectly, you should review the related material before continuing.

1. Hurricanes and typhoons are tropical storms.

   True False

2. List three potential effects of tropical cyclones and coastal storms.

   (1) ____

   (2) ____

   (3) ____

3. What is the Saffir-Simpson scale?

4. Tropical cyclone landfalls can be expected to follow a consistent pattern, geographically, along the Atlantic and Gulf of Mexico coasts.

   True False

5. Over short periods of time the actual number and timing of tropical cyclone passage and landfall may deviate substantially from long-term mean return periods.

   True False

6. Northeasters:

   a. Are tropical storms.
   b. Affect primarily the Pacific coast.
   c. Have closed circulation.
   d. Affect the Atlantic coast, usually in winter.

7. The impact of a tsunami at a particular site may be affected by both the configuration of the continental shelf and shoreline and the upland topography.

   True False

ANSWER KEY

NOTE: Some of your answers may be slightly different, but they should include the same main points.

1. Hurricanes and typhoons are tropical storms.

   True

2. List three potential effects of tropical cyclones and coastal storms.

   Any three of the following:
   - **High winds**
   - **Coastal flooding**
   - **High-velocity flows**
   - **Damaging waves**
   - **Significant erosion**
   - **Intense rainfall**
   - **Large quantities of waterborne sediments and floating debris**

3. What is the Saffir-Simpson scale?

   A scale used to classify the storm damage potential of hurricanes according to wind speed and central pressure.

4. Tropical cyclone landfalls can be expected to follow a consistent pattern, geographically, along the Atlantic and Gulf of Mexico coasts.

   False. There is wide variation in incidence of landfalls.

5. Over short periods of time the actual number and timing of tropical cyclone passage and landfall may deviate substantially from long-term mean return periods.

   True

6. Northeasters:

   d. Affect the Atlantic coast, usually in winter.

7. The impact of a tsunami at a particular site may be affected by both the configuration of the continental shelf and shoreline and the upland topography.

   True

COASTAL FLOODING

Coastal flooding can originate from a number of sources. Tropical cyclones, other coastal storms, and tsunamis generate the most significant coastal flood hazards. These hazards usually take the form of:

- Hydrostatic forces.
- Hydrodynamic forces.
- Wave effects.
- Floodborne debris effects.

NOTE

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.
- Floodborne debris.

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. Flooding can also cause **vertical** hydrostatic forces, or ***flotation*** (see Fig. 6-4).

Figure 6-4. Hurricane Hugo (1989), Garden City, South Carolina. Intact houses were floated off their foundations and carried inland.

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, which 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 Fig. 6-5).
- **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.

Figure 6-5. Storm surge and wave runup across boardwalk at South Mission Beach, California, during January 1988 storm.

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.
- Shore-normal canals, channels, or drainage features.

EXAMPLE

Anecdotal evidence after Hurricane Opal struck Navarre Beach, Florida, in 1995 suggests that large, engineered buildings channeled flow between them (see Fig. 6-6). The channelized flow caused deep scour channels across the island, undermining a pile-supported house between the large buildings (see Fig. 6-7), and washing out roads and houses (see Fig. 6-8) situated farther landward.

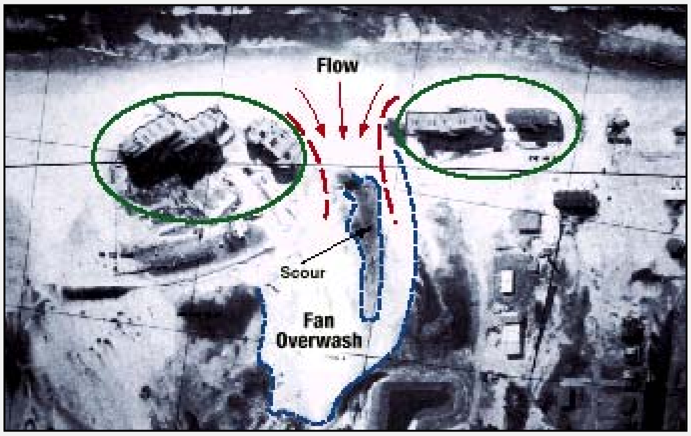


Figure 6-6.
Flow channeled between large engineered buildings (circled) scoured a deep channel across the island and damaged infrastructure and houses.

