UNIT I: HISTORICAL PERSPECTIVE

HISTORICAL PERSPECTIVE

INTRODUCTION

Through the years, FEMA and other agencies have documented and evaluated the effects of coastal flood events and the performance of coastal buildings during those events. These evaluations are useful because they provide a historical perspective on matters related to the siting, design, and construction of buildings along the Atlantic, Pacific, Gulf of Mexico, and Great Lakes coasts. They are useful also because they provide a baseline against which the impacts of later coastal flood events can be measured.

Within this context, several hurricanes, coastal storms, and other coastal flood events stand out as being especially important, either because of the nature and extent of the damage they caused or because of particular flaws they exposed in hazard identification, siting, design, construction, or maintenance practices. Many of these events—particularly the more recent ones—have been documented by FEMA in Flood Damage Assessment Reports and Building Performance Assessment Team (BPAT) reports.

This unit describes a few of the coastal flood and wind events that have affected the continental United States, Alaska, Hawaii, and U.S. Territories. Findings of post-event building performance and damage assessments are summarized, as are the lessons learned regarding factors that contribute to flood and wind damage.

UNIT OBJECTIVES

After completing this unit, you should be able to:

1.1 Define basic flood terminology.
1.2 Describe lessons learned from coastal flood disasters in relation to:
- Hazard identification.
- Siting.
- Design.
- Construction.
- Maintenance.

FLOOD TERMINOLOGY

To appreciate the lessons that can be learned from coastal flood disaster history, it is helpful to have an understanding of basic flood terminology. Some key terms are briefly explained below. More detailed discussions will be provided in later units.

NFIP, FIRM, and SFHA

FEMA's **National Flood Insurance Program (NFIP)** flood insurance zone designations shown on **Flood Insurance Rate Maps (FIRMs)** indicate the nature and magnitude of the flood hazard in a given area.

Communities who participate in the NFIP use these insurance zone designations to regulate construction in identified **Special Flood Hazard Areas (SFHAs)**—areas subject to inundation by a flood that has a one percent probability of being equaled or exceeded in any given year (also referred to as the *base flood*).

BFE and DFE

The flood elevation associated with the SFHA is termed the **Base Flood Elevation (BFE).** This course uses the term BFE when it discusses NFIP elevation requirements.

The term **Design Flood Elevation (DFE)** is used to account for situations where communities choose to enforce floodplain management requirements more stringent than those of the NFIP.

For example, many communities require **freeboard** above the BFE, and some regulate to more severe flood conditions. Where a community chooses to exceed NFIP minimum requirements, the DFE will be higher than the BFE. Where a community's requirements are the same as the NFIP requirements, the DFE and BFE will be identical.

Under the NFIP, **freeboard** is a factor of safety, usually expressed in feet above flood level, that is applied for the purposes of floodplain management. Freeboard tends to compensate for the many unknown factors that could contribute to flood heights greater than those calculated for a selected flood, such as the base flood.

FLOOD ZONES

Currently, the NFIP uses two categories of zones to differentiate between flood hazards in SFHAs: **V zones** and **A zones**. The *Coastal Construction Manual* also describes a third zone within the SFHA: **coastal A zone.** Areas outside the SFHA appear as shaded or unshaded **X zones** (B or C zones on older FIRMs). The zone icons shown with the descriptions below are provided as visual guides throughout this course to help you find information specific to your needs.

V zone — The portion of the SFHA that extends from offshore to the inland limit of a primary frontal dune along an open coast, and any other area subject to high-velocity wave action from storms or seismic sources. The V zone is also referred to as the **Coastal High Hazard Area.** The minimum NFIP regulatory requirements regarding construction in V zones are more stringent than those regarding A-zone construction. V-zone requirements account for the additional hazards associated with high-velocity wave action, such as the impact of waves and waterborne debris and the effects of severe scour and erosion.

Coastal A zone — The portion of the SFHA landward of a V zone or landward of an open coast without mapped V zones (e.g., the shorelines of the Great Lakes) in which the principal sources of flooding are astronomical tides, storm surges, seiches, or tsunamis, not riverine sources. Like the flood forces in V zones, those in coastal A zones are highly correlated with coastal winds or coastal seismic activity. Coastal A zones may therefore be subject to wave effects, velocity flows, erosion, scour, or combinations of these forces. The forces in coastal A zones are not as severe as those in V zones but are still capable of damaging or destroying buildings on inadequate foundations.

NOTE

Although the NFIP regulations do not differentiate between coastal and non-coastal A zones, the *Coastal Construction Manual* recommends that buildings in coastal A zones be designed and constructed to be more resistant to flood forces—including wave effects, velocity flows, erosion, and scour—than buildings in non-coastal A zones.

Non-Coastal A zone — Portions of the SFHA in which the principal source of flooding is runoff from rainfall, snowmelt, or a combination of both. In non-coastal A zones, flood waters may move slowly or rapidly, but waves are usually not a significant threat to buildings. However, in extreme cases (e.g., the 1993 Midwest floods), long fetches and high winds have generated damaging waves in non-coastal A zones. Designers in non-coastal A zones subject to waves may wish to employ some of the methods described in the *Coastal Construction Manual*.

WARNING

Areas outside the SFHA can still be subject to flooding and erosion. Designers should not ignore potential flooding and erosion hazards in areas labeled Zone X, Zone B, or Zone C.

X zone — Areas where the flood hazard is less than that in the SFHA. Shaded X zones shown on recent FIRMs (B zones on older FIRMs) designate areas subject to inundation by the flood with a 0.2 percent annual probability of being equaled or exceeded (the 500-year flood). Unshaded X zones (C zones on older FIRMs) designate areas where the annual exceedance probability of flooding is less than 0.2 percent.

SELF-CHECK REVIEW: FLOOD TERMINOLOGY

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

1. Some States and communities require that buildings be elevated <u>above</u> the BFE. This additional elevation is called:

   ____

2. Base Flood Elevation (BFE) is: (mark the correct answer)

   _____ The flood elevation associated with a Special Flood Hazard Area.

   _____ The flood elevation used by communities that exceed NFIP minimum requirements.

   _____ The flood elevation with a factor of safety added for floodplain management purposes.

3. Which of the following flood hazard zones has the most stringent NFIP regulatory requirements?

   _____ Coastal A zone

   _____ V zone

   _____ X zone

   _____ Non-coastal A zone

4. The flood forces in a ______________________ or _________________________ zone are highly correlated with coastal winds or coastal seismic activity.

