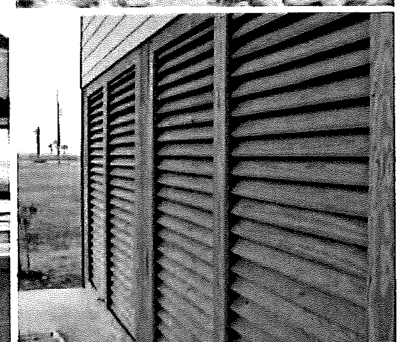

Coastal Construction Manual

Principles and Practices of Planning, Siting, Designing, Constructing, and Maintaining Residential Buildings in Coastal Areas (Fourth Edition)

FEMA P-55 / Volume II / August 2011

FEMA

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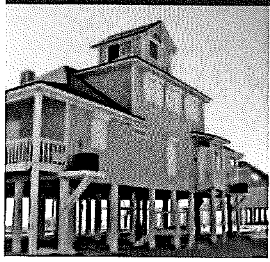


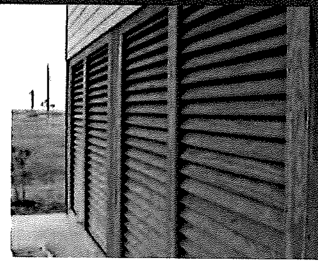


Preface

The 2011 *Coastal Construction Manual,* Fourth Edition (FEMA P-55), is a two-volume publication that provides a comprehensive approach to planning, siting, designing, constructing, and maintaining homes in the coastal environment. Volume I of the *Coastal Construction Manual* provides information about hazard identification, siting decisions, regulatory requirements, economic implications, and risk management. The primary audience for Volume I is design professionals, officials, and those involved in the decision-making process.

Volume II contains in-depth descriptions of design, construction, and maintenance practices that, when followed, will increase the durability of residential buildings in the harsh coastal environment and reduce economic losses associated with coastal natural disasters. The primary audience for Volume II is the design professional who is familiar with building codes and standards and has a basic understanding of engineering principles.

Volume II is not a standalone reference for designing homes in the coastal environment. The designer should have access to and be familiar with the building codes and standards that are discussed in Volume II and listed in the reference section at the end of each chapter. The designer should also have access to the building codes and standards that have been adopted by the local jurisdiction if they differ from the standards and codes that are cited in Volume II. If the local jurisdiction having authority has not adopted a building code, the most recent code should be used. Engineering judgment is sometimes necessary, but designers should not make decisions that will result in a design that does not meet locally adopted building codes.

The topics that are covered in Volume II are as follows:

- **Chapter 7** – Introduction to the design process, minimum design requirements, losses from natural hazards in coastal areas, cost and insurance implications of design and construction decisions, sustainable design, and inspections.

- **Chapter 8 –** Site-specific loads, including from snow, flooding, tsunamis, high winds, tornadoes, seismic events, and combinations of loads. Example problems are provided to illustrate the application of design load provisions of ASCE 7-10, *Minimum Design Loads for Buildings and Other Structures.*
- **Chapter 9 –** Load paths, structural connections, structural failure modes, breakaway walls, building materials, and appurtenances.
- **Chapter 10 –** Foundations, including design criteria, requirements and recommendations, style selection (e.g., open, closed), pile capacity in soil, and installation.
- **Chapter 11 –** Building envelope, including floors in elevated buildings, exterior doors, windows and skylights, non-loading-bearing walls, exterior wall coverings, soffits, roof systems, and attic vents.
- **Chapter 12 –** Installing mechanical equipment and utilities.
- **Chapter 13 –** Construction, including the foundation, structural frame, and building envelope. Common construction mistakes, material selection and durability, and techniques for improving resistance to decay and corrosion are also discussed.
- **Chapter 14 –** Maintenance of new and existing buildings, including preventing damage from corrosion, moisture, weathering, and termites; building elements that require frequent maintenance; and hazard-specific maintenance techniques.
- **Chapter 15 –** Evaluating existing buildings for the need for and feasibility of retrofitting for wildfire, seismic, flood, and wind hazards and implementing the retrofitting. Wind retrofit packages that can be implemented during routine maintenance are also discussed (e.g., replacing roof shingles).

For additional information on residential coastal construction, see the FEMA Residential Coastal Construction Web site at http://www.fema.gov/rebuild/mat/fema55.shtm.

Acknowledgments

Fourth Edition Authors and Key Contributors

William Coulbourne, Applied Technology Council
Christopher P. Jones, Durham, NC
Omar Kapur, URS Group, Inc.
Vasso Koumoudis, URS Group, Inc.
Philip Line, URS Group, Inc.
David K. Low, DK Low and Associates
Glenn Overcash, URS Group, Inc.
Samantha Passman, URS Group, Inc.
Adam Reeder, Atkins
Laura Seitz, URS Group, Inc.
Thomas Smith, TLSmith Consulting
Scott Tezak, URS Group, Inc. – Consultant Project Manager

Fourth Edition Volume II Reviewers and Contributors

Katy Goolsby-Brown, FEMA Region IV
John Ingargiola, FEMA Headquarters – Technical Assistance and Research Contracts Program Manager
John Plisich, FEMA Region IV
Paul Tertell, FEMA Headquarters – Project Manager
Ronald Wanhanen, FEMA Region VI
Gregory P. Wilson, FEMA Headquarters
Brad Douglas, American Forest and Paper Association
Gary Ehrlich, National Association of Home Builders
Dennis Graber, National Concrete Masonry Association
David Kriebel, United States Naval Academy
Marc Levitan, National Institute of Standards and Technology
Tim Mays, The Military College of South Carolina
Sam Nelson, Texas Department of Insurance
Janice Olshesky, Olshesky Design Group, LLC
Michael Powell, Delaware Department of Natural Resources and Environmental Control
David Prevatt, University of Florida
Timothy Reinhold, Insurance Institute for Business & Home Safety
Tom Reynolds, URS Group, Inc.
Michael Rimoldi, Federal Alliance for Safe Homes
Randy Shackelford, Simpson Strong-Tie
John Squerciati, Dewberry
Keqi Zhang, Florida International University

Fourth Edition Technical Editing, Layout, and Illustration

Diana Burke, URS Group, Inc.
Lee-Ann Lyons, URS Group, Inc.
Susan Ide Patton, URS Group, Inc.
Billy Ruppert, URS Group, Inc.

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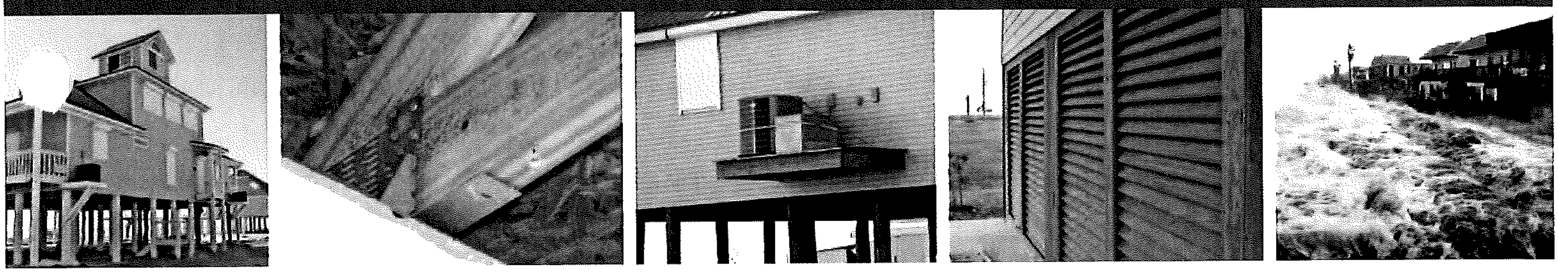


7 Pre-Design Considerations

This chapter provides an overview of the issues that should be considered before the building is designed.

CROSS REFERENCE

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

Coastal development has increased in recent years, and some of the sites that are chosen for development have higher risks of impact from natural hazards than in the past. Examples of sites with higher risks are those that are close to the ocean, on high bluffs that are subject to erosion, and on artificial fill deposits. In addition, many of the residential buildings constructed today are larger and more costly than before, leading to the potential for larger economic losses if disaster strikes. However, studies conducted by the Federal Emergency Management Agency (FEMA) and others after major coastal disasters have consistently shown that coastal residential buildings that are properly sited, designed, and constructed have generally performed well during natural hazard events.

Important decisions need to be made prior to designing the building. The decisions should be based on an understanding of regulatory requirements, the natural hazard and other risks associated with constructing a building on a particular site (see Chapter 4), and the financial implications of the decisions. The financial implications of siting decisions include the cost of hazard insurance, degree of hazard resistance and sustainability in the design, and permits and inspections.

Once a site has been selected, decisions must be made concerning building placement, orientation, and design. These decisions are driven primarily by the following:

- Owner, designer, and builder awareness of natural hazards
- Risk tolerance of the owner
- Aesthetic considerations (e.g., building appearance, proximity to the water, views from within the building, size and number of windows)
- Building use (e.g., full-time residence, part-time residence, rental property)
- Requirements of Federal, State, and local regulations and codes
- Initial and long-term costs

The interrelationships among aesthetics, building use, regulatory and code requirements, and initial cost become apparent during siting and design, and decisions are made according to the individual needs or goals of the property owner, designer, or builder. However, an understanding of the effect of these decisions on long-term and operational costs is often lacking. The consequences of the decisions can range from increased maintenance and utility costs to the ultimate loss of the building. The goal of this Manual is to provide the reader with an understanding of these natural hazards and provide guidance on concepts for designing a more hazard-resistant residential building.

7.1 Design Process

The design process includes a consideration of the types of natural hazards that occur in the area where the building site is located and the design elements that allow a building to effectively withstand the potential damaging effects of the natural hazards (see Figure 7-1). The intent of this Manual is to provide sufficient technical information, including relevant examples, to help the designer effectively design a coastal residential building.

This Manual does not describe all combinations of loads, types of material, building shapes and functions, hazard zones, and elevations applicable to building design in the coastal environment. The designer must apply engineering judgment to a range of problems. In addition, good design by itself is not enough to guarantee a high-quality structure. Although designing building components to withstand site-specific loads is important, a holistic approach that also includes good construction, inspection, and maintenance practices can lead to a more resilient structure.

Before designing a building and to optimize the usefulness of Volume II of this Manual, the designer should obtain the codes and standards, such as ASCE 7 and ASCE 24, that are listed in the reference section of each chapter and other relevant information such as locally adopted building codes and appropriate testing protocols.

Although codes and standards provide minimums, the designer may pursue a higher standard. Many decisions require the designer's judgment, but it is never appropriate to use a value or detail that will result in a building that is not constructed to code.

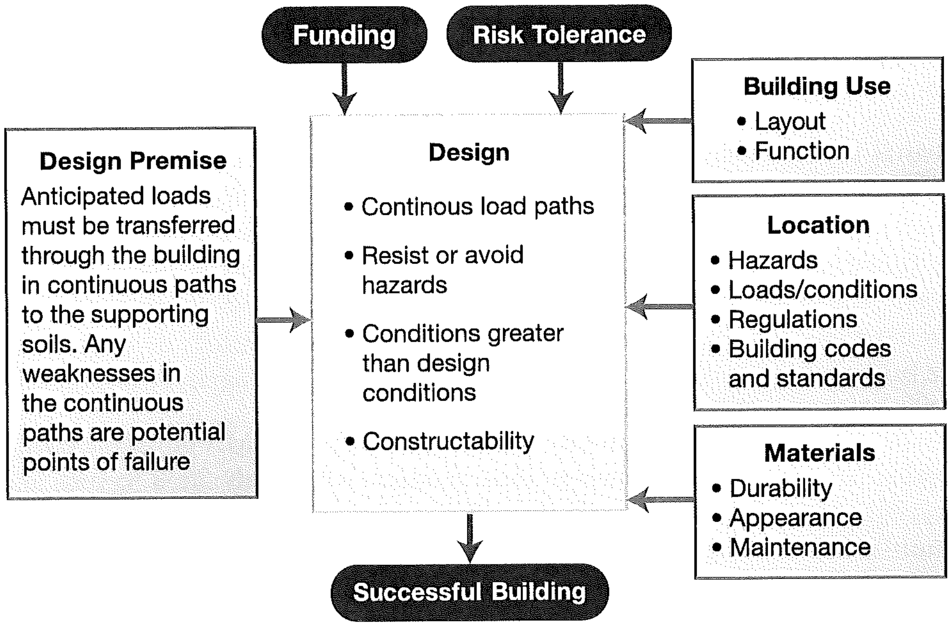


Figure 7-1.
Design framework for a successful building, incorporating cost, risk tolerance, use, location, materials, and hazard resistance

Volume II contains many design equations, but they do not cover all of the design calculations that are necessary and are provided only as examples.

7.2 Design Requirements

The minimum design requirements for loads, materials, and material resistances for a given building design are normally specified in the locally adopted building code. Nothing in this Manual is intended to recommend the use of materials or systems outside the uses permitted in building code requirements. The loads used in this Manual are based on ASCE 7-10, which is the reference load standard in model building codes. Material and material resistance requirements cited in this Manual are based on the minimum requirements of applicable building codes. However, designers are encouraged throughout the Manual to seek out information on loads and materials that exceed the minimum requirements of the building code. Other sources of information for loads and materials are also provided.

7.3 Determining the Natural Hazard Risk

Assessing risk to coastal buildings and building sites requires identifying or delineating hazardous areas and considering the following factors:

- Types of hazards known to affect a region
- Geographic variations in hazard occurrence and severity
- Methods and assumptions underlying existing hazard identification maps or products

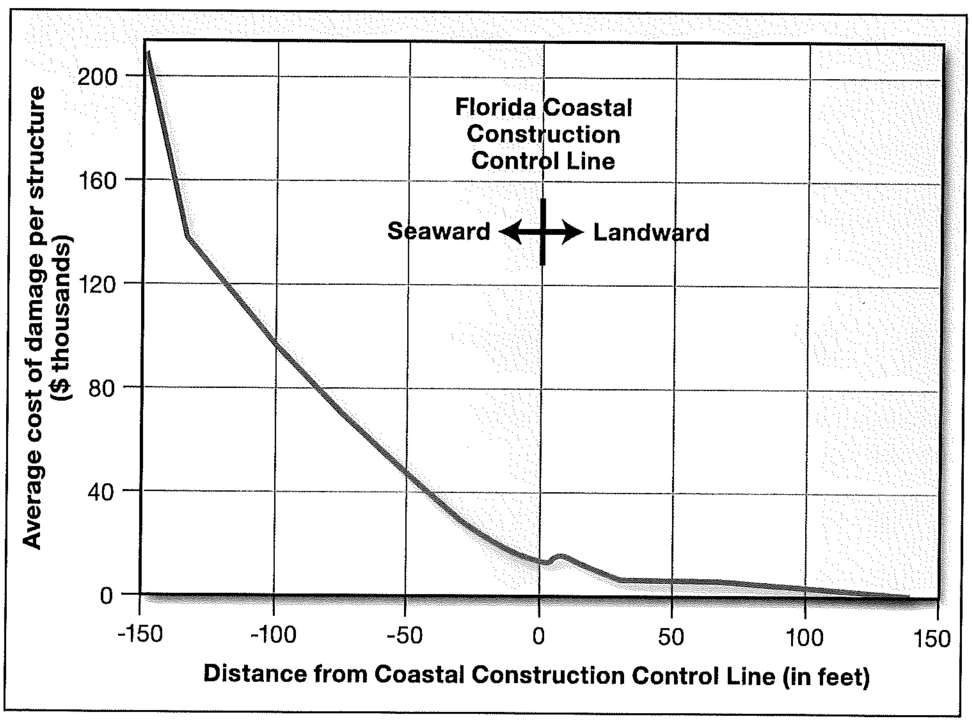
- "Acceptable" level of risk
- Consequences of using (or not using) recommended siting, design, and construction practices

Geographic variations in coastal hazards occur, both along and relative (perpendicular) to the coastline. Hazards affecting one region of the country may not affect another. Hazards such as wave loads, which affect construction close to the shoreline, usually have a lesser or no effect farther inland. For example, Figure 7-2 shows how building damage caused by Hurricane Eloise in 1975 was greatest at the shoreline but diminished rapidly in the inland direction. The figure represents data from only one storm but shows the trend of a typical storm surge event on coastlines (i.e., damage decreases significantly as wave height decreases). The level of damage and distance landward are dictated by the severity of the storm and geographic location.

Through Flood Insurance Studies (FISs) and Flood Insurance Rate Maps (FIRMs), FEMA provides detailed coastal flood hazard information (see Section 3.5). However, these products reflect only flood hazards and do not include a consideration of a number of other hazards that affect coastal areas. Other Federal agencies and some states and communities have completed additional coastal hazard studies and delineations. The Residential Coastal Construction Web site (http://www.fema.gov/rebuild/mat/fema55.shtm) provides introductory information concerning more than 25 hazard zone delineations developed by or for individual communities or states (see "Web Sites for Information about Storms, Big Waves, and Water Level"). Some delineations have been incorporated into mandatory siting and/or construction requirements.