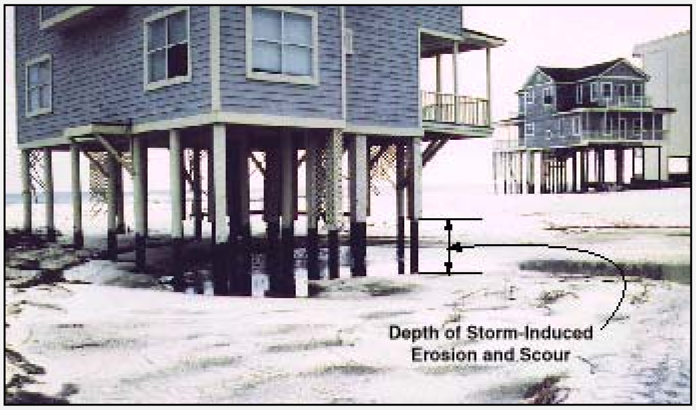


Figure 6-7.
Pile-supported house in the area of channeled flow. The building foundation and elevation prevented high-velocity flow, erosion, and scour from destroying the building.

Figure 6-8.
This house was also in an area of channeled flow. The house was undermined and washed into the bay behind the barrier island. As a result, the house is now a total loss and a threat to navigation.

WAVES

Waves can affect coastal buildings by means of breaking waves, wave runup, wave reflection or deflection, and wave uplift forces.

Breaking Waves

The most severe damage is caused by breaking waves (see Fig. 6-9). 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 6-9.
Storm waves breaking against a seawall in front of a coastal residence at Stinson Beach, California

Wave Runup

Wave runup (see Fig. 6-10) occurs as waves break and run up beaches, sloping surfaces, and vertical surfaces. Wave runup can drive large volumes of water against or around coastal buildings, inducing fluid impact forces (although smaller than breaking wave forces), current drag forces, and localized erosion and scour.

Figure 6-10.
Wave runup beneath elevated buildings at Scituate, MA, during the December 1992 northeaster. Nine homes in the area were bought with public funds and demolished following the storm.

Wave runup against a vertical wall will generally extend to a higher elevation than runup on a sloping surface and will be capable of destroying overhanging decks and porches. Figure 6-11 shows the effects of wave runup breaking against a vertical wall and adjacent building.

Figure 6-11. Damage to an oceanfront condominium in Ocean City, NJ, caused by wave runup on a timber bulkhead.

Wave Reflection or Deflection

Wave reflection or deflection from adjacent structures or objects can produce forces on a building similar to those caused by wave runup.

Wave Uplift Forces

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 sometimes occurs at the lowest floor of insufficiently elevated but well-founded residential buildings and underneath slabs-on-grade below elevated buildings (see Fig. 6-12).

Figure 6-12. Hurricane Fran (1996). Concrete slab-on-grade flipped up by wave action came to rest against two foundation members, generating large unanticipated loads on the foundation.

FLOODBORNE DEBRIS

Floodborne debris produced by coastal flood events and storms typically includes:

- Decks.
- Steps.
- Ramps.
- Breakaway wall panels.
- Portions of or entire houses.
- Heating oil and propane tanks.
- Vehicles.
- Boats.
- Decks and pilings from piers (see Fig. 6-13).
- Fences.
- Destroyed erosion-control structures.
- A variety of smaller objects.

Figure 6-13. Hurricane Opal (1995). Pier pilings were carried over 2 miles by storm surge and waves before they came to rest against this elevated house in Pensacola Beach, Florida.

Floodborne debris is often capable of destroying unreinforced masonry walls (see Fig. 6-14), light wood-frame construction, and small-diameter posts and piles (and the components of structures they support).

Figure 6-14. Hurricane Fran (1996). Debris lodged beneath a Topsail Island, NC, house elevated on unreinforced masonry walls. The wall damage could have resulted from flood and wave forces, debris loads, or both.

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 more massive debris, such as the drift logs shown in Figure 6-15.

Figure 6-15.
March 1975 storm. Drift logs driven into coastal houses at Sand Point, WA.

SEA-LEVEL RISE AND LAKE-LEVEL RISE

The coastal flood effects just described 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 over decades, in response to regional climate changes.

In either case, 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.