ANSWER KEY

1. Some States and communities require that buildings be elevated above the BFE. This additional elevation is called **freeboard.**

2. Base Flood Elevation (BFE) is:

   _✓_ **The flood elevation associated with a Special Flood Hazard Area.** The flood elevation used by communities that exceed NFIP minimum requirements (i.e., that has an added factor of safety) is termed Design Flood Elevation (DFE).

3. Which of the following flood hazard zones has the most stringent NFIP regulatory requirements?

   _✓_ **V zone**. (Note: NFIP requirements do not currently distinguish between coastal and non-coastal A zones.)

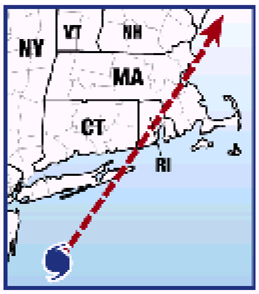
4. The flood forces in a **V zone** or **coastal A zone** are highly correlated with coastal winds or coastal seismic activity.

COASTAL FLOOD AND WIND EVENTS

NORTHEAST ATLANTIC COAST

Hurricane Bob — Buzzards Bay Area, Massachusetts
August 19, 1991

Figure 1-1.
Track of Hurricane Bob



Hurricane Bob, a Category 2 hurricane, followed the track shown in Figure 1-1. Although undistinguished by its intensity (not even ranking in the 65 most intense hurricanes to strike the United States during the 20th century), it caused $1.75 billion in damage (1996 dollars), ranking 18th in terms of damage (see Fig. 1-2).

NOTE

Hurricane categories reported in this course should be interpreted cautiously. Storm categorization based on wind speed may differ from that based on barometric pressure or storm surge. Also, storm effects vary geographically—only the area near the point of landfall will experience effects associated with the reported storm category.

A FEMA Flood Damage Assessment Report documented damage in the Buzzards Bay area. The wind speeds during Hurricane Bob were below the design wind speed and the storm tide (corresponding to a 15-year tide) was at least 5 feet below the Base Flood Elevation (BFE). Nevertheless the results of the storm allowed an evaluation of the performance of different foundation types.

Figure 1-2.
Hurricane Bob (1991) destroyed 29 homes along this reach of Mattapoisett, MA.

Post-hurricane findings regarding foundations included:

- Many buildings in the area had been elevated on a variety of foundations, either in response to Hurricane Carol (1954) or the 1978 northeaster, or as a result of community-enforced National Flood Insurance Program (NFIP) requirements.

- Buildings constructed before the date of the Flood Insurance Rate Map (FIRM) for each community—referred to as ***pre*-FIRM buildings—that had not been elevated, or that had not been elevated sufficiently, suffered major damage or complete destruction;** some destroyed buildings appeared to have had **insufficient foundation embedment**.

- Post-FIRM buildings (i.e., built after the date of the FIRM) and pre-FIRM **buildings with sufficient elevation performed well** during the storm. Where water was able to pass below buildings unobstructed by enclosed foundations, damage was limited to loss of decks and stairs.

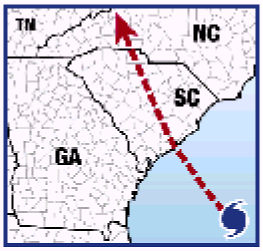
- Foundation types that appeared to survive the storm without structural damage included the following:
  - Cast-in-place concrete columns, at least 10 inches in diameter.
  - Masonry block columns with adequate embedment depth.
  - 10-inch-thick shear walls with a flow-through configuration (open ends) or modified to include garage doors at each end of the building (intended to be open during a storm).

SOUTHEAST ATLANTIC COAST AND CARIBBEAN

Hurricane Hugo — South Carolina, 1989

Hurricane Hugo was one of the strongest hurricanes known to have struck South Carolina. Widespread damage resulted from a number of factors: flooding, waves, erosion, debris, and wind. In addition, building and contents damage caused by rainfall penetration into damaged buildings, several days after the hurricane itself, often exceeded the value of direct hurricane damage.

Figure 1-3. Track of Hurricane Hugo



Damage from, and repairs following, Hugo were documented in a FEMA Flood Damage Assessment Report and a Follow-Up Investigation Report. The reports concluded the following:

- Post-FIRM buildings that were both properly constructed and elevated survived the storm (see Fig. 1-4). These buildings stood out in sharp contrast to pre-FIRM buildings and to post-FIRM buildings that were poorly designed or constructed.

Figure 1-4. Hurricane Hugo (1989), Garden City Beach, SC. House on pilings survived while others did not.

- Many **buildings elevated on masonry or reinforced concrete columns supported by shallow footings** failed. In some instances, the columns were undermined; in others, the columns failed as a result of poor construction (see Fig. 1-5).

Figure 1-5.
Hurricane Hugo (1989), South Carolina. Failure of reinforced masonry column.

- Several pile-supported buildings **not elevated entirely above the wave crest** showed damage or destruction of floor beams, floor joists, floors, and exterior walls.

- Some of the most severely damaged buildings were in the second, third, and fourth rows back from the shoreline, in **areas mapped as A zones on the FIRMs** for the affected communities. Consideration should be given to more stringent design standards for coastal A zones.

- The storm exposed many **deficiencies in residential roofing practices:** improper flashing, lack of weather-resistant ridge vents, improper shingle attachment, and failure to replace aging roofing materials.

Hurricane Andrew — Dade County, Florida August 24, 1992

Figure 1-6. Track of Hurricane Andrew

Hurricane Andrew was a strong Category 4 hurricane when it made landfall in southern Dade County (see Fig. 1-6) and caused over $26 billion in damage. The storm was the third most intense hurricane to strike the United States in the 20th century and remains the most costly natural disaster to date.