When reviewing the hazard maps and delineations that are provided on the Residential Coastal Construction Web site, designers should be aware that coastal hazards are often mapped using different levels of risk or recurrence intervals. Thus, the ***consistent*** and ***acceptable level of risk*** (the level of risk judged by the designer to be appropriate for a particular building) should be considered early in the planning and design process (see Chapter 6). The hazard maps and delineations are provided as a historical reference only. The most up-to-date information can be obtained by contacting local officials.

Figure 7-2.
Average damage per structure (in thousands of 1975 dollars) versus distance from the Florida Coastal Construction Control Line for Bay County, FL, Hurricane Eloise (Florida, 1975)
SOURCE: ADAPTED FROM SHOWS 1978



7.4 Losses Due to Natural Hazards in Coastal Areas

It is easy for property owners to become complacent about the potential for a natural disaster to affect their properties. Hurricanes and earthquakes are generally infrequent events. A geographic area may escape a major hazard event for 20 or more years. Or, if an area has recently been affected, residents may believe the chances of a recurrence in the near future are remote. These perceptions are based on inaccurate assumptions and/or a lack of understanding of natural hazards and the risk of damage.

The population and property values along the U.S. coast are both rapidly increasing. Although better warning systems have reduced the number of fatalities and injuries associated with natural disasters, increases in the number and value of structures along the coast have dramatically increased potential property losses.

From 2000 through 2009, there were 13 presidentially declared disasters resulting from hurricanes and tropical systems, each causing more than $1 billion in losses. Hurricane Katrina in 2005 was the most expensive natural disaster in U.S. history, causing estimated economic losses of more than $125 billion and insured losses of $35 billion, surpassing Hurricane Andrews's $26.5 billion in losses in 1992. Other recent memorable storms are Tropical Storm Allison (2001), Hurricane Rita (2005), Hurricane Wilma (2005), Hurricane Ike (2008), and the 2004 hurricane season in which four storms (Charley, Frances, Ivan, and Jeanne) affected much of the East Coast in both coastal and inland areas.

NOTE

According to the Mortgage Bankers Association (2006), from 1985 to 2005, hurricanes and tropical storms accounted for the major share of all catastrophic insurance losses. The percentages of property damage caused by various catastrophic events during this period were:

- 43.7 percent from hurricane/tropical storms
- 23.3 percent from wind/thunderstorms
- 5.1 percent from earthquakes

Approximately 94.4 percent of all catastrophic events occurring during this period were attributed to natural disasters.

Following Hurricane Andrew, which ravaged south Florida in 1992, studies were conducted to determine whether the damage suffered was attributable more to the intensity of the storm or to the location and type of development. According to the Insurance Institute for Business and Home Safety (IBHS):

> Conservative estimates from claim studies reveal that approximately 25 percent of Andrew-caused insurance losses (about $4 billion) were attributable to construction that failed to meet the code due to poor enforcement, as well as shoddy workmanship. At the same time, concentrations of population and of property exposed to hurricane winds in southern Florida grew many-fold (IBHS 1999).

After Hurricane Andrew, codes and regulations were enacted that support stronger building practices and wind protection. IBHS conducted a study in 2004 following Hurricane Charley that found:

> ... homes built after the adoption of these new standards resulted in a decrease in the frequency and severity of damage to various building components. Furthermore, based on the analysis of additional living expense records, it is concluded that the new building code requirements allowed homeowners to return to their home more quickly and likely reduced the disruption of their day to day lives (IBHS 2004, p. 5).

The past several decades have not resulted in major losses along the Pacific coast or Great Lakes, but periodic reminders support the need for maintaining a vigilant approach to hazard-resistant design for coastal structures in other parts of the country. In February 2009, the Hawaiian Islands and portions of California were under a tsunami watch. This type of watch occurs periodically in sections of northern California, Oregon, Washington, and Alaska and supports the need to construct buildings on elevated foundations. Although tsunamis on the Pacific coast may be less frequent than coastal hazard events on the Atlantic coast, ignoring the threat can result in devastating losses.

Hazard events on the coastlines of the Great Lakes have resulted in damage to coastal structures and losses that are consistent with nor'easters on the Atlantic coast. Surge levels and high winds can occur every year on the Great Lakes, and it is important for designers to ensure that homeowners and builders understand the nature of storms on the Great Lakes. As in other regions, storm-related losses can result in the need to live in a house during lengthy repairs or be displaced for extended periods while the house is being repaired. The loss of irreplaceable possessions or property not covered by flood or homeowners insurance policies are issues a homeowner should be warned of and are incentives to taking a more hazard-resistant design approach.

Chapters 2 and 3 contain more information about the hazards and risks associated with building in coastal areas.

7.5 Initial, Long-Term, and Operational Costs

Like all buildings, coastal residential buildings have initial, long-term, and operational costs.

- ***Initial costs*** include property evaluation, acquisition, permitting, design, and construction.
- ***Long-term costs*** include preventive maintenance and repair and replacement of deteriorated or damaged building components. A hazard-resistant design can result in lower long-term costs by preventing or reducing losses from natural hazard events.
- ***Operational costs*** include costs associated with the use of the building, such as the cost of utilities and insurance. Optimizing energy efficiency may result in a higher initial cost but save in operational costs.

In general, the decision to build in any area subject to significant natural hazards—especially coastal areas—increases the initial, long-term, and operational costs of building ownership. Initial costs are higher because the natural hazards must be identified, the associated risks assessed, and the building designed and constructed to resist damage from the natural hazard forces. Long-term costs are likely to be higher because a building in a high-risk area usually requires more frequent and more extensive maintenance and repairs than a building sited elsewhere. Operational costs are often higher because of higher insurance costs and, in some instances, higher utility costs. Although these costs may seem higher, benefits such as potential reductions in insurance premiums and reduced repair time following a natural disaster may offset the higher costs.

7.5.1 Cost Implications of Siting Decisions

The cost implications of siting decisions are as follows:

- The closer buildings are sited to the water, the more likely they are to be affected by flooding, wave action, erosion, scour, debris impact, overwash, and corrosion. In addition, wind speeds are typically higher along coastlines, particularly within the first several hundred feet inland. ***Repeated exposure to these hazards, even when buildings are designed to resist their effects, can lead to increased long-term costs for maintenance and damage repair.***

COST CONSIDERATION

Designers and homeowners should recognize that erosion control measures can be expensive, both initially and over the lifetime of a building. In some instances, erosion control costs can equal or exceed the cost of the property or building being protected.

- Erosion—especially long-term erosion—poses a serious threat to buildings near the water and on high bluffs above the floodplain. Wind-induced erosion can lower ground elevations around coastal buildings, exposing Zone V buildings to higher-than-anticipated forces, and exposing Zone A buildings to Zone V flood hazards. ***Maintenance and repair costs are high for buildings in erosion hazard areas, not only because of damage to the building, but also because of the need for remedial measures (e.g., building relocation or erosion protection projects, such as seawalls, revetments, and beach nourishment, where permitted).***

CROSS REFERENCE

For information on siting coastal residential buildings, see Chapter 4.

- Sites nearest the water are likely to be in Zone V where building foundations, access stairs, parking slabs, and other components below the building are especially vulnerable to flood, erosion, and scour effects. As a result, ***the potential for repeated damage and repair is greater for Zone V buildings than buildings in other zones, and the buildings have higher flood insurance rates and increased operational costs.*** In addition, although elevating a building can protect the superstructure from flood damage, it may make the entire building more vulnerable to earthquake and wind damage.

7.5.2 Cost Implications of Design Decisions

The cost implications of design decisions are as follows:

- For aesthetic reasons, the walls of coastal buildings often include a large number of openings for windows and doors, especially in the walls that face the water. ***Designs of this type lead to greater initial costs to strengthen the walls and to protect the windows and doors from wind and wind-borne debris (missiles).*** If adequate protection in the form of shutter systems or impact-resistant glazing is not provided, long-term costs are greater because of (1) the need to repair damage to glazing and secondary damage by the penetration of wind-driven rain and sea spray and/or (2) the need to install retrofit protection devices at a later date.

NOTE

Over the long term, poor siting decisions are rarely overcome by building design.

- As explained in Chapter 5, National Flood Insurance Program (NFIP) regulations allow buildings in Coastal A Zones to be constructed on perimeter wall (e.g., crawlspace) foundations or on earth fill. Open (pile, pier, or column) foundations are required only for Zone V buildings. Although a Coastal A Zone building on a perimeter wall foundation or fill may have a lower initial construction cost than a similar building on an open foundation, it may be subject to damaging waves, velocity flows, and/or erosion and scour over its useful life. As a result, ***the long-term costs for a building on a perimeter wall foundation or fill may actually be higher because of the increased potential for damage.***

- In an effort to reduce initial construction costs, designers may select building materials that require high levels of maintenance. Unfortunately, the initial savings are often offset because (1) coastal buildings, particularly those near bodies of saltwater, are especially prone to the effects of corrosion, and (2) owners of coastal buildings frequently fail to sustain the continuing and time-consuming levels of maintenance required. ***The net effect is often increased building deterioration and sometimes a reduced capacity of structural and non-structural components to resist the effects of future natural hazard events.***

Table 7-1 provides examples of design elements and the cost considerations associated with implementing them. Although these elements may have increased costs when implementing them on a single building, developers may find that incorporating them into speculative houses with large-scale implementation can provide some savings.

Table 7-1. Examples of Flood and Wind Mitigation Measures

Mitigation Measure	Cross References[a]	Benefits/Advantages	Costs/Other Considerations
Adding 1 to 2 feet to the required elevation of the lowest floor or lowest horizontal structural member of the building	5.4.2 6.2.1.3	Reduces the potential for the structure to be damaged by waves and/or floodwaters; reduces flood insurance premiums	May conflict with community building height restrictions; may require additional seismic design considerations; longer pilings may cost more
Increasing embedment depth of pile foundations	10.2.3 13.1.2	Adds protection against scour and erosion	Longer pilings may cost more
Improving flashing and weather-stripping around windows and doors	11.4.1.2	Reduces water and wind infiltration into building	Increases the number of important tasks for a contractor to monitor
Installing fewer breakaway walls or more openings in continuous foundation walls than currently noted on the building plans	5.4.2	Decreases potential for damage to understory of structure; reduces amount of debris during storm event	Reduces the ability to use understory structure for storage for open foundations
Elevating a building in a Coastal Zone A on an open foundation or using only breakaway walls for enclosures below the lowest floor	5.4.2 10.3.1	Reduces the potential for the structure to be damaged by waves, erosion, and floodwaters	Breakaway walls still require flood openings in Zone A

Table 7-1. Examples of Flood and Wind Mitigation Measures (concluded)

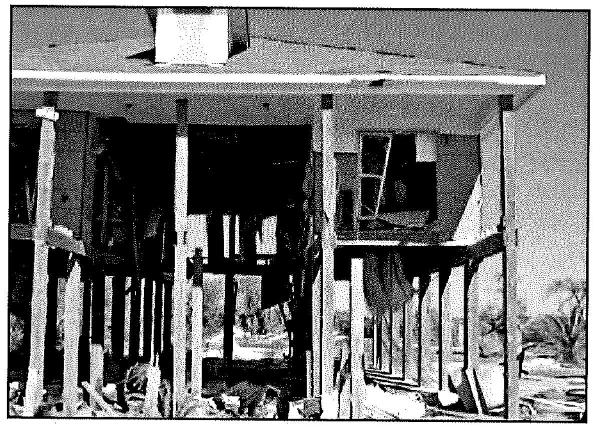
Mitigation Measure	Cross References[a]	Benefits/Advantages	Costs/Other Considerations
Adding shutters for glazing protection	11.3.1.2	Reduces the potential for damage from wind-borne debris impact during a storm event; reduces potential for wind-driven rain water infiltration	Shutters require installation or activation before a storm event
Using asphalt roof shingles with high bond strength	11.5.1	Reduces shingle blowoff during high winds	High bond strength shingles are slightly more expensive
Instead of vinyl siding, installing cladding systems that have passed a test protocol that simulates design-level fluctuating wind pressures (on a realistic installed wall specimen)	11.4.1.1 14.2.2	Tested cladding systems reduce blowoff on walls during high winds	These systems may cost more than other materials and may require additional maintenance
Using metal connectors or fasteners with a thicker galvanized coating or connectors made of stainless steel	14.1.1 14.2.6	Increases useful life of connectors and fasteners	Thicker galvanized or stainless steel coatings are more costly
Installing roof sheathing using a high-wind prescriptive approach for improved fasteners, installing additional underlayments, or improving roof covering details as required	11.5 15.3.1	Reduces wind and water damage to roof covering and interior from a severe event	Minimal increased cost when these tasks are done during a reroofing project

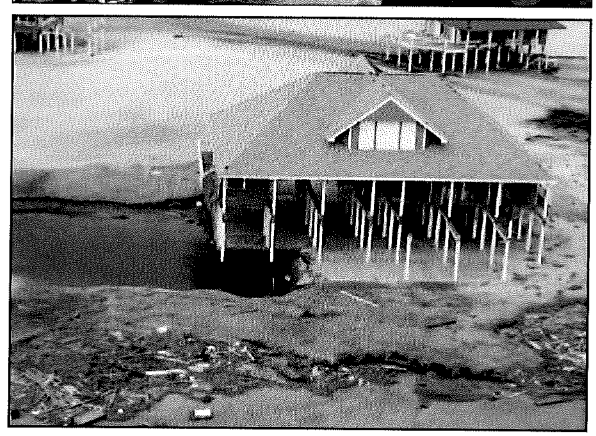
(a) Sections in this Manual

DESIGNING FOR FLOOD LEVELS ABOVE THE BASE FLOOD ELEVATION (BFE)

Designers and owners should consider designing buildings for flood levels above the BFE for the following reasons:

- Floods more severe than the base flood can and do occur, and the consequences of flood levels above the BFE can be devastating.
- Older FIRMs may not reflect current base flood hazards.
- FIRMs do ***not*** account for the effect of future conditions flood hazards; future flood hazards may exceed present-day flood hazards because of sea level rise, coastal erosion, and other factors.
- Buildings elevated above the BFE will sustain less flood damage and will be damaged less often than buildings constructed at the BFE.
- For a given coastal foundation type, the costs of building higher than the BFE are nominal when compared to reduced future costs to the owner.
- Flood damage increases rapidly with flood elevation above the lowest floor, especially when waves are present. Lateral and vertical wave forces against elevated buildings ("wave slam") can be large and destructive. Waves as small as 1.5 feet high can destroy many residential walls.
- Elevated buildings whose floor systems and walls are submerged during a flood may enhance foundation scour by constricting flow between the elevated building and the ground.
- Over a 50-year lifetime, the chance of a base flood occurring is about 40 percent. For most coastal areas, the chance of a flood approximately 3 feet higher than the BFE occurring over 50 years will only be about 10 percent. Designing and constructing to an elevation of BFE + 3 feet is not normally difficult.
- Owners whose buildings are elevated above the BFE can save significant amounts of money through reduced flood insurance premiums. Premiums can be reduced by up to 50 to 70 percent, and savings can reach several thousands of dollars per year in Zone V.





7.5.3 Benefits and Cost Implications of Siting, Design, and Construction Decisions

This Manual is designed to help property owners manage some of the risk associated with constructing a residential building in a coastal area. As noted in Chapter 2, studies of the effects of natural disasters on buildings demonstrate that sound siting, design, engineering, construction, and maintenance practices are important factors in the ability of a building to survive a hazard event with little or no damage. This chapter and the remainder of Volume II provide detailed information about how to site, design, construct, and maintain a building to help manage risks.

CROSS REFERENCE

For more information on designing coastal residential buildings, see Chapter 9.

Constructing to a model building code and complying with regulatory siting requirements provides a building with a certain level of protection against damage from natural hazards. However, compliance with minimum code and regulatory requirements does not guarantee that a building is not at risk from a natural hazard. Exceeding code and minimum regulatory requirements provides an added measure of safety but also adds to the cost of construction, which must be weighed against the benefit gained.

The often minimal initial cost of mitigation measures offers long-term benefits that provide a cost savings from damage avoided over the life of the building. Incorporating mitigation measures can reduce a homeowner's insurance premiums and better protect the building, its contents, and occupants during a natural hazard event, thus decreasing potential losses. Similar to cost reductions provided by the U.S. Green Building Council *LEED [Leadership in Energy and Environmental Design]) for Homes Reference Guide* (USGBC 2009) and ICC 700-2008, incorporating hazard mitigation measures into a building may pay for themselves over a few years based on insurance premium savings and the improved energy efficiency that some of the techniques provide.