NOTE

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

Sea-Level Rise

Tide gauge records for the **U.S. Atlantic and Gulf of Mexico coasts** show that relative sea level has been rising at long-term rates averaging 2 to 4 mm annually, with higher rates along the Louisiana and Texas coasts.

Records for the **U.S. Pacific coast** stations show that some areas have experienced rises in relative sea levels of approximately 2 mm annually, while other areas have seen relative sea levels fall. Relative sea level has fallen at rates as much as 2 mm annually in northern California and as much as 13 mm annually in Alaska.

Lake-Level Rise

NOTE

Detailed data on measured and projected water levels is available at the USACE Detroit District website: http://sparky.nce.usace.army.mil/hmpghh.html

Great Lakes seasonal water levels typically fluctuate between 1 and 2 feet. Long-term 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.

Beach and bluff erosion rates tend to increase as long-term water levels rise. As water levels fall, erosion rates diminish. Low lake levels lead to generally stable shorelines and bluffs but make navigation through harbor entrances difficult.

SELF-CHECK REVIEW: COASTAL FLOODING

Instructions: Answer the following questions. Then turn the page to check your answers. If you answered any items incorrectly, you should review the related material before continuing.

1. Coastal flood hazards usually take the form of:

   (1) ______________________________

   (2) ______________________________

   (3) ______________________________

   (4) ______________________________

2. List at least five flood parameters that must be investigated at a coastal site to correctly characterize potential flood hazards.

   (1) ______________________________

   (2) ______________________________

   (3) ______________________________

   (4) ______________________________

   (5) ______________________________

3. Standing or slowly moving water can induce both horizontal and vertical hydrostatic forces.

   True False

4. Storm surge and wave runup are typical sources of hydrodynamic forces. List three other sources.

   (1) ______________________________

   (2) ______________________________

   (3) ______________________________

5. The most severe flood damage to coastal buildings is caused by __________________________.

The Answer Key for the preceding Self-Check Review is located on the next page.

ANSWER KEY

NOTE: Some of your answers may be slightly different, but they should include the same main points.

1. Coastal flood hazards usually take the form of:

   (1) Hydrostatic forces.
   (2) Hydrodynamic forces.
   (3) Wave effects.
   (4) Floodborne debris effects.

2. List at least five flood parameters that must be investigated at a coastal site to correctly characterize potential flood hazards.

   Any of the following:
   - **Origin of flooding**
   - **Flood frequency**
   - **Flood depth**
   - **Flood velocity**
   - **Flood direction**
   - **Flood duration**
   - **Wave effects**
   - **Erosion and scour**
   - **Sediment overwash**
   - **Floodborne debris**

3. Standing or slowly moving water can induce both horizontal and vertical hydrostatic forces.

   True

4. Storm surge and wave runup are typical sources of hydrodynamic forces. List three other sources.

   (1) Tsunamis
   (2) Outflow of floodwaters
   (3) Strong currents parallel to the shoreline

5. The most severe flood damage to coastal buildings is caused by **<u>breaking waves.</u>**

HIGH WINDS

High winds can originate from a number of events; tropical cyclones, other coastal storms, and tornadoes generate the most significant coastal wind hazards.