The storm surge and wave effects of Andrew were localized and minor when compared with the damage from wind. A FEMA Building Performance Assessment Team (BPAT) evaluated damage to one- to two-story wood-frame and/or masonry residential construction in Dade County. In its report, the team concluded the following:

- Buildings designed and constructed with components and connections that transferred loads from the envelope to the foundation performed well. When these critical "**load transfer paths**" were not in evidence, damage ranged from considerable to total, depending on the type of architecture and construction.

- Catastrophic **failures of light wood-frame buildings** were observed more frequently than catastrophic failures of other types of buildings constructed on site. Catastrophic failures resulted from a number of factors:

  - Lack of bracing and load path continuity at wood-frame gable ends.
  - Poor fastening and subsequent separation of roof sheathing from roof trusses.
  - Inadequate roof truss bracing or bridging (see Fig. 1-7).
  - Improper sillplate-to-foundation or sillplate-to-masonry connections.

Figure 1-7.
Hurricane Andrew (1992). Roof structure failure from inadequate bracing.

- **Failures in masonry wall buildings** were usually attributable to one or more of the following:

  - Lack of or inadequate vertical wall reinforcing.
  - Poor mortar joints between masonry walls and monolithic slab pours.
  - Lack of or inadequate tie beams, horizontal reinforcement, tie columns, and tie anchors.
  - Missing or misplaced hurricane straps between the walls and roof structure.

- **Composite shingle and tile** (extruded concrete and clay) **roofing systems** sustained major damage during the storm. Failures usually resulted from improper attachment, impacts of windborne debris, or mechanical failure of the roof covering itself.

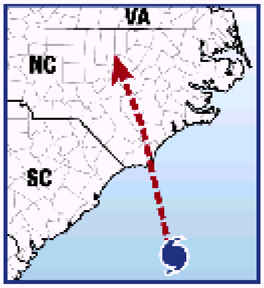
- **Loss of roof sheathing** and consequent rainfall penetration through the roof magnified damage by a factor of five over that suffered by buildings whose roofs remained intact or suffered only minor damage.

- **Exterior wall opening failures** (particularly garage doors, sliding glass doors, French doors, and double doors) frequently led to internal pressurization and structural damage. Storm shutters and the covering of windows and other openings reduced such failures significantly.

- **Quality of workmanship** played a major role in building performance. Many well-constructed buildings survived the storm intact, even though they were adjacent to or near other buildings that were totally destroyed by wind effects.

Hurricane Fran — Southeastern North Carolina
September 5, 1996

Figure 1-8.
Track of Hurricane Fran



Hurricane Fran, a Category 3 hurricane, made landfall near Cape Fear, North Carolina (see Figure 1-8). Erosion and surge damage to coastal construction were exacerbated by the previous effects of a weaker storm, Hurricane Bertha, which struck 2 months earlier. A FEMA BPAT reviewed building failures and successes and concluded the following:

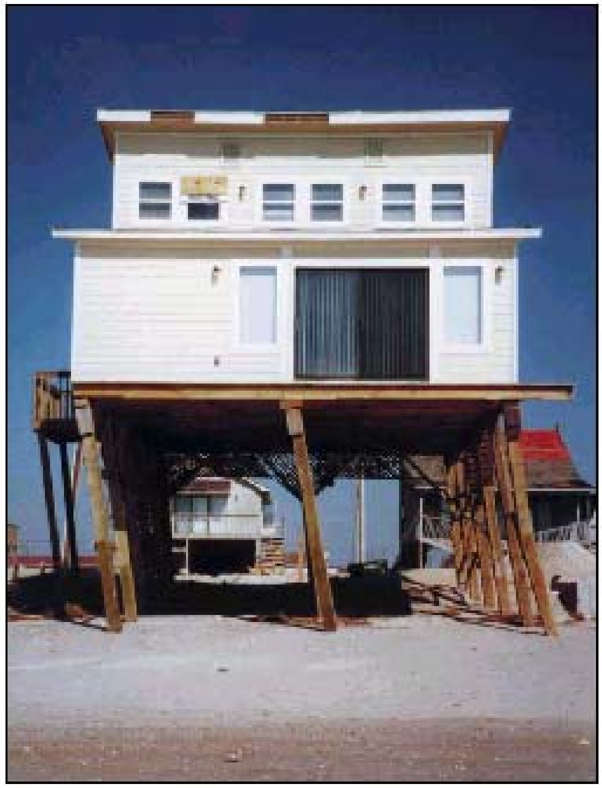
- Many buildings in **mapped A zones were exposed to conditions associated with V zones**, which resulted in building damage and failure from the effects of erosion, high-velocity flow, and waves. Remapping of flood hazard zones after the storm, based on analyses that accounted for wave runup, wave setup, and dune erosion, resulted in a significant landward expansion of V zones.

- Hundreds of oceanfront houses were destroyed by the storm, mostly as a result of **insufficient pile embedment and wave effects.** Most of the destroyed buildings had been constructed under an older building code provision that required that piling foundations extend only 8 feet below the original ground elevation. Erosion around the destroyed oceanfront foundations was typically 5–8 feet. In contrast, foundation failures were rare in similar, piling-supported buildings located farther from the ocean and not subject to erosion.

- A significant reduction in building losses was observed in similarly sized oceanfront buildings constructed after the North Carolina Building Code was amended in 1986 to require a minimum embedment to –5.0 feet National Geodetic Vertical Datum (NGVD) or 16 feet below the original ground elevation (which is shallower) for pilings near the ocean.

  A study of Topsail Island found that 98 percent of post-1986 oceanfront houses (200 of 205) remained after the hurricane. Ninety-two percent of the total displayed no significant damage to the integrity of the piling foundation. However, five percent (11) were found to have **leaning foundations** (see Figure 1-9). A nondestructive test used to measure piling length in a partial sample of the leaning buildings revealed that none of the leaning pilings tested met the required piling embedment standard. Many were much shorter. However, given the uncertainty of predicting future erosion, the BPAT recommended that consideration be given to a piling embedment standard of –10.0 feet NGVD.

Figure 1-9.
Hurricane Fran (1996). Many oceanfront houses built before the enactment of the 1986 North Carolina State Code were found to be leaning or destroyed.



- The BPAT noted a prevalence of **multi-story decks and roofs supported by posts resting on elevated decks;** these decks, in turn, were often supported by posts or piles with only 2–6 feet of embedment. Buildings with such deck and roof structures often sustained extensive damage when flood forces caused the deck to separate from the main structure or caused the loss of posts or piles and left roofs unsupported.