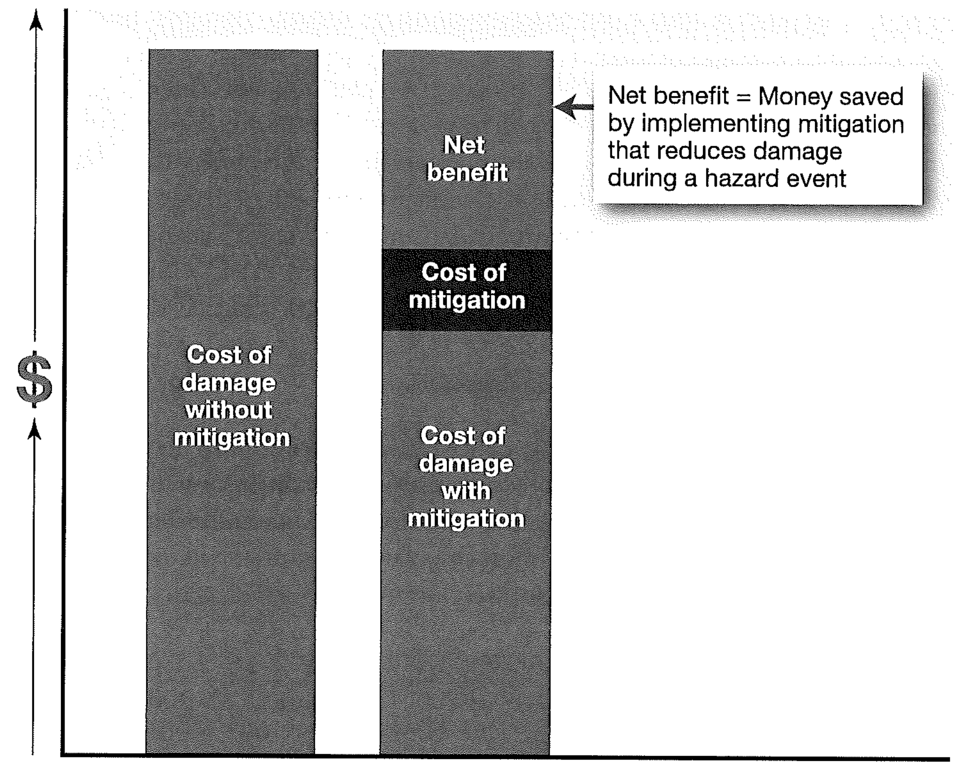
Table 7-1 lists examples of flood and wind mitigation measures that can be taken to help a structure withstand natural hazard events. The need for and benefit of some mitigation measures are difficult to predict. For example, elevating a building above the design flood elevation (DFE) could add to the cost of the building. This additional cost must be weighed against the probability of a flood or storm surge exceeding the DFE. Figure 7-3 illustrates the comparative relationship between damage, project costs, and benefits associated with a hazard mitigation project on a present-value[1] basis over the life of the project.

CROSS REFERENCE

Unless both questions presented in Section 4.8 of this Manual (regarding the acceptable level of residual risk at a site) can be answered affirmatively, the property owner should reconsider purchasing the property.

1 Present value is the current worth of future sums of money. For example, the present value of $100 to be received 10 years from now is about $38.55, using a discount rate equal to 10 percent interest compounded annually.

Figure 7-3.
Basic benefit-cost model



7.6 Hazard Insurance

Insurance should never be viewed as an alternative to damage prevention. However, despite best efforts to manage risk, structures in coastal areas are always subject to potential damage during a natural hazard event. Hazard insurance to offset potential financial exposure is an important consideration for homeowners in coastal areas. Insurance companies base hazard insurance rates on the potential for a building to be damaged by various hazards and the predicted ability of the building to withstand the hazards. Hazard insurance rates include the following considerations:

- Type of building
- Area of building footprint
- Type of construction
- Location of building
- Date of construction
- Age of the building

NOTE

A single-family home is covered by homeowners insurance, and a multi-family building is covered by a dwelling policy. A homeowner policy is different from a dwelling policy. A homeowner policy is a multi-peril package policy that automatically includes fire and allied lines, theft, and liability coverage. For a dwelling policy, peril coverages are purchased separately. In addition to Federal and private flood insurance, this chapter focuses on homeowners insurance.

- Existence and effectiveness of a fire department and fire hydrants (or other dependable, year-round sources of water)
- Effectiveness of the building code and local building department at the time of construction

Although designers and builders may not be able to control the rates and availability of insurance, they should understand the implications of siting and construction decisions on insurance costs and should make homeowners aware of the risk and potential expense associated with owning a house in a high-hazard area. Insurance considerations can and do affect the decisions about the placement and height of coastal buildings and the materials used in their construction. Input from an insurance industry representative during the design process, rather than after the completion of the building, can positively influence important decisions in addition to potentially saving homeowners money on insurance premiums.

Standard homeowners insurance policies cover multiple perils, including fire, lightning, hail, explosion, riot, smoke, vandalism, theft, volcanic eruption, falling objects, weight of snow, and freezing. Wind is usually (but not always) covered, and an endorsement can often be added for earthquake coverage. Homeowners insurance also includes liability coverage. A separate policy is normally required for flooding.

7.6.1 Flood Insurance

NOTE

Standard homeowners insurance policies do not normally cover damage from flood or earth movement (e.g., earthquakes, mudslides).

As described in Chapter 5, flood insurance is offered through the NFIP (see Section 6.2.2.1) in communities that participate in the program (e.g., incorporated cities, towns, villages; unincorporated areas of counties, parishes, and federally recognized Indian tribal governments). This flood insurance is required as a condition of receiving federally backed, regulated, or insured financial assistance for the acquisition of buildings in Special Flood Hazard Areas (SFHAs). This includes almost all mortgages secured by property in an SFHA. NFIP flood insurance is not available in communities that do not participate in the NFIP. Most coastal communities participate in the program because they recognize the risk of flood hazard events and the need for flood insurance.

The following sections summarize how coastal buildings are rated for flood insurance and how premiums are established.

7.6.1.1 Rating Factors

NOTE

NFIP regulations define basement as any area of a building with the floor subgrade (i.e., below ground level) on all sides.

The insurance rate is a factor that is used to determine the amount to be charged for a certain amount of insurance coverage, called the premium. Premiums are discussed in Section 7.6.1.3. The following seven rating factors are used for flood insurance coverage for buildings (not including contents):

- Building occupancy
- Building type
- Flood insurance zone

- Date of construction
- Elevation of lowest floor or bottom or the lowest horizontal structural member of the lowest floor
- Enclosures below the lowest floor
- Location of utilities and service equipment

CROSS REFERENCE

For additional information about enclosures, the use of space below elevated buildings, and flood insurance, see Chapter 5.

Building Occupancy

The NFIP bases rates for flood insurance in part on four types of building occupancy:

- Single-family
- Two- to four-family
- Other residential
- Non-residential

Only slight differences exist among the rates for the three types of residential buildings.

Building Type

The NFIP bases rates for flood insurance in part on the following building-type factors:

- Number of floors (one floor or multiple floors)
- Presence of a basement
- First floor elevation (whether the building is elevated and/or whether there is an enclosure below the lowest elevated floor)
- Manufactured home affixed to a permanent foundation

NFIP flood insurance is generally more expensive for buildings with basements and for buildings with enclosures below BFE.

Flood Insurance Zone

The NFIP bases rates for flood insurance in part on flood insurance zones. The zones are grouped as follows for rating purposes:

- **Zone V (V, VE, and V1–V30).** The zone closest to the water, subject to "coastal high hazard flooding" (i.e., flooding with wave heights greater than 3 feet). Flood insurance is most expensive in Zone V because of the severity of the hazard. However, the zone is often not very wide. Zones V1–V30 were used on FIRMs until 1986. FIRMs published since then show Zone VE.

- **Zone A (A, AE, AR, AO, and A1–A30).** Coastal flood hazard areas where the wave heights are less than 3 feet. Zones A1–A30 were used on FIRMs until 1986. FIRMs published since then show Zone AE.

- **Zones B, C, and X.** The zones outside the 100-year floodplain or SFHA. Flood insurance is least expensive in these zones and generally not required by mortgage lenders. Zone B and Zone C were used on FIRMs until 1986. FIRMs published since then show Zone X.

NOTE

Because Zones B, C, and X designate areas outside the SFHA, construction in these zones is not subject to NFIP floodplain regulations. Homeowners in these areas, however, can purchase Preferred Risk Policies of flood insurance. The rates in these areas are significantly lower than those in Zone V and Zone A.

FIRMs show areas designated as being in the Coastal Barrier Resource System (CBRS) or "otherwise protected areas." These areas (known as "CBRA zones") are identified in the Coastal Barrier Resources Act (CBRA) and amendments. Flood insurance is available for buildings in these zones only if the buildings were walled and roofed before the CBRA designation date shown in the FIRM legend and only if the community participates in the NFIP.

CROSS REFERENCE

For more information about the CBRA and CBRS, see Chapter 5.

Date of Construction

In communities participating in the NFIP, buildings constructed on or before the date of the first FIRM for that community or on or before December 31, 1974, whichever is later, have flood insurance rates that are "grandfathered" or "subsidized." These buildings are referred to as pre-FIRM. They are charged a flat rate based on building occupancy, building type, and flood insurance zone.

NOTE

Flood insurance is available through the NFIP for the following types of buildings: single-family, 2- to 4-family, other residential, and non-residential buildings. Condominium policies are also available. Designers may wish to consult knowledgeable insurance agents and the *Flood Insurance Manual* (FEMA 2011) for policy details and exclusions that affect building design and use. Additional information is available in FEMA FIA-2, *Answers to Questions about the National Flood Insurance Program* (2004).

The rates for buildings constructed after the date of the first FIRM (post-FIRM buildings) are based on building occupancy, building type, flood insurance zone, and two additional factors: (1) elevation of the top of the lowest floor (in Zone A) or bottom of the lowest horizontal structural member of the lowest floor (in Zone V), and (2) enclosed areas below the lowest floor in an elevated building.

If a pre-FIRM building is substantially improved (i.e., the value of the improvement exceeds 50 percent of the market value of the building before the improvement was made), it is rated as a post-FIRM building. If a pre-FIRM building is substantially damaged for any reason (i.e., the true cost of repairing the building to its pre-damaged condition exceeds 50 percent of the value of the building before it was damaged), it is also rated as a post-FIRM building regardless of the amount of repairs actually undertaken. The local building official or floodplain administrator, not the insurance agent, determines whether a building is substantially improved or substantially damaged. If a building is determined to be substantially improved or substantially damaged, the entire structure must be brought into compliance with the current FIRM requirements.

An additional insurance rate table is applied to buildings constructed in Zone V on or after October 1, 1981. The table differentiates between buildings with an obstruction below the elevated lowest floor and those without such an obstruction.

Elevation of Lowest Floor or Bottom or Lowest Horizontal Structural Member of the Lowest Floor

In Zone A, the rating for post-FIRM buildings is based on the elevation of the lowest floor in relation to the BFE. In Zone V, the rating for post-FIRM buildings is based on the elevation of the bottom of the lowest floor's lowest horizontal structural member in relation to the BFE. Flood insurance rates are lower for buildings elevated above the BFE. Rates are significantly higher for buildings rated at 1 foot or more below the BFE.

WARNING

Differences exist between what is permitted under floodplain management regulations and what is covered by NFIP flood insurance. Some building design considerations should be guided by floodplain management requirements and by knowledge of the design's impact on flood insurance policy premiums. Although allowable, some designs that meet NFIP requirements will result in higher premiums.

Ductwork or electrical, plumbing, or mechanical components under the lowest floor must either be designed to prevent water infiltration or elevated above the BFE. Additional elevation of the lowest floor may be required.

In Zone A, a building on a crawlspace must have openings in the crawlspace walls that allow for the unimpeded flow of floodwaters more than 1-foot deep. If the crawlspace walls do not have enough properly sized openings, the crawlspace is considered an enclosed floor, and the building may be rated as having its lowest floor at the elevation of the grade inside the crawlspace. Similarly, if furnaces and other equipment serving the building are below the BFE, the insurance agent must submit more information on the structure to the NFIP underwriting department before the policy's premium can be determined.

Enclosures Below the Lowest Floor

In Zone V, buildings built on or after October 31, 1981, are rated in one of three ways:

COST CONSIDERATION

Significant financial penalties may be associated with the improper design, construction, conversion, or use of areas below the lowest floor.

1. A building is rated as "free of obstruction" if there is no enclosure below the lowest floor other than insect screening or open wood latticework. "Open" means that at least 50 percent of the lattice construction is open.
2. A building is subject to a more expensive "with obstruction" rate if service equipment or utilities are located below the lowest floor or if breakaway walls enclose an area of less than 300 square feet below the lowest floor.
3. If the area below the lowest floor has more than 300 square feet enclosed by breakaway walls, has non-breakaway walls, or is finished, the floor of the enclosed area is the building's lowest floor and

the insurance agent must submit more information on the structure to the NFIP before the policy's premium can be determined.

Although the NFIP allows enclosures below the lowest floor, enclosures affect the flood insurance premiums. The addition of a floor system above the ground, but below the lowest floor of the living space, can result in additional impacts to flood insurance premiums.

7.6.1.2 Coverage

The flood insurance that is available under the NFIP is called a Standard Flood Insurance Policy (SFIP). See FEMA F-122, *National Flood Insurance Program Dwelling Form: Standard Flood Insurance Policy* (FEMA 2009a) for more information about NFIP coverage.

> **NOTE**
>
> The amount of building and contents coverage should be based on replacement value, not market value. Replacement value is the actual cost of rebuilding the building or replacing the contents. This may be higher or lower than market value.

To be insurable under the NFIP, a building must be walled and roofed with two or more rigid exterior walls and must be more than 50 percent above grade. Examples of structures that are ***not*** insurable because they do not meet this definition are gazebos, pavilions, docks, campers, underground storage tanks, swimming pools, fences, retaining walls, seawalls, bulkheads, septic tanks, and tents. Buildings constructed entirely over water or seaward of mean high tide after October 1, 1982, are not eligible for flood insurance coverage. Certain parts of boathouses located partially over water (e.g., ceiling, roof over the area where boats are floated) are not eligible for coverage.

Coverage does not include contents. Contents of insurable walled and roofed buildings can be insured under separate coverage within the same policy. Finishing materials and contents in basements or in enclosures below the lowest elevated floor in post-FIRM buildings are not covered with some exceptions. Certain building components and contents in areas below the elevated floors of elevated buildings are covered. Coverage can even include some items ***prohibited*** by FEMA/local floodplain management regulations if the NFIP deems the items essential to the habitability of the building. ***Designers and building owners should not confuse insurability with proper design and construction. Moreover, significant financial penalties (e.g., increased flood insurance rates, increased uninsured losses) may result from improper design or use of enclosed areas below the BFE.***

With the above caveats in mind, buildings insured under the NFIP include coverage (up to specified policy limits) for the following items below the BFE:

- Minimum-code-required utility connections, electrical outlets, switches, and circuit breaker boxes
- Footings, foundation, posts, pilings, piers, or other foundation walls and anchorage system(s) as required for the support of the building
- Drywall for walls and ceilings and nonflammable insulation (in basements only)
- Stairways and staircases attached to the building that are not separated from the building by an elevated walkway

- Elevators, dumbwaiters, and relevant equipment, except for such relevant equipment installed below the BFE on or after October 1, 1987
- Building and personal property items—necessary for the habitability of the building—connected to a power source and installed in their functioning location as long as building and personal property coverage has been purchased. Examples of building and personal property items are air conditioners, cisterns, fuel tanks, furnaces, hot water heaters, solar energy equipment, well water tanks and pumps, sump pumps, and clothes washers and dryers.
- Debris removal for debris that is generated during a flood

An SFIP does ***not*** provide coverage for the following building components and contents in areas below the elevated floors of elevated residential buildings:

- Breakaway walls and enclosures that do not provide support to the building
- Drywall for walls and ceilings
- Non-structural slabs beneath an elevated building
- Walks, decks, driveways, and patios outside the perimeter of the exterior walls of the building
- Underground structures and equipment, including wells, septic tanks, and septic systems
- Equipment, machinery, appliances, and fixtures not deemed necessary for the habitability of the building
- Fences, retaining walls, seawalls, and revetments
- Indoor and outdoor swimming pools
- Structures over water, including piers, docks, and boat houses
- Personal property
- Land and landscaping

7.6.1.3 Premiums

Premiums are based on the seven rating factors discussed in Section 7.6.1.1, plus the following:

- An expense constant
- A Federal policy fee
- The cost of Increased Cost of Compliance coverage
- The amount of deductible the insured chooses

If a community elects to exceed the minimum NFIP requirements, it may apply for a classification under the NFIP Community Rating System (CRS). Based on its floodplain management program, the community could receive a CRS classification that provides up to a 45 percent premium discount for property owners within the community. At the time of this publication, nearly 1,250 communities were participating in the CRS, representing more than 69 percent of all flood insurance policies. For more information on the CRS, see Section 5.2.4.

Tables 7-2, 7-3, and 7-4 list sample NFIP premiums for a post-FIRM, one-story, single-family residence without a basement located in various flood zones. For buildings in Zone V, premiums are somewhat higher for structures with breakaway obstructions, and premiums are dramatically higher for structures with obstructions (e.g., service equipment, utilities, non-breakaway walls) below the lowest floor.

Reductions in flood insurance premiums can quickly offset the increased costs associated with building above the BFE.