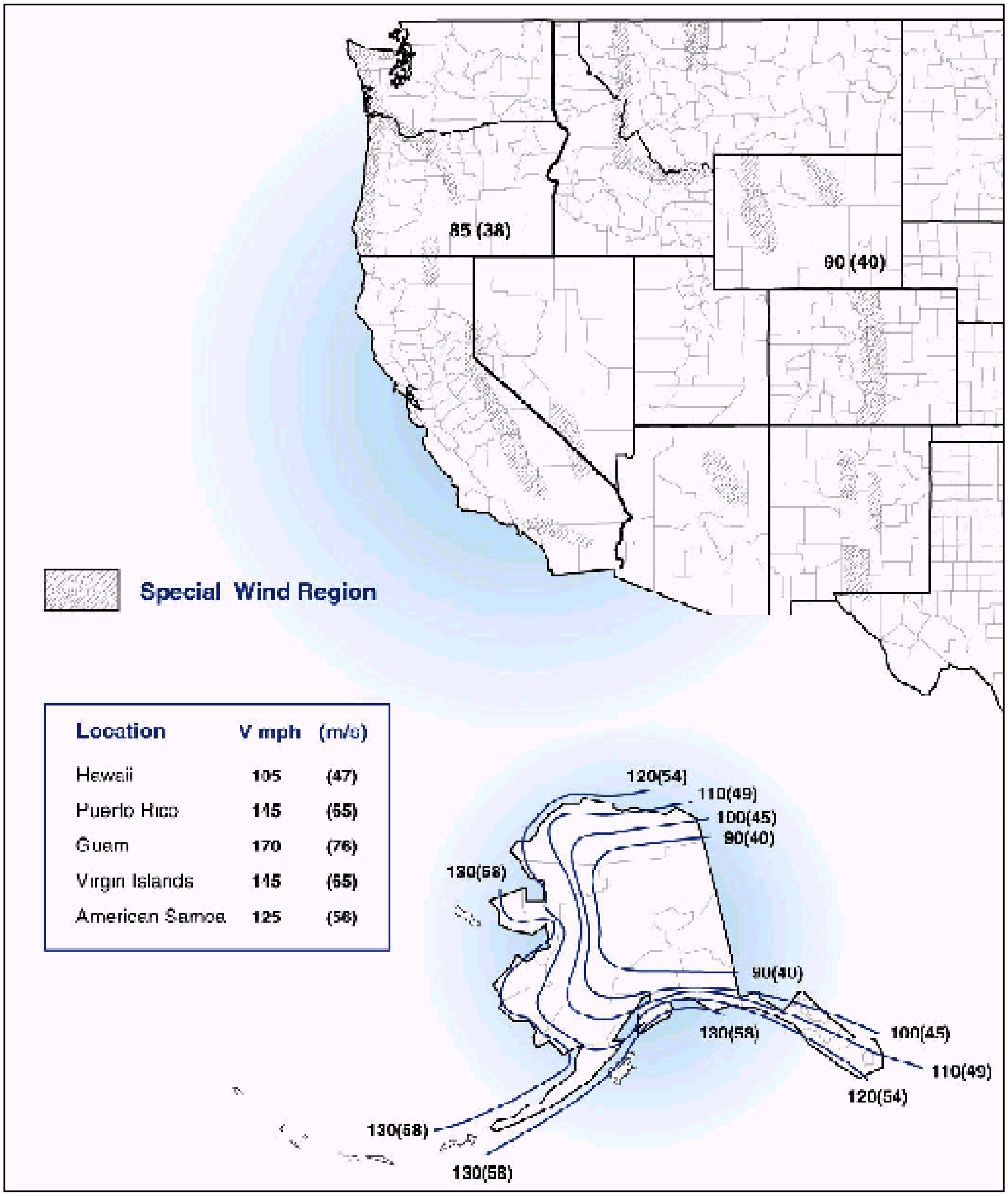
The most current design wind speeds are given by the national load standard, *ASCE 7-98* (American Society of Civil Engineers, 1998). Figure 6-16, taken from *ASCE 7-98*, shows the geographic distribution of design wind speeds for the continental United States and Alaska. Design wind speeds for Hawaii, Puerto Rico, Guam, American Samoa, and the Virgin Islands are also listed.

NOTE

Basic wind speeds shown in Figure 6-16 correspond to:

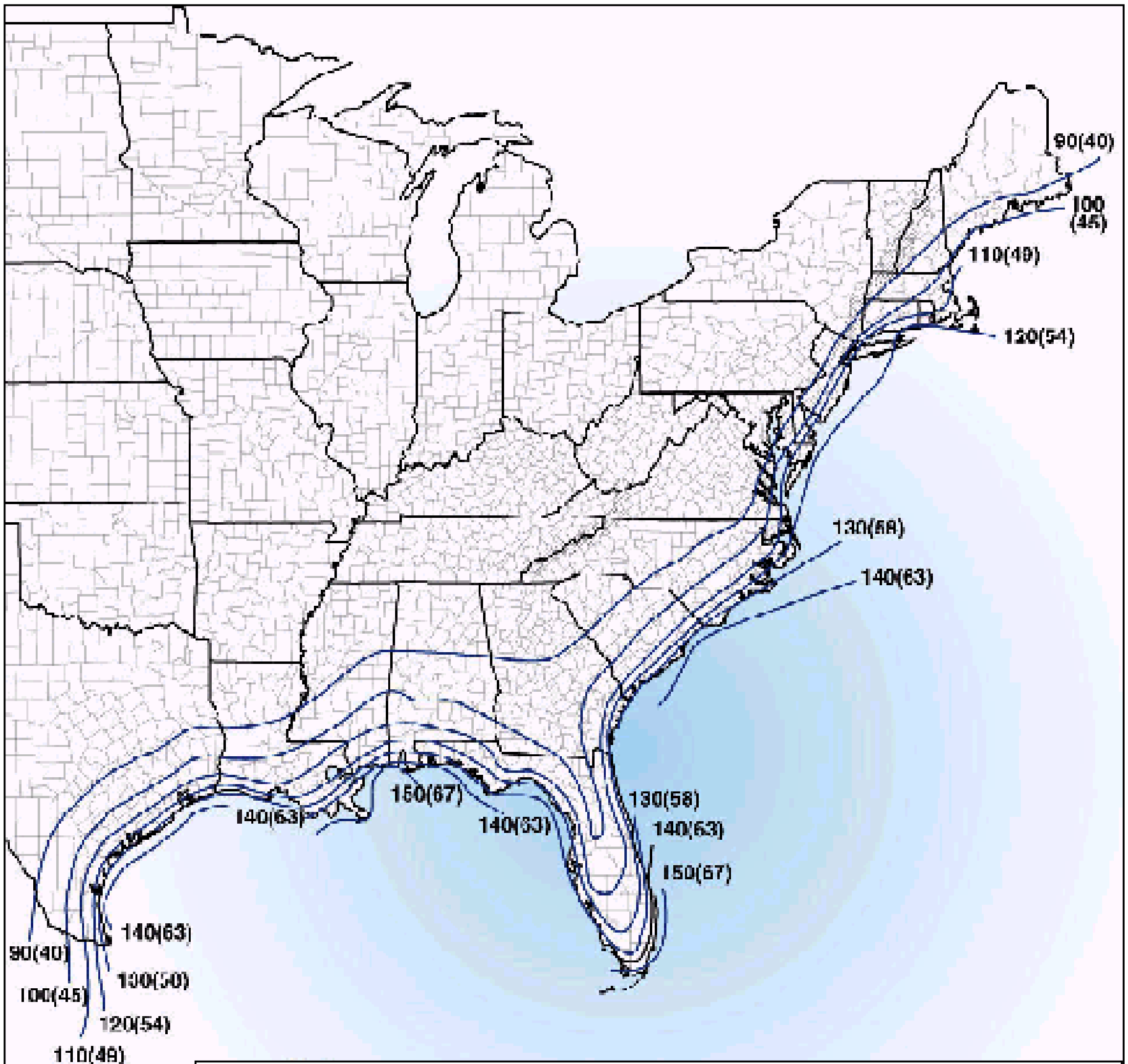
- A wind with a recurrence interval between 50 and 100 years in **hurricane-prone regions** (Atlantic and Gulf of Mexico coasts with a basic wind speed greater than 90 mph, and Hawaii, Puerto Rico, Guam, the U.S. Virgin Islands, and American Samoa).
- A recurrence interval of 50 years in **non-hurricane-prone areas.**

Figure 6-16. ASCE 7-98 wind speed map (continued on the next page)



Location	V mph	(m/s)
Hawaii	105	(47)
Puerto Rico	145	(65)
Guam	170	(76)
Virgin Islands	145	(65)
American Samoa	125	(56)

Figure 6-16. ASCE 7-98 wind speed map (continued)



Notes:

1. Values are nominal design 3-sec gust wind speeds in miles per hour (mph) at 33 ft (10 m) above ground for Exposure Category C.
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.

Source: *Minimum Design Loads for Buildings and Other Structures,* ASCE 7-98.

EFFECTS OF HIGH WINDS

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 Figs. 6-17 and 6-18).

Wind Effect Factors

The effects of high winds on a building will depend on several factors:

- 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 the 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 windborne debris.

WARNING

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

Figure 6-17. Hurricane Andrew (1992). End-wall failure of typical first-floor masonry/second-floor wood-frame building in Dade County, Florida.

Figure 6-18. Hurricane Iniki (1992), Kauai County, Hawaii. Loss of roof sheathing from improper nailing design and schedule.