- Design or construction flaws were often found in **breakaway walls.** These flaws included:

  - Excessive connections between breakaway panels and the building foundation (however, the panels were observed generally to have failed as intended).

  - Placement of breakaway wall sections immediately seaward of foundation cross-bracing.

  - Attachment of utility lines to breakaway wall panels.

- Wind damage to **poorly connected porch roofs** and **large roof overhangs** was frequently observed.

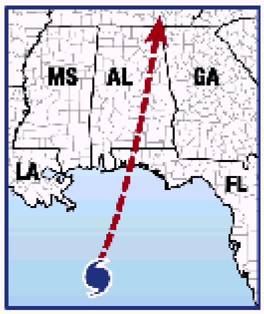
- **Corrosion of galvanized metal connectors** (e.g., hurricane straps and clips) may have contributed to the observed wind damage to elevated buildings.

- As has been observed time and time again following coastal storms, properly designed and constructed coastal residential buildings generally perform well. Damage to well-designed, well-constructed buildings usually results from the effects of **long-term erosion, multiple storms, large debris loads** (e.g., parts of damaged adjacent houses), or **storm-induced inlet formation/modification.**

GULF OF MEXICO COAST

Hurricane Opal — Florida Panhandle, October 4, 1995

Figure 1-10.
Track of Hurricane Opal



Hurricane Opal was one of the most damaging hurricanes to ever affect Florida. In fact, the State concluded that more coastal buildings were damaged or destroyed by the effects of flooding and erosion during Opal than in all other coastal storms affecting Florida in the previous 20 years combined. Erosion and structural damage were exacerbated by the previous effects of Hurricane Erin, which hit the same area just one month earlier.

The Florida Bureau of Beaches and Coastal Systems (FBBCS) conducted a post-storm survey to assess structural damage to major residential and commercial buildings constructed seaward of the Florida Coastal Construction Control Line (CCCL). The survey revealed that out of 1,942 existing buildings, 651 had sustained some amount of structural damage. None of these damaged buildings had been permitted by FBBCS (all pre-dated CCCL permit requirements). Among the 576 buildings for which FBBCS had issued permits, only two sustained structural damage as a result of Opal, and those two did not meet the State's currently implemented standards.

A FEMA BPAT evaluated damage in the affected area and concluded the following:

- Damaged buildings generally fell into one of the following four categories:
  - Pre-FIRM buildings founded on **slabs or shallow footings** and located in mapped V zones.
  - Post-FIRM buildings outside mapped V zones and on slab or shallow footing foundations, but subject to high-velocity wave action, high-velocity flows, erosion, impact by floodborne debris, and/or overwash.
  - **Poorly designed or constructed** post-FIRM elevated buildings.
  - Pre-FIRM and post-FIRM buildings dependent on **failed seawalls or bulkheads** for protection and foundation support.

- Oceanfront foundations were exposed to 3–7 feet of vertical erosion in many locations (see Figure 1-11). **Lack of foundation embedment**, especially in the case of older elevated buildings, was a significant contributor to building loss.

Figure 1-11. Hurricane Opal (1995), Bay County, Florida. Building damage from erosion and undermining.

- Two communities enforced **freeboard and V zone foundation requirements in coastal A zones.** In these communities, the performance of buildings subject to these requirements was excellent.

- State-mandated elevation, foundation, and construction requirements seaward of the CCCL **exceeded minimum NFIP requirements** and undoubtedly reduced storm damage.

The National Association of Home Builders (NAHB) Research Center also conducted a survey of damaged houses. In general, the survey revealed that newer wood-frame construction built to varying degrees of compliance with the requirements of the *Standard for Hurricane Resistant Residential Construction SSTD 10-93*, or similar construction requirements, performed very well overall, with virtually no wind damage. In addition, the Research Center found that even older houses not on the immediate coastline performed well, partly because the generally wooded terrain helped shield these houses from the wind.

PACIFIC COAST *Winter Coastal Storms — California, Oregon, and Washington, 1982–83*

A series of El Nino-driven coastal storms caused widespread and significant damage to beaches, cliffs, and buildings along the coast between Baja California and Washington. These storms were responsible for more coastal erosion and property damage from wave action than had occurred since the winter of 1940–41. One assessment of winter storm damage in the Malibu, California, area found the following storm effects:

- Many beaches were stripped of their sand, resulting in 8–12 feet of vertical **erosion**.
- Bulkheads failed when **scour** exceeded the depth of embedment and backfill was lost.
- Many oceanfront houses were damaged or destroyed, particularly older houses.
- **Sewage disposal systems that relied on sand for effluent filtration** were damaged or destroyed.
- Battering by **floating and wave-driven debris** (pilings and timbers from damaged piers, bulkheads, and houses) caused further damage to coastal development.

A 1985 conference on coastal erosion, storm effects, siting, and construction practices was organized largely as a result of the 1982–83 storms. The proceedings highlighted many of the issues and problems associated with construction along California's coast:

- The need for high-quality data on coastal erosion and storm effects.
- The vulnerability of houses constructed atop coastal bluffs, out of mapped floodplains, but subject to destruction by erosion or collapse of the bluffs.
- The benefits, adverse impacts, and costs associated with various forms of bluff stabilization, erosion control, and beach nourishment.
- The need for rational siting standards in coastal areas subject to erosion, wave effects, or bluff collapse.

Winter Coastal Storms — California and Oregon, 1997–98

Another series of severe El Nino-driven coastal storms battered the Pacific coast. The distinguishing feature of the 1997–98 event was rainfall. The California Coastal Commission reported widespread soil saturation, which resulted in thousands of incidents of debris flows, landslides, and bluff collapse (see Figure 1-12).

Figure 1-12.
Winter Coastal storms, California and Oregon (1997–1998). House in Pacifica, CA, undermined by bluff erosion.

Alaska Tsunami — March 27, 1964

This tsunami, generated by the 1964 Good Friday earthquake, affected parts of Washington, Oregon, California, and Hawaii; however, the most severe effects were near the earthquake epicenter in Prince William Sound, southeast of Anchorage, Alaska.