For buildings in Zone A, premiums are higher when proper flood openings are not provided in enclosed areas or when service equipment or utilities are located below the BFE.

Table 7-2. Sample NFIP Flood Insurance Premiums for Buildings in Zone A; $250,000 Building/$100,000 Contents Coverage

Floor Elevation above BFE	Reduction in Annual Flood Premium	Annual Premium	Savings
0	0%	$ 1,622	$ 0
1 foot	45%	$ 897	$ 725
2 feet	61%	$ 638	$ 984
3 feet	66%	$ 548	$ 1,074
4 feet	67%	$ 530	$ 1,092

Rates as of May 2011 per the National Flood Insurance Program Flood Insurance Manual (FEMA 2011) for a Zone V structure free of obstruction. Rates include building ($250,000), contents ($100,000), and associated fees, including increased cost of compliance.

Table 7-3. Sample NFIP Flood Insurance Premiums for Buildings in Zone V Free of Obstruction Below the Lowest Floor; $250,000 Building/$100,000 Contents Coverage

Floor Elevation above BFE	Reduction in Annual Flood Premium	Annual Premium	Savings
0	0%	$ 7,821	$ 0
1 foot	33%	$ 5,256	$ 2,565
2 feet	55%	$ 3,511	$ 4,310
3 feet	65%	$ 2,764	$ 5,057
4 feet	71%	$ 2,286	$ 5,535

Rates as of May 2011 per the National Flood Insurance Program Flood Insurance Manual (FEMA 2011) for a Zone V structure free of obstruction. Rates include building ($250,000), contents ($100,000), and associated fees, including increased cost of compliance; premium to be determined by NFIP underwriting.

Table 7-4. Sample NFIP Flood Insurance Premiums for Buildings in Zone V with Obstruction Below the Lowest Floor; $250,000 Building/$100,000 Contents Coverage

Floor Elevation above BFE	Reduction in Annual Flood Premium	Annual Premium	Savings
0	0%	$ 10,071	$ 0
1 foot	22%	$ 7,901	$ 2,170
2 feet	40%	$ 6,056	$ 4,015
3 feet	50%	$ 5,076	$ 4,995
4 feet	54%	$ 4,591	$ 5,480

Rates as of May 2011 per the National Flood Insurance Program Flood Insurance Manual (FEMA 2011) for a Zone V structure free of obstruction. Rates include building ($250,000), contents ($100,000), and associated fees, including increased cost of compliance; premium to be determined by NFIP underwriting.

7.6.1.4 Designing to Achieve Lower Flood Insurance Premiums

Tables 7-2, 7-3, and 7-4 demonstrate that considerable savings can be achieved on flood insurance premiums by elevating a building above the BFE and by constructing it to be free of obstruction. Other siting, design and construction decisions can also lower premiums. Designers should refer to FEMA's V Zone Risk Factor Rating Form to estimate flood insurance premium discounts and as a planning tool to use with building owners. The form is in Chapter 5 of the Flood Insurance Manual (FEMA 2011), available at http://www.fema.gov/business/nfip/manual.shtm. Discount points, which translate into reduced premiums, are awarded for:

- Lowest floor elevation
- Siting and environmental considerations
- Building support systems and design details
- Obstruction-free and enclosure construction considerations

In addition to lowest floor elevation and free-of-obstruction discounts illustrated in Tables 7-2 and 7-3, flood insurance premium discounts also can be obtained for:

- Distance from shoreline to building
- Presence of large dune seaward of the building
- Presence of certified erosion control device or ongoing beach nourishment project
- Foundation design based on eroded grade elevation and local scour
- Foundation design based on this Manual and ASCE 7-10 loads and load combinations
- Minimizing foundation bracing

- Spacing of piles/columns/piers
- Size and depth of piles and pier footings
- Superior connections between piles/columns/piers and girders

Some poor practices reduce discount points. Negative discount points, which result in higher flood insurance premiums, are given for:

- Shallow pile embedment
- Certain methods of pile installation
- Small-diameter piles or columns
- Non-bolted connections between piles/columns/piers and girders
- Over-notching of wood piles
- Small pier footings
- Presence of elevators, equipment, ductwork and obstructions below the BFE
- Presence of solid breakaway walls
- Presence of finished breakaway walls

Table 10 (V Zone Risk Relativities) in the *Flood Insurance Manual* (FEMA 2011) provides an indication of how building discount points translate into flood premium discounts. Designers and owners should review this table and consult with a knowledgeable flood insurance agent regarding the flood insurance premium implications of using or avoiding certain design construction practices

7.6.2 Wind Insurance

Wind insurance coverage is generally part of a homeowners insurance policy. At the time this Manual was published, underwriting associations (or "pools") provided last resort insurance to homeowners in coastal areas who could not obtain coverage from private companies. The following seven states had beach and windstorm insurance plans at the time this Manual was released: Alabama, Florida, Louisiana, Mississippi, North Carolina, South Carolina, and Texas. Georgia and New York provide this kind of coverage for windstorm and hail in certain coastal communities through other property pools. In addition, New Jersey operates the Windstorm Market Assistance Program (Wind-MAP) to help residents in coastal communities find homeowners insurance on the voluntary market. When Wind-MAP does not identify an insurance carrier for a homeowner, the New Jersey Insurance Underwriting Association, known as the FAIR Plan, may provide a policy for windstorm, hail, fire, and other perils but does not cover liability.

Many insurance companies encourage their policyholders to retrofit their homes to resist wind-related damage, and some companies have established discount programs to reduce premiums, and other types of financial incentives, to reflect the risk reduction for homes that have been properly retrofitted. Some State insurance departments also have put in place insurance discount programs for properly retrofitted homes. The IBHS FORTIFIED *for Existing Homes* Program has been designed with the support of IBHS member insurance companies, although each individual company makes its own decisions about how it is implemented.

Wind is only one part of the rating system for multi-peril insurance policies such as a homeowners insurance policy. Most companies rely on the Homeowner's Multistate General Rules and State-specific exceptions Manual of the Insurance Services Office (ISO) as the benchmark for developing their own manuals. ISO stresses that the rules in the manual are advisory only and that each company decides what to use and charge. The ISO publishes a homeowner's manual in every state except Hawaii, North Carolina, and Washington (where State-mandated insurance bureaus operate).

The seven basic factors in rating a homeowners insurance policy are:

- Form (determines type of coverage)
- Age of the structure
- Territory
- Fire protection class
- Building code effectiveness
- Construction type
- Protective devices

The last five factors are discussed below. Premiums can also vary because of factors such as amount of coverage and deductible, but these additional factors are not related to building construction. Some companies, however, adjust their higher optional deductible credit according to construction type, giving more credit to more fire-resistant concrete and masonry buildings.

7.6.2.1 Territory

Wind coverage credit varies by territory. An entire state may be one territory, but some states, such as Florida, are divided into county and sub-county territories. In Florida, the Intracoastal Waterway is often used as the boundary line.

7.6.2.2 Fire Protection Class

ISO publishes a public protection classification for each municipality or fire district based on an analysis of the local fire department, water system, and fire alarm system. This classification does not affect wind coverage but is an important part of the rate.

7.6.2.3 Building Code Effectiveness Grading Schedule

The adoption and enforcement of building codes by local jurisdictions are routinely assessed through the Building Code Effectiveness Grading Schedule (BCEGS) program, developed by the ISO. Participation in BCEGS is voluntary and may be declined by local governments if they do not wish to have their local building codes evaluated. The results of BCEGS assessments are routinely provided to ISO's member private insurance companies, which in turn may offer rating credits for new buildings constructed in communities with strong BCEGS classifications. Conceptually, communities with well-enforced, up-to-date codes should experience fewer disaster-related losses and as a result, should have lower insurance rates.

In conducting the assessment, ISO collects information related to personnel qualification and continuing education, as well as number of inspections performed per day. This type of information combined with local building codes is used to determine a grade for the jurisdiction. The grades range from 1 to 10, with a BCEGS grade of 1 representing exemplary commitment to building code enforcement, and a grade of 10 indicating less than minimum recognized protection. Most participating communities fall in the 3 to 5 grade range.

7.6.2.4 Construction Type

To simplify insurance underwriting procedures, buildings are identified as being in only one of four categories:

- **Frame:** exterior walls of wood or other combustible construction, including stucco and aluminum siding
- **Masonry veneer:** exterior walls of combustible material, veneered with brick or stone
- **Masonry:** exterior walls of masonry materials; floor and roof of combustible materials
- **Superior:** non-combustible, masonry non-combustible, or fire resistive

Masonry veneer and masonry are often difficult to differentiate and are therefore often given the same rating.

Not many single-family homes qualify for the superior category, which results in a 15 percent credit off rates for the masonry categories. A home in the superior category may also qualify for a wind credit because some insurers believe that buildings with walls, floors, and roofs made of concrete products offer good resistance to windstorms and Category 1 hurricanes. Therefore, a fire-resistive home may get a wind-resistive credit.

ISO's dwelling insurance program allows companies to collect data from the owner, the local building department, or their own inspectors to determine whether a house can be classified as wind-resistive or semi-wind-resistive for premium credit purposes.

7.6.2.5 Protective Devices

Protective devices are not considered basic factors but items that may deserve some credits. This approach is more common for fire and theft coverage than for wind. Fire and theft coverage credits sprinklers and fire and/or burglar alarms tied to the local fire or police stations. ISO's rules do not address wind-protective devices except in Florida. In Florida, a premium credit is given if exterior walls and roof openings (not including roof ridge and soffit vents) are fully protected with storm shutters of any style and material that are designed and properly installed to meet the latest ASCE 7-10 engineering standard. This standard has been adopted by Dade County. Shutters must be able to withstand impact from wind-borne debris in accordance with the standards set by the municipality, or if there are no local standards, by Dade County. The rules also provide specifications for alternatives to storm shutters, such as windstorm protective glazing material.

7.6.3 Earthquake Insurance

Earthquake insurance is an addition to a regular homeowners insurance policy. Earthquake insurance carries a very high deductible—usually 10 or 15 percent of the value of the house. In most states, ISO has developed advisory earthquake loss costs based on a seismic model used to estimate potential damage to individual properties in the event of an earthquake. The model is based on seismic data, soil types, damage information from previous earthquakes, and structural analysis of various types of buildings. Based on this model, postal Zip codes have been assigned to rating bands and loss costs developed for each band. The number of bands varies within each state and, at times, within a county.

In California, the California Earthquake Authority (CEA), a State-chartered insurance company, writes most earthquake policies for homeowners. These policies cover the dwelling and its contents and are subject to a 15-percent deductible. CEA rates are also based on a seismic model used to estimate potential damage to individual properties in the event of an earthquake.

7.7 Sustainable Design Considerations

Sustainability concepts are increasingly being incorporated into residential building design and construction. The voluntary green building rating systems of the past decade are being replaced with adoption by local and State jurisdictions of mandatory minimum levels of compliance with rating systems such as the U.S. Green Building Council *LEED for Homes Reference Guide* (USGBC 2009) or consensus-based standards such as ICC 700-2008. These programs and standards use a system in which credits are accumulated as points assigned to favorable green building attributes pertaining to lot design, resource efficiency, energy efficiency, water efficiency, and indoor environmental quality.

Although green building programs are implemented as above-minimum building code practices, many aspects of green construction and its impact on structural performance and durability are not readily apparent upon initial consideration. Green building programs such as National Association of Home Builders (NAHB) Green, EarthAdvantage, and other State and local programs may incorporate LEED for Homes, ICC 700-2008, EnergyStar and other rating systems or product certifications as part of their offerings. For example, a homeowner may decide to add a rooftop solar panel system after the home is built. Depending on its configuration, this system could act as a "sail" in high winds, adding significant uplift loads to the roof and possibly triggering localized structural failure. To maintain expected structural performance in a high-wind event, these additional loads not only must be accommodated by the roof framing, but the complete load path for these additional loads must be traced and connections or framing enhanced as needed.

Examples of other green attributes that may require additional design consideration for resistance to natural hazards are large roof overhangs for shading (due to the potential for increased wind loads), vegetative green roofs (due to the presence of added weight and moisture to sustain the roof), and optimized or advanced framing systems that reduce overall material usage and construction waste (due to larger spacing between framing members and smaller header and framing member sizes).

It is important to verify that the design wind speed for an area is not in excess of the recommended maximum wind speeds for these systems. Building for resilience should not work against other green practices by unreasonably increasing the material resources needed to construct the building. However, buildings constructed to survive natural hazards reduce the need to be rebuilt and thus provide a more sustainable design approach.

When new green building attributes introduce new technology or new building materials into the building design, new interactions may affect the building's structural integrity and durability. Examples of interactions between green building attributes and resistance to natural hazards (e.g., resilience of the building) are described in FEMA P-798, *Natural Hazard Sustainability of Residential Construction* (FEMA 2010c). When implementing green attributes into a design, the designer should consider that building for resilience is possibly the most important green building practice. A green building fails to provide benefits associated with green building practices if it is more susceptible to heavy damage from natural hazard events that result in lost building function and increased cost of repair.

7.8 Inspection Considerations

After the completion of building permits and construction plans, good inspection and enforcement procedures are crucial. For coastal construction, building inspectors, code officers, designers, and floodplain managers must understand the flood-resistant design and construction requirements for which they need to check. The earlier a deviation is found, the easier it is to take corrective action working with the homeowner and builder.

A plan review and inspection checklist tailored to flood-related requirements should be used. Some of the inspections that can be performed to meet compliance directives with the local community's flood-resistant provisions are listed below. For a community that does not have a DFE, a BFE is applicable.

- Stake-out or site inspection to verify the location of a building; distances from the flood source or body of water can also be checked
- Fill inspection to check compaction and final elevation when fills are allowed in SFHAs
- Footing or foundation inspection to check for flood-opening specifics for closed foundations, lowest floor inspection for slab-on-grade buildings, and embedment depth and pile plumbness for pile-supported structures
- Lowest floor inspection (floodplain inspection) per Section 109.3.3 of 2012 IBC and Section R109.1.3 of 2012 IRC. This is also a good time to verify that the mechanical and electrical utilities are above the BFE or DFE for additional protection.
- Final inspection points for flood-prone buildings can include:
  - Enclosures below elevated buildings for placement of flood vents and construction of breakaway walls, where applicable
  - Use of enclosures for consistency with the use in the permit
  - Placement of exterior fill, where permitted, according to plans and specifications

- Materials below the DFE for flood-resistance; see NFIP Technical Bulletin 2, *Flood Damage-Resistant Materials Requirements* (FEMA 2008)
- Building utilities to determine whether they have been elevated or, when instructions are provided, installed to resist flood damage
- Existence of as-built documentation of elevations
- If a plan review and inspection checklist have been used, verification that have been signed off and placed in the permit file with all other inspection documentation

More information regarding inspections is available in FEMA P-762, *Local Officials Guide for Coastal Construction* (FEMA 2009b).

7.9 References

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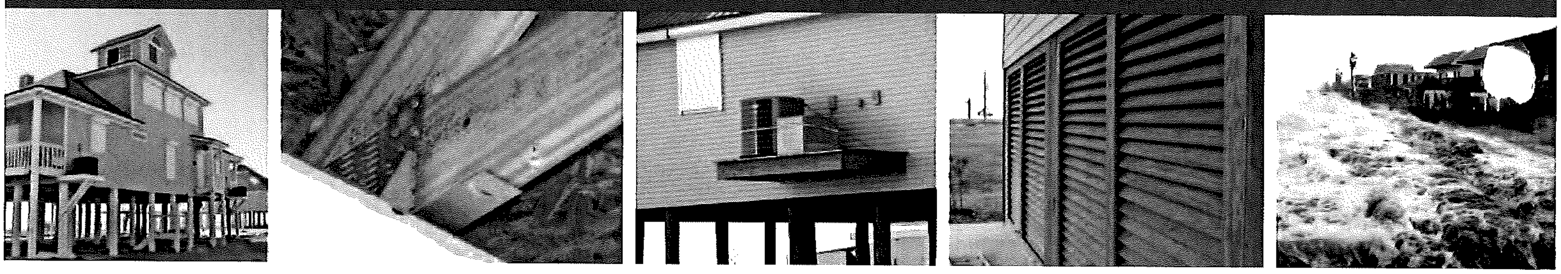


8 Determining Site-Specific Loads

This chapter provides guidance on determining site-specific loads from high winds, flooding, and seismic events. The loads determined in accordance with this guidance are applied to the design of building elements described in Chapters 9 through 15.

The guidance is intended to illustrate important concepts and best practices in accordance with building codes and standards and does not represent an exhaustive collection of load calculation methods. Examples of problems are provided to illustrate the application of design load provisions of ASCE 7-10. For more detailed guidance, see the applicable building codes or standards.

Figure 8-1 shows the process of determining site-specific loads for three natural hazards (flood, wind, and seismic events). The process includes identifying the applicable building codes and standards for the selected site, identifying building characteristics that affect loads, and determining factored design loads using applicable load combinations. Model building codes and standards may not provide

CROSS REFERENCE

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

NOTE

All coastal residential buildings must be designed and constructed to prevent flotation, collapse, and lateral movement due to the effects of wind and water loads acting simultaneously.

load determination and design guidance for the hazards that are listed in the figure. In such instances, supplemental guidance should be sought.