SPEEDUP OF WINDS FROM TOPOGRAPHIC EFFECTS

Speedup of winds resulting from 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 7-98* 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, will not be 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 from topographic effects.

WINDBORNE DEBRIS AND RAINFALL PENETRATION

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

As the insured wind losses following Hurricanes Hugo and Andrew demonstrate:

- **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 interior damage by water seeping through exposed roof sheathing (e.g., following loss of shingles or roof tiles).
- **Higher levels of damage magnification** are associated with interior damage by 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.

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.

Damage from 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 windborne shrapnel that causes additional damage.

Implications for Design

It is generally beyond the scope of most building designs to account for a direct strike by a tornado (the *ASCE 7-98* wind map in Figure 6-16 excludes tornado effects). However, use of wind-resistant design techniques will reduce damage caused by a tornado passing nearby.

NOTE

Additional information about tornadoes and tornado hazards is presented in *Taking Shelter from the Storm: Building a Safe Room Inside Your House*, FEMA 320 (1999).

SELF-CHECK REVIEW: HIGH WINDS

Instructions: Answer the following questions. Then turn the page to check your answers. If you answered any items incorrectly, you should review the related material before continuing.

1. Proper design and construction of coastal buildings requires that all pertinent wind factors be investigated and addressed. Mark all factors below that affect the impact of high winds on a building.

   ___ Wind speed and duration
   ___ Building height
   ___ Exposure of the building relative to wind direction
   ___ Strength of structural frame, connections, and envelope
   ___ Shape of the building and its components
   ___ Number, size, location, and strength of openings
   ___ Protection for openings
   ___ Type, quantity, and velocity of windborne debris

2. Speedup of winds from topographic effects is most common in large, flat expanses where wind can rapidly pick up speed (e.g., plains or long beaches).

   True False

3. As long as damage to the building envelope is minor, it is not a concern—economically speaking.

   True False

4. Wind damage in combination with ________________ accounts for much of the insured wind losses in hurricanes.

5. The strength and number of tornadoes are directly related to the strength of the hurricane that generates them.

   True False

6. Most well-designed coastal buildings are designed to withstand a direct strike by a tornado.

   True False

The Answer Key for the preceding Self-Check Review is located on the next page.

ANSWER KEY

NOTE: Some of your answers may be slightly different, but they should include the same main points.

1. Proper design and construction of coastal buildings requires that all pertinent wind factors be investigated and addressed. Mark all factors below that affect the impact of high winds on a building.

   _x_ Wind speed and duration
   _x_ Building height
   _x_ Exposure of the building relative to wind direction
   _x_ Strength of structural frame, connections, and envelope
   _x_ Shape of the building and its components
   _x_ Number, size, location, and strength of openings
   _x_ Protection for openings
   _x_ Type, quantity, and velocity of windborne debris

2. Speedup of winds from topographic effects is most common in large, flat expanses where wind can rapidly pick up speed (e.g., plains or long beaches).

   False. It occurs in the vicinity of mountainous areas, gorges, and ocean promontories.

3. As long as damage to the building envelope is minor, it is not a concern—economically speaking.

   False. Even minor damage to the building envelope can lead to large economic losses.

4. Wind damage in combination with **rain** accounts for much of the insured wind losses in hurricanes.

5. The strength and number of tornadoes are directly related to the strength of the hurricane that generates them.

   False. The weakest hurricanes often produce the most tornadoes.

6. Most well-designed coastal buildings are designed to withstand a direct strike by a tornado.

   False. It is generally beyond the scope of most building designs to account for a direct strike, but use of wind-resistant design techniques will reduce damage caused by a tornado passing nearby.

UNIT VI EXERCISE

Instructions: Use this Unit Exercise to test how well you learned the material presented in Unit VI. When you complete the exercise, check your answers against those in the Answer Key that follows. If you answered any questions incorrectly, be sure to review the corresponding section of the unit before proceeding to Unit VII.