The tsunami flooded entire towns and caused extensive damage to waterfront and upland buildings (see Figure 1-13). Tsunami runup reached approximately 20 feet above sea level in places, despite the fact that the main tsunami struck near the time of low tide. Also, liquefaction of coastal bluffs in Anchorage resulted in the loss of buildings.

Figure 1-13. 1964 Good Friday earthquake. Damage in Kodiak City, Alaska, caused by the tsunami of the 1964 Alaskan earthquake.

The 1968 report provided recommendations for land and waterfront buildings, including the following:

- Buildings on exposed land should have deep foundations of reinforced concrete or of the beam-and-rafter type, to resist scour and undermining.
- Buildings should be oriented, if possible, to expose their shorter sides to potential wave inundation.
- Reinforced concrete or steel-frame buildings with shearwalls are desirable.
- Wood-frame buildings should be located in the lee of more substantial buildings.

- Wood-frame buildings should be well secured to their foundations and have corner bracing at ceiling level.

- Wood-frame buildings in very exposed, low-lying areas should be designed so that the ground floor area may be considered expendable, because wetting damage would be inevitable. Elevated “stilt” designs of aesthetic quality should be considered.

- Tree screening should be considered as a buffer zone against the sea and for its aesthetic value.

SELF-CHECK REVIEW: COASTAL FLOOD AND WIND EVENTS

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

1. Pre-FIRM buildings generally perform as well as or better than post-FIRM buildings during coastal flood and wind events.

   True False

2. Damage to well designed, well constructed buildings usually results from the effects of long-term erosion, multiple storms, large debris loads, or storm-induced inlet formation/modification.

   True False

3. What are some of the most common design/construction problems that have resulted in major building damage and destruction during hurricanes? Name at least three.

4. Why have buildings in mapped A zones often sustained significant damage during coastal events?

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

ANSWER KEY

NOTE: Your answers to questions 3 and 4 may be slightly different, but they should include the same main points.

1. Pre-FIRM buildings generally perform as well as or better than post-FIRM buildings during coastal flood and wind events.

   False

2. Damage to well-designed, well-constructed buildings usually results from the effects of long-term erosion, multiple storms, large debris loads, or storm-induced inlet formation/modification.

   True

3. What are some of the most common design/construction problems that have resulted in major building damage and destruction during hurricanes? Name at least three.

   Your answer should have included at least three of the following:
   - **Insufficient foundation embedment**
   - **Insufficient elevation**
   - **Failure to create a continuous load transfer path**
   - **Poor quality of workmanship or failure of the building envelope**
   - **Building on slab foundations or on concrete columns with shallow footings**
   - **Deficiencies in residential roofing practices**
   - **Design or construction flaws in breakaway walls**
   - **Dependence on seawalls or bulkheads for protection and foundation support**

4. Why have buildings in mapped A zones often sustained significant damage during coastal events?

   Significant damage occurred because these buildings were exposed to conditions associated with V zones, including erosion, high-velocity flow, and waves.

LESSONS LEARNED

Although flood events and physiographic features vary throughout the coastal areas of the United States, post-event damage reports show that the nature and extent of damage caused by coastal flood events are remarkably similar. Moreover, review of these reports shows that the types of damage experienced today are, in many ways, similar to those experienced decades ago. It is clear that although we have improved many aspects of coastal construction over the years, we make many of the same mistakes over and over.

NOTE

Although there is no statistical basis for the conclusions presented in this section, they are based on numerous post-event damage assessments, which serve as a valuable source of information on building performance and coastal development practices.

The conclusions of post-event assessments can be classified according to those factors that contribute to both building damage and successful building performance:

- Hazard identification
- Siting
- Design
- Construction
- Maintenance

Reduction of building damages in coastal areas will require attention to these conclusions and coordination between owners, designers, buildings, and local officials.

Conclusions related to these five factors are presented in the tables that follow.

LESSONS RELATED TO HAZARD IDENTIFICATION

The following table summarizes lessons learned from coastal flood and wind events with regard to hazard identification issues.

ISSUE	CONCLUSION
Multiple Flood Hazards	Flood damage can result from the effects of short- and long-term increases in water levels (storm surge, tsunami, seiche, sea-level rise), wave action, high-velocity flows, erosion, and debris. Addressing all potential flood hazards at a site will help reduce the likelihood of building damage or loss.
Multiple Events	Failure to consider the effects of multiple storms or flood events may lead to an underestimation of flood hazards in coastal areas. Coastal buildings left intact by one storm may be vulnerable to damage or destruction by a second storm.
Long-Term Erosion	Long-term erosion can increase coastal flood hazards through time, causing loss of protective beaches, dunes, and bluffs, and soils supporting building foundations. Failure to account for long-term erosion is one of the more common errors made by those siting and designing coastal residential buildings.
Coastal A Zones	Flood hazards in areas mapped as A zones on coastal FIRMs can be much greater than flood hazards in riverine A zones. There are two reasons for this situation: 1. Waves 2–3 feet high (i.e., too small for an area to be classified as a V zone, but still capable of causing structural damage and erosion) will occur during base flood conditions in many coastal A zones. 2. Aging FIRMs may fail to keep pace with changing site conditions (e.g., long-term erosion, loss of dunes during previous storms) and revised flood hazard mapping procedures. Therefore, minimum A-zone foundation and elevation requirements should not be assumed adequate to resist coastal flood forces without a review of actual flood hazards. The concept of a “coastal A zone” with elevation and foundation requirements closer to those of V zones should be considered. **WARNING** FIRMs do not account for future effects of long-term erosion. Users are cautioned that all mapped flood hazard zones (V, A, and X) in areas subject to long-term erosion will likely underestimate the extent and magnitude of actual flood hazards that a coastal building will experience over its lifetime.