The loads and load combinations used in this Manual are required by ASCE 7-10 unless otherwise noted. Although the design concepts that are presented in this Manual are applicable to both Allowable Stress Design (ASD) and Load and Resistance Factor Design (LRFD), all calculations, analyses, and load combinations are based on ASD. Extension of the design concepts presented in this Manual to the LRFD format can be achieved by modifying the calculations to use strength-level loads and resistances.

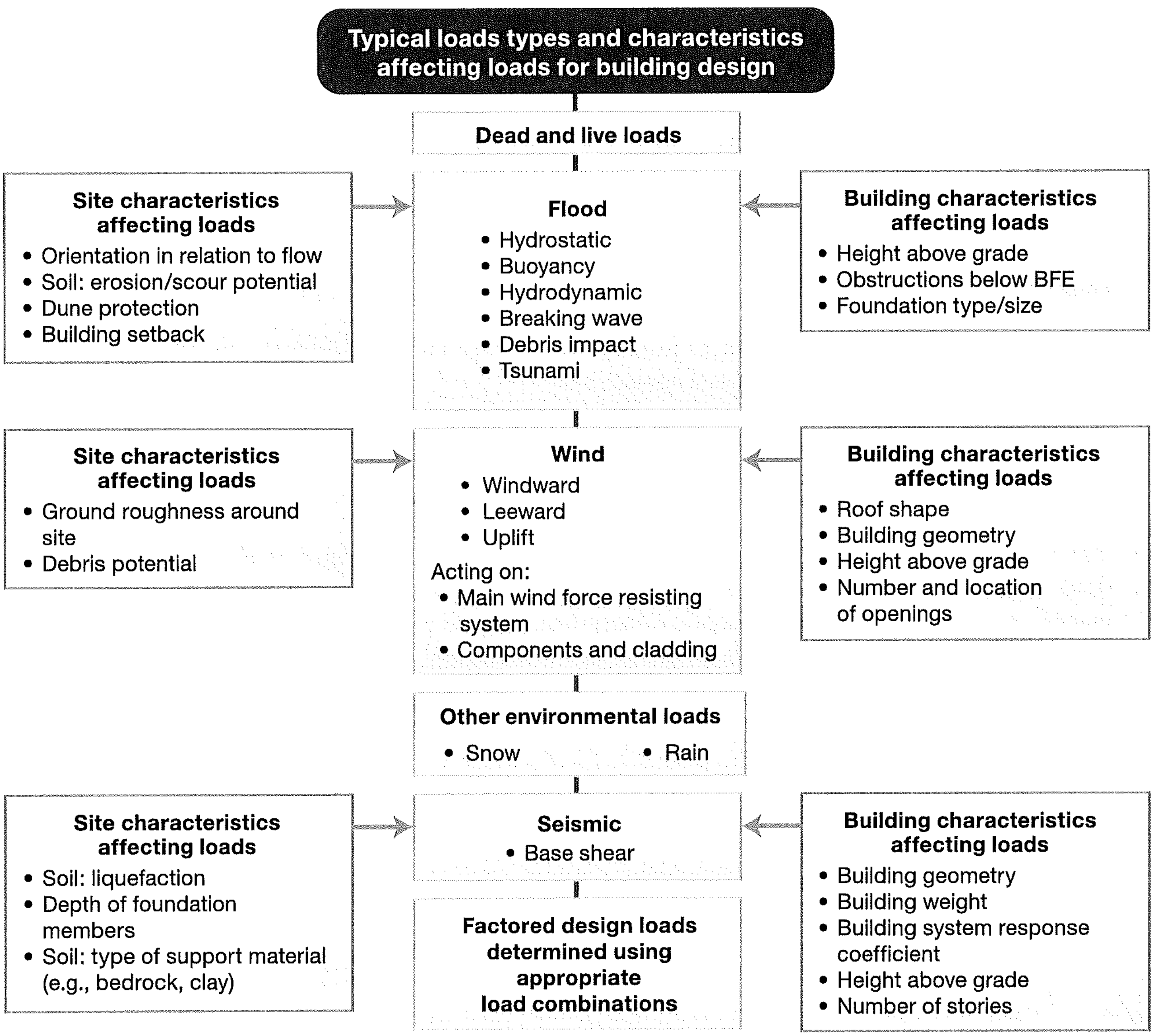


Figure 8-1.
Summary of typical loads and characteristics affecting determination of design load

8.1 Dead Loads

Dead load is defined in ASCE 7-10 as "… the weight of all materials of construction incorporated into the building including, but not limited to, walls, floors, roofs, ceilings, stairways, built-in partitions, finishes, cladding, and other similarly incorporated architectural and structural items, and fixed service equipment including the weight of cranes." The sum of the dead loads of all the individual elements equals the unoccupied weight of a building.

The total weight of a building is usually determined by multiplying the unit weight of the various building materials—expressed in pounds per unit area—by the surface area of the materials. Unit weights of building elements, such as exterior walls, floors and roofs, are commonly used to simplify the calculation of building weight. Minimum design dead loads are contained in ASCE 7-10, *Commentary*. Additional information about material weights can be found in *Architectural Graphic Standards* (The American Institute of Architects 2007) and other similar texts.

Determining the dead load is important for several reasons:

- The dead load determines in part the required size of the foundation (e.g., footing width, pile embedment depth, number of piles).
- Dead load counterbalances uplift forces from buoyancy when materials are below the stillwater depth (see Section 8.5.7) and from wind (see Example 8.9).
- Dead load counterbalances wind and earthquake overturning moments.
- Dead load changes the response of a building to impacts from floodborne debris and seismic forces.
- Prescriptive design in the following code references and other code references is dependent on the dead load of the building. For example, wind uplift strap capacity, joist spans, and length of wall bracing required to resist seismic forces are dependent on dead load assumptions used to tabulate the prescriptive requirements in the following examples of codes and prescriptive standards:
  - 2012 IRC, *International Residential Code for One-and Two-Family Dwellings* (ICC 2011b)
  - 2012 IBC, *International Building Code* (ICC 2011a)
  - ICC 600-2008, *Standard for Residential Construction in High-Wind Regions* (ICC 2008)
  - WFCM-12, *Wood Frame Construction Manual for One- and Two-Family Dwellings* (AF&PA 2012)
  - AISI S230-07, *Standard for Cold-formed Steel Framing-prescriptive Method for One- and Two-family Dwellings* (AISI 2007)

8.2 Live Loads

Live loads are defined in ASCE 7-10 as "… loads produced by the use and occupancy of the building … and do not include construction or environmental loads such as wind load, snow load, rain load, earthquake load, flood load, or dead load." Live loads are usually taken as a uniform load spread across the surface being designed. For residential one- and two-family buildings, the uniformly distributed live load for habitable areas (except sleeping and attic areas) in ASCE 7-10 is 40 pounds/square foot. For balconies and decks on one- and two-family buildings, live load is 1.5 times the live load of the occupancy served but not to exceed 100 pounds/square foot. This requirement typically translates to a live load of 60 pounds/square foot for a deck or balcony accessed from a living room or den, or a live load of 45 pounds/square foot for a deck or balcony accessed from a bedroom. ASCE 7-10 contains no requirements for supporting a concentrated load in a residential building.

NOTE

The live loads in the 2012 IBC and 2012 IRC for balconies and decks attached to one- and two-family dwellings differ from those in ASCE 7-10. Under the 2012 IBC, the live load for balconies and decks is the same as the occupancy served. Under the 2012 IRC, a minimum 40 pounds/square foot live load is specified for balconies and decks. Strict adherence to the ASCE 7-10 live loads for a residential deck requires a complete engineering design and does not permit use of the prescriptive deck ledger table in the 2012 IRC or the prescriptive provisions in AWC DCA6, which are based on a 40 pounds/square foot live load.

8.3 Concept of Tributary or Effective Area and Application of Loads to a Building

The tributary area of an element is the area of the floor, wall, roof, or other surface that is supported by that element. The tributary area is generally a rectangle formed by one-half the distance to the adjacent element in each applicable direction.

The tributary area concept is used to distribute loads to various building elements. Figure 8-2 illustrates tributary areas for roof loads, lateral wall loads, and column or pile loads. The tributary area is a factor in calculating wind pressure coefficients, as described in Examples 8.7 and 8.8.

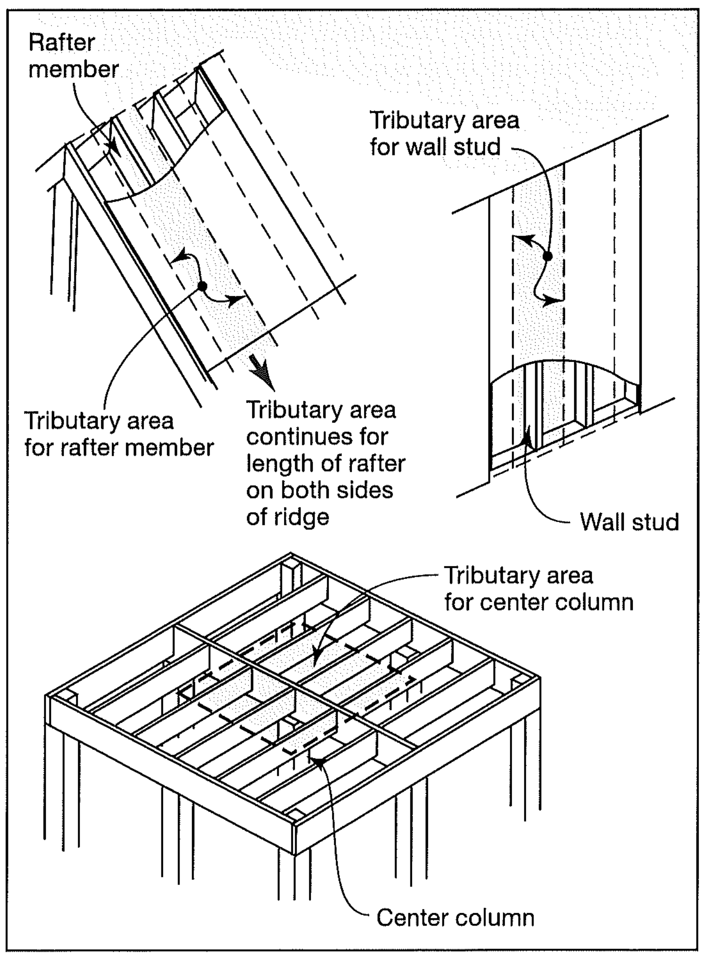


Figure 8-2. Examples of tributary areas for different structural elements

8.4 Snow Loads

Snow loads are applied as a vertical load on the roof or other exposed surfaces such as porches or decks. Ground snow loads are normally specified by the local building code or building official. In the absence of local snow load information, ASCE 7-10 contains recommended snow loads shown on a map of the United States.

When the flat roof snow load exceeds 30 pounds/square foot, a portion of the weight of snow is added to the building weight when the seismic force is determined.

8.5 Flood Loads

Floodwaters can exert a variety of load types on building elements. Both hydrostatic and depth-limited breaking wave loads depend on flood depth.

Flood loads that must be considered in design include:

- Hydrostatic load – buoyancy (flotation) effects, lateral loads from standing water, slowly moving water, and nonbreaking waves
- Breaking wave load
- Hydrodynamic load – from rapidly moving water, including broken waves
- Debris impact load – from waterborne objects

NOTE

- Flood load calculation procedures cited in this Manual are conservative, given the uncertain conditions of a severe coastal event.
- Background information and procedures for calculating coastal flood loads are presented in a number of publications, including ASCE 7-10 and the *Coastal Engineering Manual* (USACE 2008).

The effects of flood loads on buildings can be exacerbated by storm-induced erosion and localized scour and by long-term erosion, all of which can lower the ground surface around foundation elements and cause the loss of load-bearing capacity and loss of resistance to lateral and uplift loads. As discussed in Section 8.5.3, the lower the ground surface elevation, the deeper the water, and because the wave theory used in this Manual is based on depth-limited waves, deeper water creates larger waves and thus greater loads.

8.5.1 Design Flood

In this Manual, "design flood" refers to the locally adopted regulatory flood. If a community regulates to minimum NFIP requirements, the design flood is identical to the base flood (the 1-percent-annual-chance flood or 100-year flood). If a community has chosen to exceed minimum NFIP building elevation requirements, the design flood can exceed the base flood. The design flood is always equal to or greater than the base flood.

TERMINOLOGY: FREEBOARD

Freeboard is additional height incorporated into the DFE to account for uncertainties in determining flood elevations and to provide a greater level of flood protection. Freeboard may be required by State or local regulations or be desired by a property owner.

8.5.2 Design Flood Elevation

Many communities have chosen to exceed minimum NFIP building elevation requirements, usually by requiring freeboard above the base flood elevation (BFE) but sometimes by regulating to a more severe flood than the base flood. In this Manual, "design flood elevation" (DFE) refers to the locally adopted regulatory flood elevation.

In ASCE 24-05, the DFE is defined as the "elevation of the design flood, including wave height, relative to the datum specified on the community's flood hazard map." The design flood is the "greater of the following two flood events: (1) the base flood, affecting those areas identified as SFHAs on the community's FIRM or (2) the flood corresponding to the area designated as a flood hazard area on a community's flood hazard map or otherwise legally designated." The DFE is often taken as the BFE plus any freeboard required by a community, even if the community has not adopted a design flood more severe than the 100-year flood.

Coastal floods can and do exceed BFEs shown on FIRMs and minimum required DFEs established by local and State governments. When there are differences between the minimum required DFE and the recommended elevation based on consideration of other sources, the designer, in consultation with the owner, must decide whether elevating above the DFE provides benefits relative to the added costs of elevating higher than the minimum requirement. For example, substantially higher elevations require more stairs to access the main floor and may require revised designs to meet the community's height restriction. Benefits include reduced flood damage, reduced flood insurance premiums, and the ability to reoccupy homes faster than owners of homes constructed at the minimum allowable elevation. In both Hurricanes Katrina and Ike, high water marks after the storms indicated that if the building elevations had been set to the storm surge elevation, the buildings may have survived. See FEMA 549, *Hurricane Katrina in the Gulf Coast* (FEMA 2006), and FEMA P-757, *Hurricane Ike in Texas and Louisiana* (FEMA 2009), for more information.

In addition to considering the DFE per community regulations, designers should consider the following before deciding on an appropriate lowest floor elevation:

- **The 500-year flood elevation as specified in the Flood Insurance Study (FIS) or similar study.** The 500-year flood elevation (including wave effects) represents a larger but less frequent event than the typical basis for the DFE (e.g., the 100-year event). In order to compare the DFE to the 500-year flood elevation, the designer must obtain the 500-year wave crest elevation from the FIS or convert the 500-year stillwater level to a wave crest elevation if the latter is not included in the FIS report.

- **The elevation of the expected maximum storm surge as specified by hurricane evacuation maps.** Storm surge evacuation maps provide a maximum storm surge elevation for various hurricane categories. Depending on location, maps may include all hurricane categories (1 to 5), or elevations for selected storm categories only. Most storm surge evacuation maps are prepared by the U.S. Army Corps of Engineers (USACE) and are usually available from the USACE District Office or State/local emergency management agencies. Storm surge elevations are stillwater levels and do not include wave heights, so the designer must convert storm surge elevations to wave crest elevations.

  When storm surge evacuation maps are based on landmark boundaries (e.g., roads or other boundaries of convenience) rather than storm surge depths, the designer needs to obtain the surge elevations for a building site from the evacuation study (if available). The topographic map of the region may also provide information about the storm surge depths because the physical boundary elevation should establish the most landward extent of the storm surge.

- **Historical information and advisory flood elevations.** Historical information showing flood levels and flood conditions during past flood events, if available, is an important consideration for comparison to the DFE. For areas subject to a recent coastal flood event, advisory flood elevations may be available based on the most recent flooding information unique to the site.

Community FIRMs do not account for the effects of long-term erosion, subsidence, or sea level rise, all of which could be considered when establishing lowest floor elevations in excess of the DFE. Erosion can increase future flood hazards by removing dunes and lowering ground levels (allowing larger waves to reach a building site). Sea level rise can increase future flood hazards by allowing smaller and more frequently occurring storms to inundate coastal areas and by increasing storm surge elevations.

Section 3.6 discusses the process a designer could follow to determine whether a FIRM represents flood hazards associated with the site under present-day and future-based flood conditions.

This section provides more information on translating erosion and sea level rise data into d_s (design flood depth) calculations. Figure 8-3 illustrates a procedure that designers can follow to determine d_s under a variety of future conditions. In essence, designers should determine the lowest expected ground elevation at the base of a building during its life and the highest expected stillwater elevation at the building during its life.