1. Match the coastal events on the left with the descriptions on the right.

____	Tropical storm	a.	Rapidly rotating vortex of wind.
____	Hurricane	b.	Western North Pacific storm, winds 100 mph.
____	Typhoon	c.	North Atlantic storm, winds 100 mph.
____	Super typhoon	d.	Earthquake-induced long-period water wave.
____	Class 5 (catastrophic) hurricane	e.	North Atlantic storm, winds 175 mph.
____	Northeaster	f.	Western North Pacific storm, winds 175 mph.
____	Tsunami	g.	North Atlantic winter storm lacking closed circulation.
____	Tornado	h.	Closed circulation, winds 50 mph.

2. Tropical cyclone landfalls are / are not evenly distributed on a geographic basis. (Circle one.)

3. The average number of landfalling hurricanes would probably be LOWEST in:

   a. Maine
   b. South Carolina
   c. Oregon
   d. Florida

4. A tsunami has the greatest likelihood of striking:

   a. Alaska
   b. North Carolina
   c. Louisiana
   d. New England

5. What effect does coinciding with seasonal high tides have on a storm's potential impact?

   a. No effect.
   b. Magnifies the impact.
   c. Lessens the impact.
   d. Eliminates the impact.

6. Match terms on the left with phrases on the right.

___ Hydrostatic forces	a. Sloping surfaces
___ Hydrodynamic forces	b. Standing or slowly moving water
___ Breaking waves	c. Separate pier decks from pilings
___ Wave runup	d. High velocity flows
___ Wave uplift forces	e. Vehicles, boats, and propane tanks
___ Floodborne debris	f. Cause most severe damage

7. Great Lakes water levels:

    a. Do not fluctuate.
    b. Have seasonal and long-term fluctuations.
    c. Fluctuate over hundreds or thousands of years.
    d. Fluctuate daily by as much as 20 feet.

8. Standing or slowly moving water:

    a. Can induce only horizontal hydrostatic forces.
    b. Cannot induce hydrostatic or hydrodynamic forces.
    c. Can induce horizontal and vertical hydrostatic forces.
    d. Can induce extreme hydrodynamic forces.

9. Which of the following wave effects typically causes the most severe damage?

    a. Wave runup
    b. Wave deflection
    c. Breaking waves
    d. Wave uplift forces

10. The shape of a building affects the impact of high winds on the building.

    True False

11. A house atop a 100-foot bluff may be at risk for:

    a. Wind speedup.
    b. Floodborne debris.
    c. Storm surge.
    d. A higher mean return period.

The Answer Key for the preceding Unit Exercise is located on the next page.

UNIT VI EXERCISE—ANSWER KEY

NOTE: Some of your answers may be slightly different, but they should include the same main points.

1. Match the coastal events on the left with the examples on the right.

h	Tropical storm	a.	Rapidly rotating vortex of wind.
c	Hurricane	b.	Western North Pacific storm, winds 100 mph.
b	Typhoon	c.	North Atlantic storm, winds 100 mph.
f	Super typhoon	d.	Earthquake-induced long-period water wave.
e	Class 5 (catastrophic) hurricane	e.	North Atlantic storm, winds 175 mph.
g	Northeaster	f.	Western North Pacific storm, winds 175 mph.
d	Tsunami	g.	North Atlantic winter storm lacking closed circulation.
a	Tornado	h.	Closed circulation, winds 50 mph.

2. Tropical cyclone landfalls **are not** evenly distributed on a geographic basis. (Circle one.)

3. The average number of landfalling hurricanes would probably be LOWEST in:

   c. Oregon

4. A tsunami has the greatest likelihood of striking:

   a. Alaska

5. What effect does coinciding with seasonal high tides have on a storm's potential impact?

   b. Magnifies the impact.

6. Match terms on the left with phrases on the right.

b	Hydrostatic forces	a.	Sloping surfaces
d	Hydrodynamic forces	b.	Standing or slowly moving water
f	Breaking waves	c.	Separate pier decks from pilings
a	Wave runup	d.	High velocity flows
c	Wave uplift forces	e.	Vehicles, boats, and propane tanks
e	Floodborne debris	f.	Cause most severe damage

7. Great Lakes water levels:

   b. Have seasonal and long-term fluctuations.

8. Standing or slowly moving water:

   c. Can induce horizontal and vertical hydrostatic forces.

9. Which of the following wave effects typically causes the most severe damage?

   c. Breaking waves

10. The shape of a building affects the impact of high winds on the building.

    True

11. A house atop a 100-foot bluff may be at risk for:

    a. Wind speedup.