ISSUE	CONCLUSION
Effects of Topography on Wind Speeds	Failure to consider the effects of topography (and changes in topography—e.g., bluff erosion) on wind speeds can lead to underestimation of wind speeds that will be experienced during the design event. Siting buildings on high bluffs or near high-relief topography requires special attention by the designer.
Slope Stability	In coastal bluff areas, consideration of the potential effects of surface and subsurface drainage, removal of vegetation, and site development activities can help reduce the likelihood of problems resulting from slope stability hazards and landslides.
Septic Systems	Drainage from septic systems on coastal land can destabilize coastal bluffs and banks, accelerate erosion, and increase the risk of damage and loss to coastal buildings.
Groundwater in Bluffs	Vertical cracks in the soils of some cohesive bluffs cause a rapid rise of groundwater in the bluffs during extremely heavy and prolonged precipitation events and rapidly decrease the stability of such bluffs.
Seismic Hazards	Some coastal areas are also susceptible to seismic hazards. Although the likelihood of flood and seismic hazards acting simultaneously is small, each hazard should be identified carefully and factored into siting, design, and construction practices.

SELF-CHECK REVIEW: HAZARD IDENTIFICATION LESSONS

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

1. When siting atop high coastal bluffs, what hazards should receive special attention? Name at least two.

2. Addressing all potential ______________________________ at a site will help reduce the likelihood of building damage or loss.

3. _____________________________________ over time can cause loss of protective beaches, dunes, and bluffs and soil supporting building foundations.

4. Meeting minimum A zone foundation and elevation requirements is generally adequate to resist coastal flood forces.

   True False

5. FIRMs do not account for the future effects of long-term erosion.

   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. When siting atop high coastal bluffs, what hazards should receive special attention? Name at least two.

   Your answer should have included at least two of the following:
   - **Effects of topography on wind speeds**
   - **Potential effects on slope stability of surface and subsurface drainage, removal of vegetation, and site development activities**
   - **Drainage from septic systems**
   - **Vertical cracks that can cause rapid rise of groundwater**

2. Addressing all potential **hazards** at a site will help reduce the likelihood of building damage or loss.

3. **Long-term erosion** over time can cause loss of protective beaches, dunes, and bluffs and soil supporting building foundations.

4. Meeting minimum A zone foundation and elevation requirements is generally adequate to resist coastal flood forces.

   False.
   Minimum A-zone foundation and elevation requirements should not be assumed adequate to resist coastal flood forces without a review of actual flood hazards.

5. FIRMs do not account for the future effects of long-term erosion.

   True.
   All mapped flood hazard zones (V, A, and X) in areas subject to long-term erosion will likely underestimate the extent and magnitude of actual flood hazards that a coastal building will experience over its lifetime.

LESSONS RELATED TO SITING

The following table summarizes lessons learned from coastal flood and wind events with regard to siting issues.

ISSUE	CONCLUSION
Building Close to the Shoreline	Building close to the shoreline is a common, but possibly poor, siting practice. It may render a building more vulnerable to wave, flood, and erosion effects; may remove any margin of safety against multiple storms or erosion events; and may require moving, protecting, or demolishing the building if flood hazards increase over time.
Poor Siting of Elevated Buildings	In coastal areas subject to long-term or episodic erosion, poor siting often results in otherwise well-built elevated buildings standing on the active beach. While a structural success, such buildings are generally uninhabitable (because of the loss of utilities and access). This situation can also lead to conflicts over beach use and increase pressure to armor or renourish beaches (controversial and expensive measures).
Building Close to Other Structures	Building close to other structures may increase the potential for damage from flood, wind, debris, and erosion hazards. Of particular concern is the siting of homes or other small buildings adjacent to large, engineered high-rise structures. The larger structures can redirect and concentrate flood, wave, and wind forces and have been observed to increase flood and wind forces as well as scour and erosion.
Siting Too Close to Protective Structures	Depending on erosion or flood protection structures often leads to building damage or destruction. Seawalls, revetments, berms, and other structures may not afford the required protection during a design event and may themselves be vulnerable as a result of erosion and scour or other prior storm impacts. Siting too close to these structures may also preclude or make difficult any maintenance of the protective structure.
Siting on Top of Erodible Dunes and Bluffs	Siting buildings on the tops of erodible dunes and bluffs renders those buildings vulnerable to damage caused by the undermining of foundations and the loss of supporting soil around vertical foundation members.
Siting Downdrift of Stabilized Tidal Inlets	Siting buildings on the downdrift shoreline of an inlet whose location has been fixed by jetties often places the buildings in an area subject to increased erosion rates.
Depending on Barrier Islands	Siting along shorelines protected against wave attack by barrier islands or other land masses does not guarantee protection against flooding. In fact, storm surge elevations along low-lying shorelines in embayments are often higher than storm surge elevations on open coast shorelines.

SELF-CHECK REVIEW: SITING LESSONS

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

1. Building close to ____________________________ may require moving, protecting, or demolishing the building if flood hazards increase over time.

2. Give an example of a situation in which a building would be considered a structural success but a siting failure.

3. Why is it unwise to site buildings close to protective structures?

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

ANSWER KEY

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

1. Building close to **the shoreline** may require moving, protecting, or demolishing the building if flood hazards increase over time.

2. Give an example of a situation in which a building would be considered a structural success but a siting failure.

   A structurally sound elevated building sited too close to the shoreline will be a siting failure if erosion leaves it standing on the active beach without access or utilities.

3. Why is it unwise to site buildings close to protective structures?

   - **Seawalls, revetments, berms, and other structures may not provide the needed protection during a design event.**
   - **The structures themselves may become vulnerable as a result of erosion, scour, or other prior storm impacts.**
   - **Siting too close to the structure may also interfere with maintenance of the structure.**

LESSONS RELATED TO DESIGN

The following table summarizes lessons learned from coastal flood and wind events with regard to design issues.

ISSUE	CONCLUSION
Shallow Spread Footing and Slab Foundations	Use of shallow spread footing and slab foundations in areas subject to wave impact and/or erosion can result in building collapse, even during minor flood or erosion events. Because of the potential for undermining by erosion and scour, these foundations may not be appropriate for some coastal A zones and some coastal bluff areas outside the mapped floodplain.
Continuous Perimeter Wall Foundations	In areas subject to wave impact and/or erosion, the use of continuous perimeter wall foundations, such as crawlspace foundations (especially those constructed of unreinforced masonry) may result in building damage, collapse, or total loss.
Inadequate Embedment	Inadequate depth of foundation members (e.g., pilings not embedded deeply enough, shallow footings supporting masonry and concrete walls and columns) is a common cause of failure in elevated one- to four-family residential buildings.
Lack of Freeboard	Elevating a building sufficiently will help protect the superstructure from damaging wave forces. Designs should incorporate freeboard above the required elevation of the lowest floor or bottom of lowest horizontal member.
Non-Corrosion-Resistant Connectors	Failure to use corrosion-resistant structural connectors (e.g., wooden connectors, stainless steel connectors, or galvanized connectors made of heavier gauge metal or with thicker galvanizing) can compromise structural integrity and may lead to building failures under less than design conditions.