Determine subsidence effects (if any) on the site

- Obtain published subsidence rates
- Multiply the subsidence rate by the building lifetime; lower ground elevations by this amount

↓

Determine the most landward expected shoreline location over the anticipated life of the building

- Use published or calculated long-term erosion rate (feet/year), increasing the rate to account for errors and uncertainty. It is recommended that a minimum rate of 1.0 feet/year be used unless durable shore protection or erosion-resistant soil is present
- Multiply the resulting erosion rate by the building lifetime (years) to compute the long-term erosion distance (feet). Use a minimum lifetime of 50 years
- Measure landward (from the most landward historical shoreline) a distance equal to the long-term erosion distance. This will define the most landward expected shoreline

↓

Determine the lowest expected ground elevation at the base of the building or structure

Beginning with the most landward expected shoreline location:

- calculate an eroded dune profile using a storm erosion model; or
- calculate a stable bluff profile using available guidance and data

↓

Determine the highest expected stillwater elevation at the building

- Obtain published sea level rise rates for the site
- Multiply sea level rise rate by the building lifetime; increase present SWEL by this amount

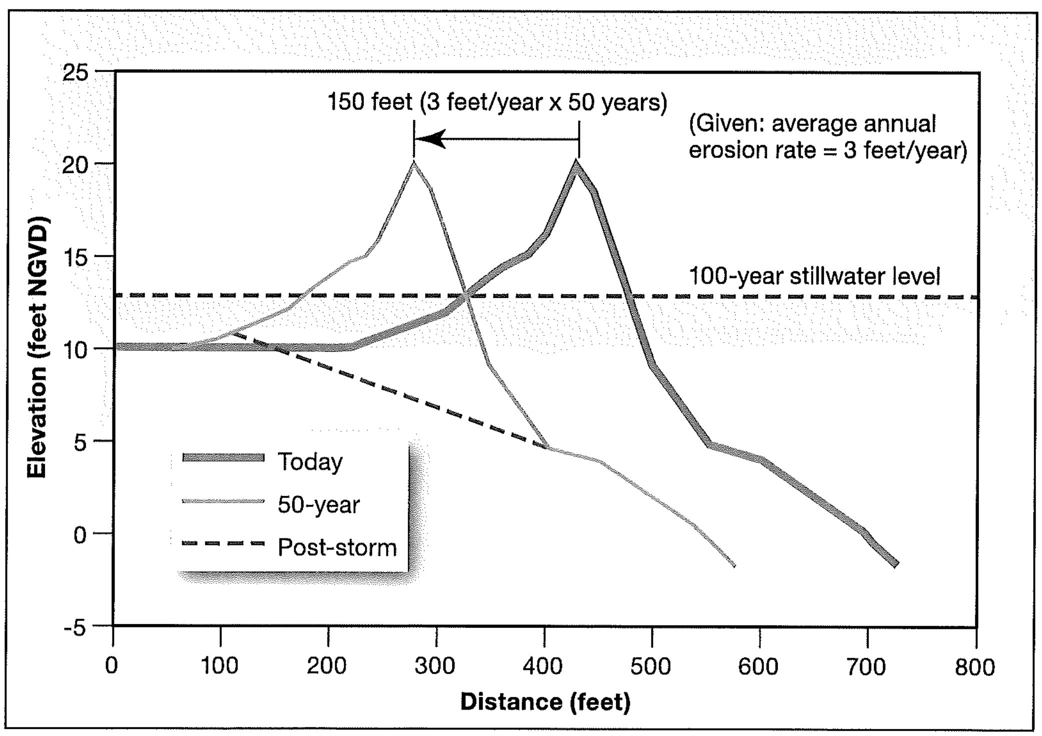
↓

Subtract future eroded ground elevation from future stillwater elevation to obtain design stillwater flood depth

Figure 8-3. Flowchart for estimating maximum likely design stillwater flood depth at the site

- The lowest expected ground elevation is determined by considering subsidence, long-term erosion, and erosion during the base flood.
  - Subsidence effects can be estimated by lowering all existing ground elevations at the site by the product of the subsidence rate and the building lifetime. For example, if subsidence occurs at a rate of 0.005 foot/year and the building lifetime is 50 years, the profile should be lowered 0.25 foot.
  - Figure 8-4 illustrates a simple way to estimate long-term effects on ground elevations at the building. Translate the beach and dune portion of the profile landward by an amount equal to the product of the long-term erosion rate and the building lifetime. If the erosion rate is 3 feet/year and the building lifetime is 50 years, shift the profile back 150 feet.
  - Figure 8-4 also shows the next step in the process, which is to assess dune erosion (see Section 3.5.1) to determine whether the dune will be removed during a base flood event.
  - The lowest expected grade will be evident once the subsidence, long-term erosion, and dune erosion calculations are made.
- The stillwater level is calculated by adding the expected sea level rise element to the base flood stillwater elevation. For example, if the FIS states the 100-year stillwater elevation is 12.2 feet NAVD, and if sea level is rising at 0.01 foot/year, and if the building lifetime is 50 years, the future conditions stillwater level will be 12.7 feet NAVD (12.2 + [(50)(0.01)]).
- The design stillwater flood depth, d_s, is then calculated by subtracting the future conditions eroded grade elevation from the future conditions stillwater elevation.

Figure 8-4. Erosion's effects on ground elevation



8.5.3 Design Stillwater Flood Depth

In a general sense, flood depth can refer to two different depths (see Figure 8-5):

- **Stillwater flood depth.** The vertical distance between the eroded ground elevation and the stillwater elevation associated with the design flood. This depth is referred to as the design stillwater flood depth (d_s).

- **Design flood protection depth.** The vertical distance between the eroded ground elevation and the DFE. This depth is referred to as the design flood protection depth (d_{fp}) but is not used extensively in this Manual. This Manual emphasizes the use of the DFE as the minimum elevation to which flood-resistant design and construction efforts should be directed.

NOTE

The design stillwater flood depth (d_s) (including wave setup; see Section 8.5.4) should be used for calculating wave heights and flood loads.

Determining the maximum design stillwater flood depth over the life of a building is the most important flood load calculation. Nearly every other coastal flood load parameter or calculation (e.g., hydrostatic load, design flood velocity, hydrodynamic load, design wave height, DFE, debris impact load, local scour depth) depends directly or indirectly on the design stillwater flood depth.

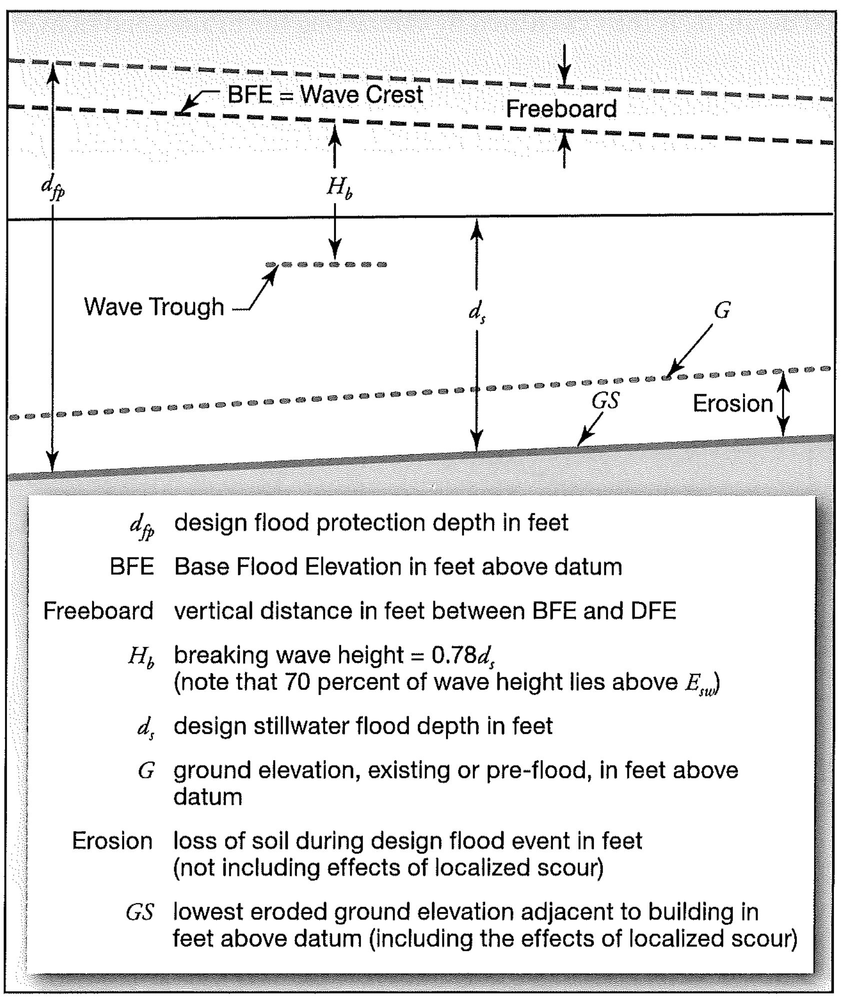


Figure 8-5. Parameters that are determined or affected by flood depth

In this Manual, the design stillwater flood depth (d_s) is defined as the difference between the design stillwater flood elevation (E_{sw}) and the lowest eroded ground surface elevation (GS) adjacent to the building (see Equation 8.1) where wave setup is included in the stillwater flood elevation.

EQUATION 8.1. DESIGN STILLWATER FLOOD DEPTH

$$d_s = E_{sw} - GS \qquad \text{(Eq. 8.1)}$$

where:

d_s = design stillwater flood depth (ft)

E_{sw} = design stillwater flood elevation in ft above datum (e.g., NGVD, NAVD)

GS = lowest eroded ground elevation, in ft above datum, adjacent to a building, excluding effects of localized scour around the foundation

Figure 8-5 illustrates the relationships among the various flood parameters that determine or are affected by flood depth. Note that in Figure 8-5 and Equation 8.1, GS is not the lowest existing pre-flood ground surface; it is the lowest ground surface that will result from long-term erosion and the amount of erosion expected to occur during a design flood, excluding local scour effects. The process for determining GS is described in Section 3.6.4.

CROSS REFERENCE

For a discussion of localized scour, see Section 8.5.10.

Values for E_{sw} are not shown on FEMA FIRMs, but they are given in the FISs, which are produced in conjunction with the FIRM for communities. FISs are usually available from community officials and NFIP State Coordinating Agencies. Some states have made FISs available on their Web sites. Many FISs are also available on the FEMA Web site for free or are available for download for a small fee. For more information, go to http://www.msc.fema.gov.

Design stillwater flood depth (d_s) is determined using Equation A in Example 8.1 for scenarios in which a non-100-year frequency-based DFE is specified by the Authority Having Jurisdiction (AHJ). Freeboard tied to the 100-year flood should not be used to increase d_s since load factors in ASCE 7 were developed for the 100-year nominal flood load.

Example 8.1 demonstrates the calculation of the design stillwater flood depth for five scenarios. All solutions to example problems are in bold text in this Manual.

EXAMPLE 8.1. DESIGN STILLWATER FLOOD DEPTH CALCULATIONS

Given:

- Oceanfront building site on landward side of a primary frontal dune (see Illustration A)
- Topography along transect perpendicular to shoreline is shown in Illustration B; existing ground elevation at seaward row of pilings = 7.0 ft NGVD
- Soil is dense sand; no terminating stratum above –25 ft NGVD
- Data from FIRM is as follows: flood hazard zone at site is Zone VE; BFE = 14.0 ft NGVD
- Data from FIS is as follows: 10-year stillwater elevation = 5.0 ft NGVD; 50-year stillwater elevation = 8.7 ft NGVD; 100-year stillwater elevation = 10.1 ft NGVD; 500-year stillwater elevation = 12.2 ft NGVD
- 500-year wave crest elevation (DFE) specified by AHJ = 18.0 ft NGVD
- Local government requires 1.0 ft freeboard; therefore DFE = 14.0 ft NGVD (BFE) + 1.0 ft = 15.0 ft NGVD
- Direction of wave and flow approach during design event is perpendicular to shoreline
- The eroded ground elevation (base flood conditions) at the seaward row of pilings = 5.5 ft NGVD
- Assume sea level rise is 0.01 ft/yr
- Assume long-term average annual erosion rate is 2.0 ft/yr, no beach nourishment or shoreline stabilization
- Assume building life = 50 years

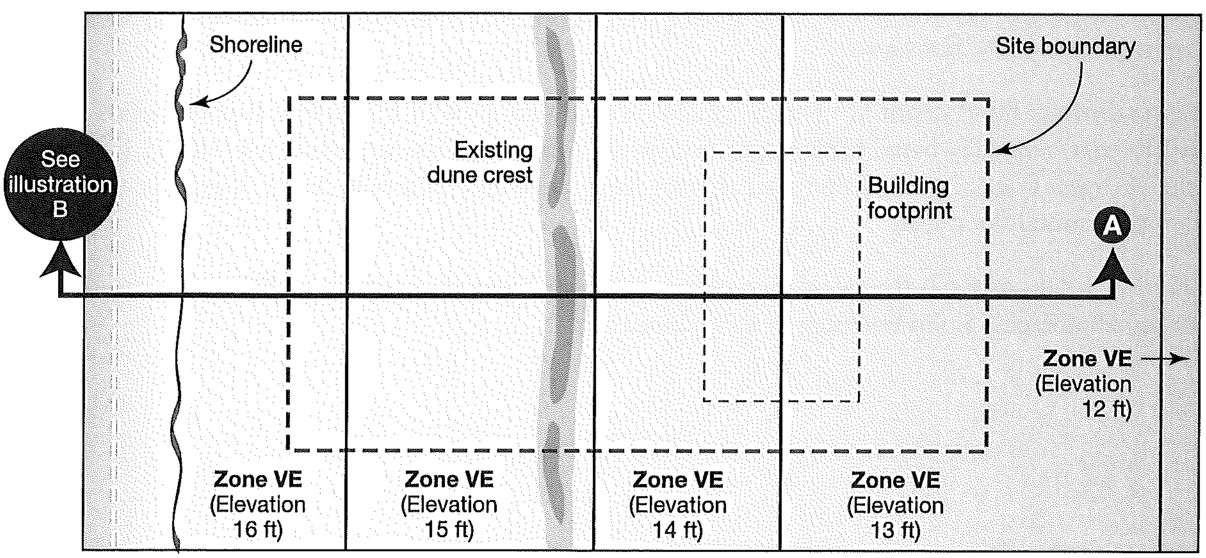


Illustration A. Plan view of site and building location with flood hazard zones

EXAMPLE 8.1. DESIGN STILLWATER FLOOD DEPTH CALCULATIONS (continued)

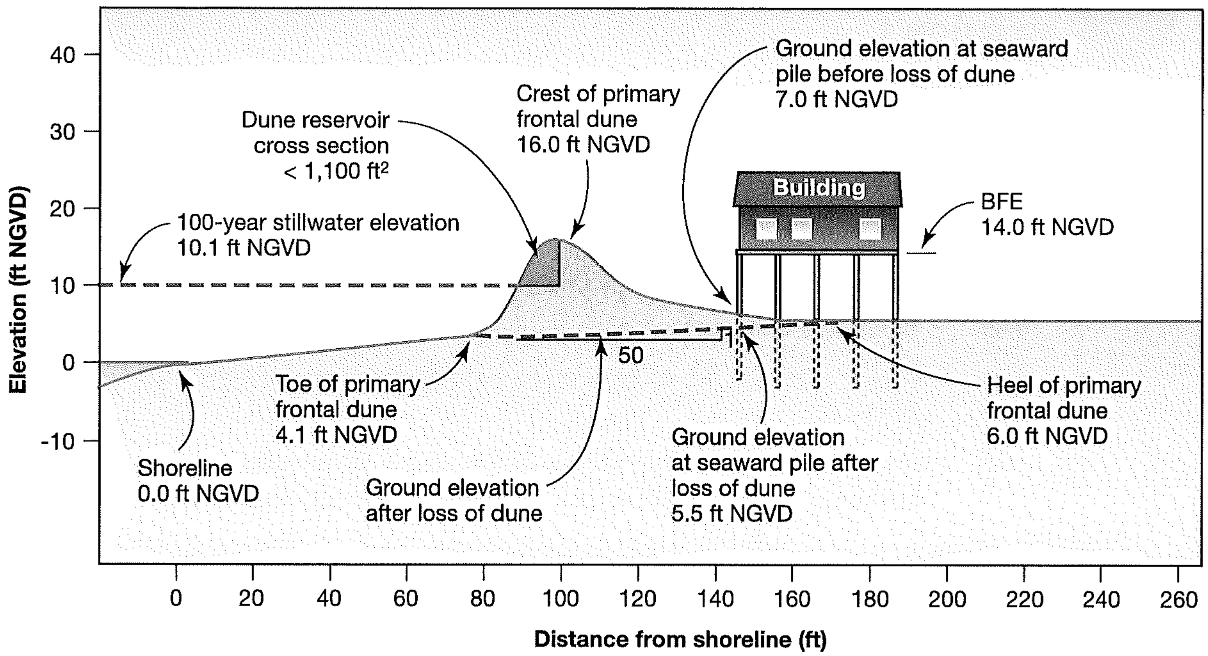


Illustration B. Primary frontal dune will be lost to erosion during a 100-year flood because dune reservoir is less than 1,100 ft² (Section A of Illustration A)

Find:

The design stillwater flood depth (d_s) at the seaward row of piles for varying values of stillwater elevation, presence of freeboard, and consideration of the effects of future conditions (e.g., sea-level rise and long-term erosion).