ISSUE	CONCLUSION
Corrosion of Metal Building Components	Corrosion of metal building components is accelerated by salt spray and breaking waves. Nails, screws, sheet-metal connector straps, and truss plates are the most likely to be threatened by corrosion.
Lack of a Continuous Load Path	Failure to provide a continuous load path using adequate connections between all parts of the building, from roof to foundation, may lead to structural failure.
Multi-Story Decks/Roofs	Multi-story decks/roofs supported by inadequately embedded vertical members can lead to major structural damage, even during minor flood and erosion events. Either roof overhangs should be designed to remain intact without vertical supports, or supports should be designed to the same standards as the main foundation. Decks must be designed to withstand all design loads or should be designed so that they do not cause damage to the main building when they fail.
Porch Roofs and Overhangs	Failure to adequate connect porch roofs and to limit the size of roof overhangs can lead to extensive damage to the building envelope.
Low-Slope Roofs	Many coastal communities have building height restrictions that, when coupled with building owners' desires to maximize building size and areas, encourage the use of low-slope roofs. These roofs can be more susceptible to wind damage and water penetration problems.
Unbraced Gable Ends and Wide Overhangs	Roof designs that incorporate gable ends (especially unbraced gable ends) and wide overhangs are susceptible to failure unless adequately designed and constructed for the expected loads. Alternative designs that are more resistant to wind effects should be used in coastal areas.
Roof Sheathing and Roof Coverings	Many commonly used residential roofing techniques, systems, and materials are susceptible to damage from wind and windborne debris. Designs should pay special attention to the selection and attachment of roof sheathing and roof coverings in coastal areas.

ISSUE	CONCLUSION
Protection of Building Envelope	Protection of the entire building envelope is necessary in high-wind areas. Therefore, proper specification of windows, doors, and their attachment to the structural frame is essential. Protecting openings with temporary or permanent storm shutters and the use of impact-resistant (e.g., laminated) glass will help protect the building envelope and reduce damage caused by wind, windborne debris, and rainfall penetration.
Treatment of Below-BFE Areas	Designs should maximize the use of lattice and screening below the BFE and minimize the use of breakaway wall enclosures in V zones and solid wall enclosures in A zones. Post-construction conversion of enclosures to habitable space remains a common violation of floodplain management requirements and is difficult for communities and States to control.
Swimming Pools	The design and placement of swimming pools can affect the performance of adjacent buildings. Pools should not be structurally attached to buildings, because an attached pool can transfer flood loads to the building. Building foundation designs should also account for increased flow velocities, wave ramping, wave deflection, and scour that can result from the redirection of flow by an adjacent pool.

SELF-CHECK REVIEW: DESIGN LESSONS

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

1. Place a check mark next to design alternatives that should generally be AVOIDED in coastal areas subject to wave impact.

_____ Shallow spread footings

_____ Slab foundations

_____ Elevation on pilings

_____ Corrosion-resistant connectors

_____ Continuous-perimeter wall foundations

_____ Deck supports designed to the same standards as the main foundation

_____ Continuous load path from roof to foundation

_____ Extensive use of breakaway wall enclosures below the BFE

_____ Attachment of a swimming pool to the building

_____ Shutters and impact-resistant glass on wall openings

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

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

ANSWER KEY

1. Place a check mark next to design alternatives that should generally be AVOIDED in coastal areas subject to wave impact.

  ✓   **Shallow spread footings**

  ✓   **Slab foundations**

_____ Elevation on pilings

_____ Corrosion-resistant connectors

  ✓   **Continuous-perimeter wall foundations**

_____ Deck supports designed to the same standards as the main foundation

_____ Continuous load path from roof to foundation

  ✓   **Extensive use of breakaway wall enclosures below the BFE**

  ✓   **Attachment of a swimming pool to the building**

_____ Shutters and impact-resistant glass on wall openings

LESSONS RELATED TO CONSTRUCTION

The following table summarizes lessons learned from coastal flood and wind events with regard to construction issues.

ISSUE	CONCLUSION
Poorly Made Structural Connections	Poorly made structural connections, particularly in wood-frame and masonry structures (e.g., pile/pier/column to beam, joist to beam) have been observed to cause the failure of residential structures throughout the coastal areas of the United States.
Fastener Selection	Connections must be made with the appropriate fastener for the design structural capacity to be attained. For example, post-event investigations have revealed many inadequate connections (e.g., made with the wrong size nails) that either failed during the event or could have failed if the design loads had been realized at the connection.
Use of Nail and Staple Guns	Nail and staple guns, which are used frequently to speed construction, have disadvantages that can lead to connections with reduced capacity. These guns can easily overdrive nails or staples, or drive them at an angle. In addition, it is often difficult for the nail gun operator to determine whether a nail has penetrated an unexposed wood member (such as a rafter or truss below roof sheathing) as intended.
Inadequate Embedment	Failure to achieve the pile or foundation embedment specified by building plans or local/State requirements will render an otherwise properly constructed building vulnerable to flood, erosion, and scour damage.
Improperly Constructed Breakaway Walls	Improperly constructed breakaway walls (e.g., improperly fastened wall panels, panels constructed immediately seaward of foundation cross-bracing) can cause preventable damage to the main structure. Lack of knowledge or inattention by contractors can cause unnecessary damage.
Utility Systems	Improperly installed utility system components (e.g., plumbing and electrical components attached to breakaway walls or on the waterward side of vertical foundation members; unelevated or insufficiently elevated heat pumps, air conditioning compressors, and ductwork) will fail during a flood event. They can also cause damage to the main structure that otherwise might not have occurred.

ISSUE	CONCLUSION
Roofs and Walls	Bracing and fastening roofs and walls can help prevent building envelope failures in high-wind events.
Roofing Connections	Lack of or inadequate connections between shingles and roof sheathing and between sheathing and roof framing (e.g., nails that fail to penetrate roof truss members or rafters) can cause roof failures and subsequent building failures.
Inspection	Communities often have insufficient resources to inspect buildings frequently during construction. Although contractors are responsible for following plans and satisfying code requirements, infrequent inspections may result in failure to find and remedy construction deficiencies.

LESSONS RELATED TO MAINTENANCE

The following table summarizes lessons learned from coastal flood and wind events with regard to maintenance issues.

ISSUE	CONCLUSION
Deterioration Repair and Replacement	Repairing and replacing structural elements, connectors, and building envelope components that have deteriorated over time, because of decay or corrosion, will help maintain the building's resistance to natural hazards. Maintenance of building components in coastal areas should be a constant and ongoing process. The ultimate costs of deferred maintenance in coastal areas can be high when natural disasters strike.
Damage Repair	Failure to inspect and repair damage caused by a wind, flood, erosion, or other event will make the building even more vulnerable during the next event.
Maintenance of Erosion Control and Flood Protection Structures	Failure to maintain erosion control or coastal flood protection structures will lead to increased vulnerability of those structures and the buildings behind them.

SELF-CHECK REVIEW: CONSTRUCTION AND MAINTENANCE LESSONS

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

1. Bracing and fastening roofs and walls can help prevent building envelope failures in high wind events.

   True False

2. Inadequate connections between shingles and roof sheathing, or between sheathing and roof framing, can lead to roof failures.

   True False

3. The best schedule for inspecting and maintaining building components in coastal areas is once every 5 years and after storm damage.

   True False

4. Nail guns are highly recommended for coastal construction because of the uniformity they provide.

   True False

ANSWER KEY

1. Bracing and fastening roofs and walls can help prevent building envelope failures in high wind events.

   True

2. Inadequate connections between shingles and roof sheathing, or between sheathing and roof framing, can lead to roof failures.

   True

3. The best schedule for inspecting and maintaining building components in coastal areas is once every 5 years and after storm damage.

   False.
   Maintenance should be a constant and ongoing process, and buildings should be inspected following any wind, flood, erosion, or other event that could cause damage. The ultimate costs of deferred maintenance in coastal areas can be high when natural disasters strike.

4. Nail guns are highly recommended for coastal construction because of the uniformity they provide.

   False.
   Nail guns can overdrive nails or drive them at an angle. It may also be difficult to determine whether a nail has adequately penetrated an underlying wood member.

UNIT I EXERCISE

Instructions: Use this Unit Exercise to test how well you learned the material presented in Unit I. 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 II.

1. Which of the following terms is used to describe flood elevation in communities that enforce floodplain management requirements more stringent than those of the NFIP?

   _____ Base Flood Elevation (BFE)

   _____ Design Flood Elevation (DFE)

2. Areas that are subject to inundation by a flood that has a one percent probability of being equaled or exceeded in any given year are called:

   ____

3. The portion of the SFHA that extends from offshore to the inland limit of a primary frontal dune along an open coast, and any other area subject to high-velocity wave action from storms or seismic sources is called:

   ____

4. On Flood Insurance Rate Maps, the portion of the SFHA that is inland of the V zone is:

   ____

5. What have past coastal flood and wind events taught us about multiple events?

6. When siting a building on a coastal bluff, failure to consider the effects of __________________ on wind speeds can lead to underestimation of wind speeds that will be experienced during the design event.

7. What have past coastal flood and wind events taught us about building close to the shoreline?

8. A builder wants to build homes on a shoreline that is protected from the open ocean by barrier islands. What would you tell this person, based past coastal flood and wind events?

9. What lesson about freeboard can designers derive from past coastal flood and wind events?

10. What is the most common foundation problem that leads to significant building damage in coastal events?

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

UNIT I EXERCISE — ANSWER KEY

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

1. Which of the following terms is used to describe flood elevation in communities that enforce floodplain management requirements more stringent than those of the NFIP?

   __✓__ **Design Flood Elevation (DFE)**

2. Areas that are subject to inundation by a flood that has a one percent probability of being equaled or exceeded in any given year are called:

   Special Flood Hazard Areas (SFHAs).

3. The portion of the SFHA that extends from offshore to the inland limit of a primary frontal dune along an open coast, and any other area subject to high-velocity wave action from storms or seismic sources is called:

   The V zone. (The V zone is also referred to as the Coastal High Hazard Area).

4. On Flood Insurance Rate Maps, the portion of the SFHA that is inland of the V zone is:

   The A zone (the Coastal A zone designation is not currently used on FIRMS).

5. What have past coastal flood and wind events taught us about multiple events?

   Coastal buildings left intact by one storm may be vulnerable to damage or destruction by a second storm. Failure to consider the effects of multiple storms or flood events may lead to an underestimation of flood hazards in coastal areas.

6. When siting a building on a coastal bluff, failure to consider the effects of **<u>topography</u>** on wind speeds can lead to underestimation of wind speeds that will be experienced during the design event.

7. What have past coastal flood and wind events taught us about building close to the shoreline?

   Building close to the shoreline is a common, but possibly poor, siting practice. It may render a building more vulnerable to wave, flood, and erosion effects. It may remove any margin of safety against multiple storms or erosion events. It may require moving, protecting, or demolishing the building if flood hazards increase over time.

8. A builder wants to build homes on a shoreline that is protected from the open ocean by barrier islands. What would you tell this person, based past coastal flood and wind events?

   Siting along shorelines protected against wave attack by barrier islands or other land masses does not guarantee protection against flooding. In fact, storm surge elevations along low-lying shorelines in embayments are often higher than storm surge elevations on open coast shorelines.

9. What lesson about freeboard can designers derive from past coastal flood and wind events?

   Elevating a building sufficiently will help protect the superstructure from damaging wave forces. Designs should incorporate freeboard above the required elevation of the lowest floor or the bottom of the lowest horizontal member.

10. What is the most common foundation problem that leads to significant building damage in coastal events?

    Inadequate embedment of foundation members (e.g., pilings not embedded deeply enough, shallow footings supporting masonry and concrete walls and columns).