The basis of the design flood for four scenarios are as follows:

1. 100-year stillwater elevation (NGVD). Future conditions not considered.
2. 100-year stillwater elevation (NGVD) plus freeboard. Future conditions not considered.
3. 100-year stillwater elevation (NGVD). Future conditions (sea-level rise and long-term erosion) in 50 years considered.
4. 500-year wave crest elevation (NGVD). Future conditions not considered.

Note: *Design stillwater flood depth (d_s) is determined using Equation A for scenarios in which a non-100-year frequency-based DFE is specified by the AHJ. Freeboard tied to the 100-year flood should not be used to increase d_s since load factors in ASCE 7 were developed for the 100-year nominal flood load.*

EXAMPLE 8.1. DESIGN STILLWATER FLOOD DEPTH CALCULATIONS (continued)

EQUATION A

$$d_s = \left(\frac{DFE}{BFE}\right)(E_{SW}) - GS$$

where:

d_s = design stillwater flood depth

DFE = design flood elevation for a greater than 100-year flood event

BFE = base flood elevation

E_{SW} = design stillwater flood elevation in feet above datum (e.g. NGVD, NAVD)

GS = lowest eroded ground elevation, in feet above datum, adjacent to building, excluding effects of localized scour around foundations

Solution for Scenario #1: The design stillwater flood depth (d_s) at seaward row of pilings using the 100-year stillwater elevation can be calculated using Equation 8.1 as follows:

$d_s = E_{sw} - GS$

d_s = 10.1 ft NGVD – 5.5 ft NGVD

d_s = **4.6 ft**

Note: *This is the same solution that is calculated in Example 8.4, #3*

Solution for Scenario #2: The design stillwater flood depth (d_s) at seaward row of pilings using the 100-year stillwater elevation and freeboard will be calculated just as in Scenario #1–freeboard should not be included in the stillwater depth calculation but is used instead to raise the building to a higher-than-BFE level:

$d_s = E_{sw} - GS$

d_s = 10.1 ft NGVD – 5.5 ft NGVD

d_s = **4.6 ft**

Solution for Scenario #3: The design stillwater flood depth (d_s) at seaward row of pilings using the 100-year stillwater elevation and the future conditions of sea-level rise and long-term erosion can be calculated as follows:

Step 1: Increase 100-year stillwater elevation 50 years in the future to account for sea-level rise

E_{SW} = 10.1 ft NGVD + (0.01 ft/yr)(50 years) = 10.6 ft NGVD

Step 2: Calculate the lowest ground elevation in ft above the datum adjacent to the seaward row of pilings in 50 years

EXAMPLE 8.1. DESIGN STILLWATER FLOOD DEPTH CALCULATIONS (concluded)

- In 50 years, the front toe of the dune will translate horizontally toward the building by (50 yr)(2 ft/yr) = 100 ft landward
- Taking into account the 1:50 (*v:h*) slope of the eroded dune, the ground at the seaward row of piles will drop (100 ft)(1/50) = 2 ft over 50 years

GS = 5.5 ft – 2 ft = 3.5 ft NGVD in 50 years

Step 3: Combine the effects of sea-level rise and erosion to calculate d_s

$$d_s = E_{sw} - GS$$

$$d_s = 10.6 \text{ ft NGVD} - 3.5 \text{ ft NGVD} = \mathbf{7.1 \text{ ft}}$$

Solution for Scenario #4: The design stillwater flood depth (d_s) at seaward row of pilings using the AHJ's 500-year wave crest elevation (DFE) can be calculated using Equation A of Example 8.1 as follows:

$$d_s = \left(\frac{DFE}{BFE}\right)(E_{SW}) - GS$$

$$d_s = \left(\frac{18 \text{ ft}}{14 \text{ ft}}\right)(10.1 \text{ ft}) - 5.5 \text{ ft} = 13.0 \text{ ft} - 5.5 \text{ ft} = \mathbf{7.5 \text{ ft}}$$

Note: *Scenarios #1 through #4 show incremental increases in the design stillwater flood depth d_s, depending on how conservative the designer wishes to be in selecting the design scenario. As the design stillwater flood depth increases, the flood loads to which the building foundation must be designed also increase. The increase factor listed in Table A represents the square of the ratio of stillwater flood depth to the stillwater flood depth from Scenario #1(reference case).*

Table A. Stillwater Flood Depths for Various Design Scenarios and Approximate Load Increase Factor from Increased Values of d_s

Scenario #	Design Condition	d_s (ft)	Approximate Load Increase Factor
#1 (reference case)	100-year	4.6	1.0
#2	100-year + freeboard	4.6	1.0
#3	100-year + future conditions	7.1	2.4
#4	500-year	7.5	2.7

Note: *In subsequent examples, the building in Illustrations A and B and d_s in Scenario #1 are used.*

8.5.4 Wave Setup Contribution to Flood Depth

Pre-1989 FIS reports and FIRMs do not usually include the effects of wave setup (d_{ws}), but some post-1989 FISs and FIRMs do. Because the calculation of design wave heights and flood loads depends on an accurate determination of the total stillwater flood depth, designers should review the effective FIS carefully, using the following procedure:

- Check the hydrologic analyses section of the FIS for mention of wave setup. Note the magnitude of the wave setup.
- Check the stillwater elevation table of the FIS for footnotes regarding wave setup. If wave setup is included in the listed BFEs but not in the 100-year stillwater elevation, add wave setup before calculating the design stillwater flood depth, the design wave height, the design flood velocity, flood loads, and localized scour. If wave setup is already included in the 100-year stillwater elevation, use the 100-year stillwater elevation to determine the design stillwater flood depth and other parameters. Wave setup should not be included in the 100-year stillwater elevation when calculating primary frontal dune erosion.

NOTE

Flood loads are applied to structures as follows:

- **Lateral hydrostatic loads** – at two-thirds depth point of stillwater elevation
- **Breaking wave loads** – at stillwater elevation
- **Hydrodynamic loads** – at mid-depth point of stillwater elevation
- **Debris impact loads** – at stillwater elevation

TERMINOLOGY: WAVE SETUP

Wave setup is an increase in the stillwater surface near the shoreline due to the presence of breaking waves. Wave setup typically adds 1.5 to 2.5 feet to the 100-year stillwater flood elevation and should be discussed in the FIS.

8.5.5 Design Breaking Wave Height

The design breaking wave height (H_b) at a coastal building site is one of the most important design parameters. Unless detailed analysis shows that natural or manmade obstructions will protect the site during a design event, wave heights at a site should be calculated as the heights of depth-limited breaking waves, which are equivalent to 0.78 times the design stillwater flood depth (see Figure 8-5). Note that 70 percent of the breaking wave height lies above the stillwater elevation. In some situations, such as steep ground slopes immediately seaward of a building, the breaking wave height can exceed 0.78 times the stillwater flood depth. In such instances, designers may wish to increase the breaking wave height used for design, with an upper limit for the breaking wave height equal to the stillwater flood depth.

8.5.6 Design Flood Velocity

Estimating design flood velocities (V) in coastal flood hazard areas is subject to considerable uncertainty. There is little reliable historical information concerning the velocity of floodwaters during coastal flood events. The direction and velocity of floodwaters can vary significantly throughout a coastal flood event. Floodwaters can approach a site from one direction during the beginning of a flood event and then shift

WARNING

This Manual does not provide guidance for estimating flood velocities during tsunamis. The issue is highly complex and site-specific. Designers should look for model results from tsunami inundation or evacuation studies.

to another direction (or several directions). Floodwaters can inundate low-lying coastal sites from both the front (e.g., ocean) and back (e.g., bay, sound, river). In a similar manner, flow velocities can vary from close to zero to high velocities during a single flood event. For these reasons, flood velocities should be estimated conservatively by assuming floodwaters can approach from the most critical direction relative to the site and by assuming flow velocities can be high (see Equation 8.2).

EQUATION 8.2. DESIGN FLOOD VELOCITY

Lower bound $$V = \frac{d_s}{t}$$ (Eq. 8.2a)

Upper bound $$V = (gd_s)^{0.5}$$ (Eq. 8.2b)

where:

V = design flood velocity (ft/sec)

d_s = design stillwater flood depth (ft)

t = 1 sec

g = gravitational constant (32.2 ft/sec^2)

For design purposes, flood velocities in coastal areas should be assumed to lie between $V = (gd_s)^{0.5}$ (the expected upper bound) and $V = d_s/t$ (the expected lower bound). It is recommended that designers consider the following factors before deciding whether to use the upper- or lower-bound flood velocity for design:

- Flood zone
- Topography and slope
- Distance from the source of flooding
- Proximity to other buildings or obstructions

The upper bound should be taken as the design flood velocity if the building site is near the flood source, in Zone V, in Zone AO adjacent to Zone V, in Zone A subject to velocity flow and wave action, on steeply sloping terrain, or adjacent to other large buildings or obstructions that will confine or redirect floodwaters and increase local flood velocities. The lower bound is a more appropriate design flood velocity if the site is distant from the flood source, in Zone A, on flat or gently sloping terrain, or unaffected by other buildings or obstructions.

Figure 8-6 shows the velocity versus design stillwater flood depth relationship for non-tsunami, upper- and lower-bound velocities. Equation 8.2 shows the equations for the lower-bound and upper-bound velocity conditions.

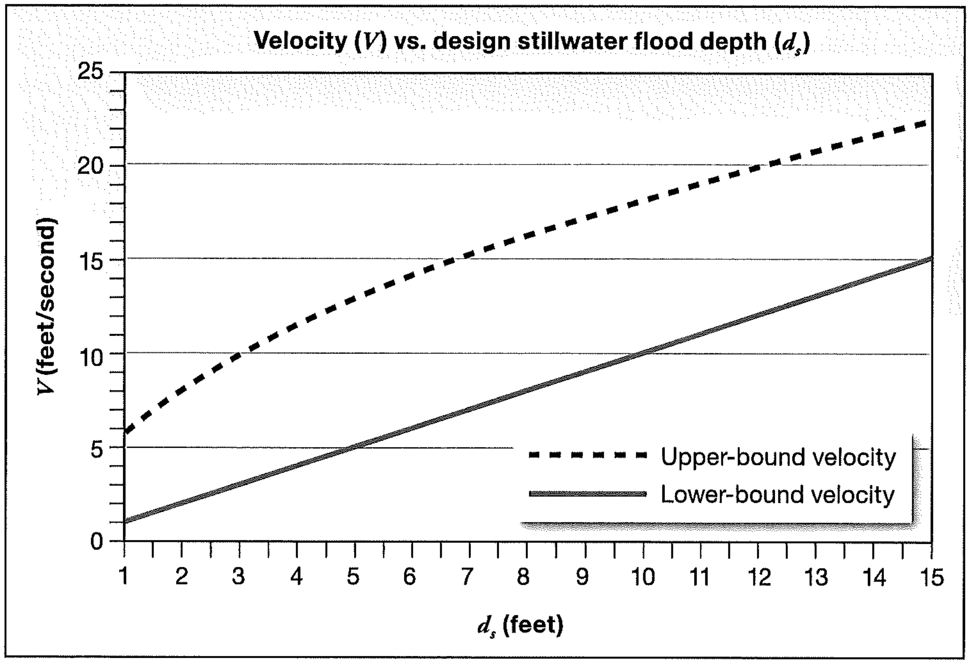


Figure 8-6. Velocity versus design stillwater flood depth

8.5.7 Hydrostatic Loads

Hydrostatic loads occur whenever floodwaters come into contact with a foundation, building, or building element. Hydrostatic loads can act laterally or vertically.

Lateral hydrostatic forces are generally not sufficient to cause deflection or displacement of a building or building element unless there is a substantial difference in water elevation on opposite sides of the building or component. This is why the NFIP requires that openings be provided in vertical walls that form enclosures below the BFE for buildings constructed in Zone A (see Section 5.2.3.2).

Likewise, vertical hydrostatic forces (buoyancy or flotation) are not generally a concern for properly constructed and elevated coastal buildings founded on adequate foundations. However, buoyant forces can have a significant effect on inadequately elevated buildings on shallow foundations. Such buildings are vulnerable to uplift from flood and wind forces because the weight of a foundation or building element is much less when submerged than when not submerged. For example, one cubic foot of a footing constructed of normal weight concrete weighs approximately 150 pounds. But when submerged, each cubic foot of concrete displaces a cubic foot of saltwater, which weighs about 64 pounds/cubic foot. Thus, the foundation's submerged weight is only 86 pounds if submerged in saltwater (150 pounds/cubic foot – 64 pounds/cubic foot = 86 pounds/cubic foot), or 88 pounds if submerged in fresh water (150 pounds/cubic foot – 62 pounds/cubic foot = 88 pounds/cubic foot). A submerged footing contributes approximately 40 percent less uplift resistance during flood conditions.

Section 3.2.2 of ASCE 7-10 states that the full hydrostatic pressure of water must be applied to floors and foundations when applicable. Sections 2.3.3 and 2.4.2 of ASCE 7-10 require factored flood loads to be considered in the load combinations that model uplift and overturning design limit states. For ASD, flood loads are increased by a factor of 1.5 in Zone V and Coastal A Zones (and 0.75 in coastal flood zones with base flood wave heights less than 1.5 feet, and in non-coastal flood zones). These load factors are applied to account for uncertainty in establishing design flood intensity. As indicated in Equations 8-3 and 8-4 (per Figure 8-7), the design stillwater flood depth should be used when calculating hydrostatic loads.

Any buoyant force (F_{buoy}) on an object must be resisted by the weight of the object and any other opposing force (e.g., anchorage forces) resisting flotation. The contents of underground storage tanks and the live load on floors should not be counted on to resist buoyant forces because the tanks may be empty or the building may be vacant when the flood occurs. Buoyant or flotation forces on a building can be of concern if the actual stillwater flood depth exceeds the design stillwater flood depth. Buoyant forces are also of concern for empty or partially empty aboveground tanks, underground tanks, and swimming pools.

Lateral hydrostatic loads are given by Equation 8.3 and illustrated in Figure 8-7. Note that f_{sta} (in Equation 8.3) is equivalent to the area of the pressure triangle and acts at a point equal to 2/3 d_s below the water surface (see Figure 8-7). Figure 8-7 is presented here solely to illustrate the application of lateral hydrostatic force. In communities participating in the NFIP, local floodplain ordinances or laws require that buildings in Zone V be elevated above the BFE on an open foundation and that the foundation walls of buildings in Zone A be equipped with openings that allow floodwater to enter so that internal and external hydrostatic pressures will equalize (see Section 5.2) and not damage the structure.

Vertical hydrostatic forces are given by Equation 8.4 and are illustrated by Figure 8-8.

EQUATION 8.3. LATERAL HYDROSTATIC LOAD

$$f_{sta} = \frac{1}{2}\gamma_w d_s^{\,2} \qquad \text{(Eq. 8.3a)}$$

where:

f_{sta} = hydrostatic force per unit width (lb/ft) resulting from flooding against vertical element

γ_w = specific weight of water (62.4 lb/ft^3 for fresh water and 64.0 lb/ft^3 for saltwater)

d_s = design stillwater flood depth (ft)

$$F_{sta} = f_{sta}(w) \qquad \text{(Eq. 8.3b)}$$

where:

F_{sta} = total equivalent lateral hydrostatic force on a structure (lb)

f_{sta} = hydrostatic force per unit width (lb/ft) resulting from flooding against vertical element

w = width of vertical element (ft)

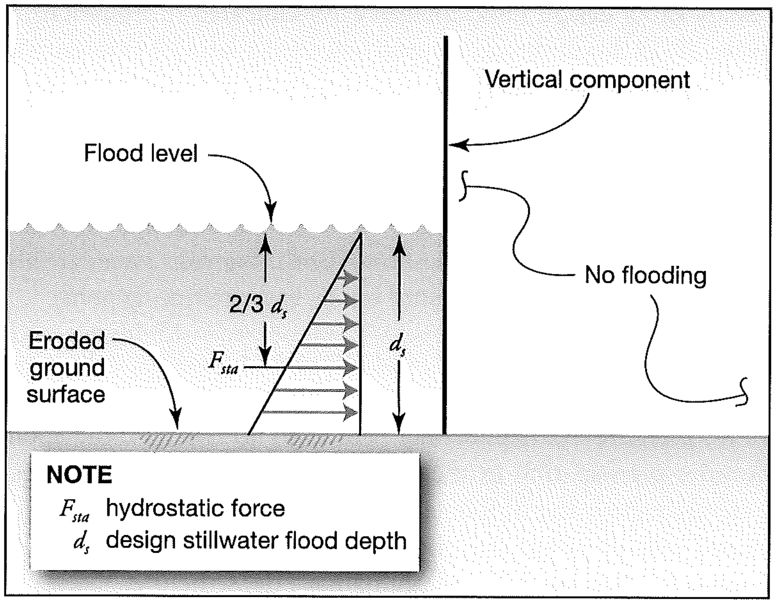


Figure 8-7. Lateral flood force on a vertical component

EQUATION 8.4. VERTICAL (BUOYANT) HYDROSTATIC FORCE

$$F_{buoy} = \gamma_w (Vol) \tag{Eq. 8.4}$$

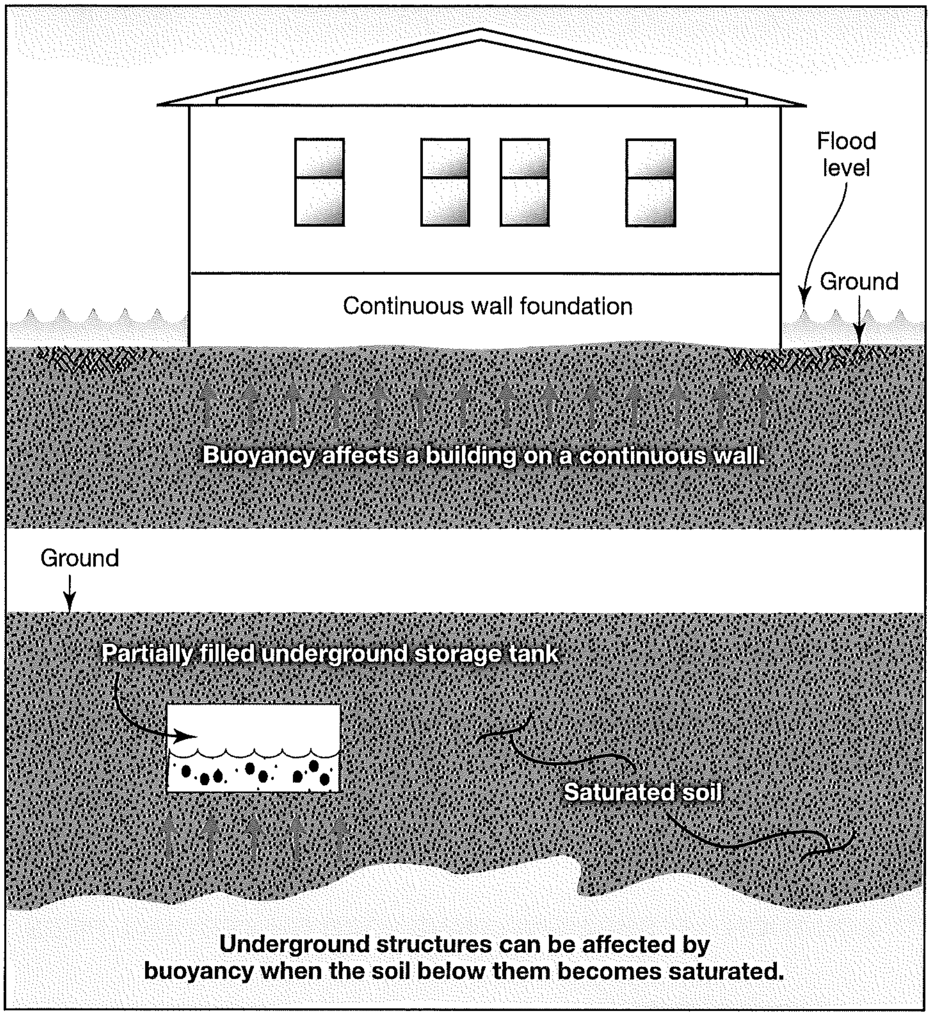
where:

F_{buoy} = vertical hydrostatic force (lb) resulting from the displacement of a given volume of floodwater

γ_w = specific weight of water (62.4 lb/ft^3 for fresh water and 64.0 lb/ft^3 for saltwater)

Vol = volume of floodwater displaced by a submerged object (ft^3)

Figure 8-8.
Vertical (buoyant) flood force; buoyancy forces are drastically reduced for open foundations (piles or piers)



8.5.8 Wave Loads

Calculating wave loads requires the designer to estimate expected wave heights, which, for the purposes of this Manual, are limited by water depths at the site of interest. These data can be estimated using a variety of models. FEMA uses its Wave Height Analysis for Flood Insurance Studies (WHAFIS) model to estimate wave heights and wave crest elevations, and results from this model can be used directly by designers to calculate wave loads.

CROSS REFERENCE

For additional guidance in calculating wave loads, see ASCE 7-10.

Wave forces can be separated into four categories:

- From nonbreaking waves – can usually be computed as hydrostatic forces against walls and hydrodynamic forces against piles
- From breaking waves – short duration but large magnitude
- From broken waves – similar to hydrodynamic forces caused by flowing or surging water

- Uplift – often caused by wave run-up, deflection, or peaking against the underside of horizontal surfaces

CROSS REFERENCE

For more information about FEMA's WHAFIS model, see http://www.fema.gov/plan/prevent/fhm/dl_wfis4.shtm.

The forces from breaking waves are the highest and produce the most severe loads. It is therefore strongly recommended that the breaking wave load be used as the design wave load.

The following three breaking wave loading conditions are of interest in residential design:

- Waves breaking on small-diameter vertical elements below the DFE (e.g., piles, columns in the foundation of a building in Zone V)
- Waves breaking against walls below the DFE (e.g., solid foundation walls in Zone A, breakaway walls in Zone V)
- Wave slam, where just the top of a wave strikes a vertical wall

8.5.8.1 Breaking Wave Loads on Vertical Piles

The breaking wave load on a pile can be assumed to act at the stillwater elevation and is calculated using Equation 8.5.

EQUATION 8.5. BREAKING WAVE LOAD ON VERTICAL PILES

$$F_{brkp} = \frac{1}{2} C_{db} \gamma_w D H_b^2 \qquad \text{(Eq. 8.5)}$$

where:

F_{brkp} = drag force (lb) acting at the stillwater elevation

C_{db} = breaking wave drag coefficient (recommended values are 2.25 for square and rectangular piles and 1.75 for round piles)

γ_w = specific weight of water (62.4 lb/ft^3 for fresh water and 64.0 lb/ft^3 for saltwater)

D = pile diameter (ft) for a round pile or 1.4 times the width of the pile or column for a square pile (ft)

H_b = breaking wave height (0.78 d_s), in ft, where d_s = design stillwater flood depth (ft)

Wave loads produced by breaking waves are greater than those produced by nonbreaking or broken waves. Example 8.3 shows the difference between the loads imposed on a vertical pile by nonbreaking waves and by breaking waves.

8.5.8.2 Breaking Wave Loads on Vertical Walls

Breaking wave loads on vertical walls are best calculated according to the procedure described in *Criteria for Evaluating Coastal Flood-Protection Structures* (Walton et al. 1989). The procedure is suitable for use in wave conditions typical during coastal flood and storm events. The relationship for breaking wave load per unit length of wall is shown in Equation 8.6.

NOTE

Equation 8.6 includes the hydrostatic component calculated using Equation 8.3. If Equation 8.6 is used, lateral hydrostatic force from Equation 8.3 should not be added to avoid double counting.

EQUATION 8.6. BREAKING WAVE LOAD ON VERTICAL WALLS

Case 1 (enclosed dry space behind wall):

$$f_{brkw} = 1.1C_p \gamma_w d_s^2 + 2.4\gamma_w d_s^2 \quad \text{(Eq. 8.6a)}$$

Case 2 (equal stillwater elevation on both sides of wall):

$$f_{brkw} = 1.1C_p \gamma_w d_s^2 + 1.9\gamma_w d_s^2 \quad \text{(Eq. 8.6b)}$$

where:

f_{brkw} = total breaking wave load per unit length of wall (lb/ft) acting at the stillwater elevation

C_p = dynamic pressure coefficient from Table 8-1

γ_w = specific weight of water (62.4 lb/ft^3 for fresh water and 64.0 lb/ft^3 for saltwater)

d_s = design stillwater flood depth (ft)

$$F_{brkw} = f_{brkw}(w) \quad \text{(Eq. 8.6c)}$$

where:

F_{brkw} = total breaking wave load (lb) acting at the stillwater elevation

f_{brkw} = total breaking wave load per unit length of wall (lb/ft) acting at the stillwater elevation

w = width of wall (ft)

The procedure assumes that the vertical wall causes a reflected or standing wave to form against the seaward side of the wall and that the crest of the wave reaches a height of 1.2 d_s above the stillwater elevation. The resulting dynamic, static, and total pressure distributions against the wall and resulting loads are as shown in Figure 8-9.

Table 8-1. Value of Dynamic Pressure Coefficient (C_p) as a Function of Probability of Exceedance

C_P	Building Type	Probability of Exceedance
1.6	Buildings and other structures that represent a low hazard to human life or property in the event of failure	0.5
2.8	Coastal residential building	0.01
3.2	Buildings and other structures, the failure of which could pose a substantial risk to human life	0.002
3.5	High-occupancy building or critical facility or those designated as essential facilities	0.001

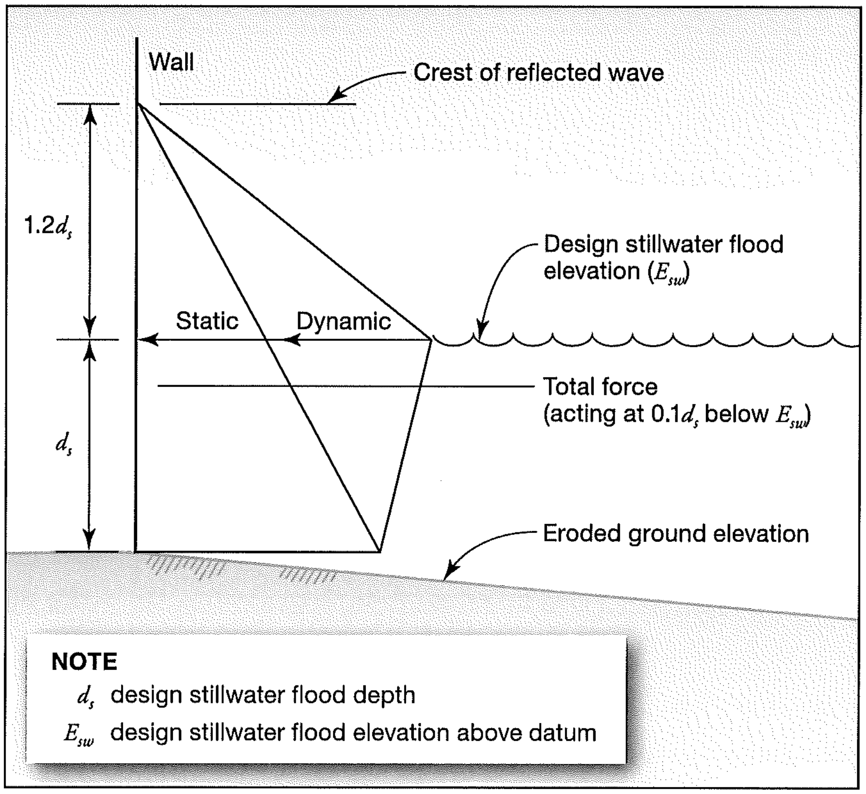
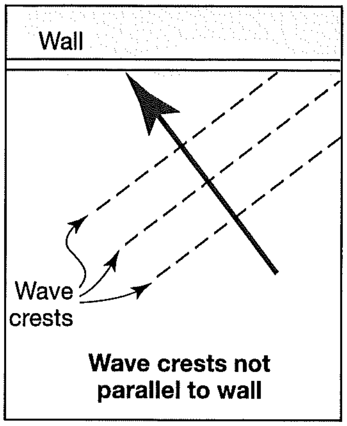


Figure 8-9. Breaking wave pressure distribution against a vertical wall

Equation 8.6 includes two cases: (1) a wave breaks against a vertical wall of an enclosed dry space, shown in Equation 8.6a, and (2) the stillwater elevation on both sides of the wall is equal, shown in Equation 8.6b. Case 1 is equivalent to a situation in which a wave breaks against an enclosure in which there is no floodwater inside the enclosure. Case 2 is equivalent to a situation in which a wave breaks against a breakaway wall or a wall equipped with openings that allow floodwaters to equalize on both sides of the wall. In both cases, waves are normally incident (i.e., wave crests are parallel to the wall). If breaking waves are obliquely incident (i.e., wave crests are not parallel to the wall; see Figure 8-10), the calculated loads would be lower.

Figure 8-10.
Wave crests not parallel to wall



NOTE: BREAKAWAY WALLS

When designing breakaway versus solid foundation walls using Equation 8.6, the designer should use a C_p of 1.0 rather than the C_p of 1.6 shown in Table 8-1. For more information on breakaway walls, see Section 9.3.

WARNING

The likelihood of damage or loss can be reduced by installing louvered panels in solid walls or creating flood openings in breakaway walls for small flood depths, so that the panels do not break away under minor (nuisance) flood conditions.

Figure 8-11 shows the relationship between water depth and wave height, and between water depth and breaking wave force, for the 1 percent and 50 percent exceedance interval events (Case 2). The Case 1 breaking wave force for these two events is approximately 1.1 times those shown for Case 2.

The breaking wave forces shown in Figure 8-11 are much higher than the typical wind forces that act on a coastal building, even wind pressures that occur during a hurricane or typhoon. However, the duration of the wave pressures and loads is brief; peak pressures probably occur within 0.1 to 0.3 second after the wave breaks against the wall. See *Wave Forces on Inclined and Vertical Wall Surfaces* (ASCE 1995) for a discussion of breaking wave pressures and durations.

WARNING

Even waves less than 3 feet high can impose large loads on foundation walls. Buildings in Coastal A Zones should be designed and constructed to meet Zone V requirements (see Section 6.5.2 in Chapter 6).

Post-storm damage inspections show that breaking wave loads have destroyed virtually all types of wood-frame walls and unreinforced masonry walls below the wave crest elevation. Only highly engineered, massive structural elements are capable of withstanding breaking wave loads. Damaging wave pressures and loads can be generated by waves much lower than the 3-foot wave currently used by FEMA to distinguish Zone A from Zone V. This fact was confirmed by the results of FEMA-sponsored laboratory tests of breakaway wall failures in which measured pressures

WARNING

Under the NFIP, construction of solid foundation walls (such as those that the calculations of Figure 8-11 represent) is not permitted in Zone V for new, substantially damaged, and substantially improved buildings.

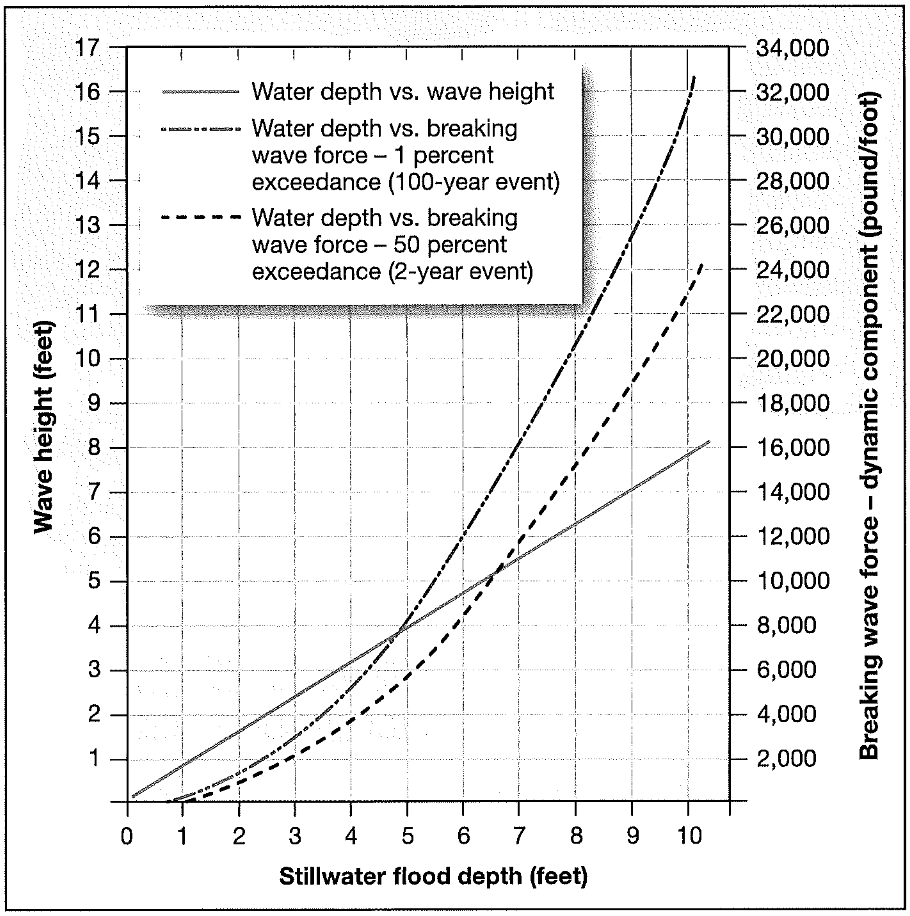


Figure 8-11. Water depth versus wave height, and water depth versus breaking wave force against, a vertical wall

on the order of hundreds of pounds/ square foot were generated by waves that were only 12 to 18 inches high. See Appendix H for the results of the tests.

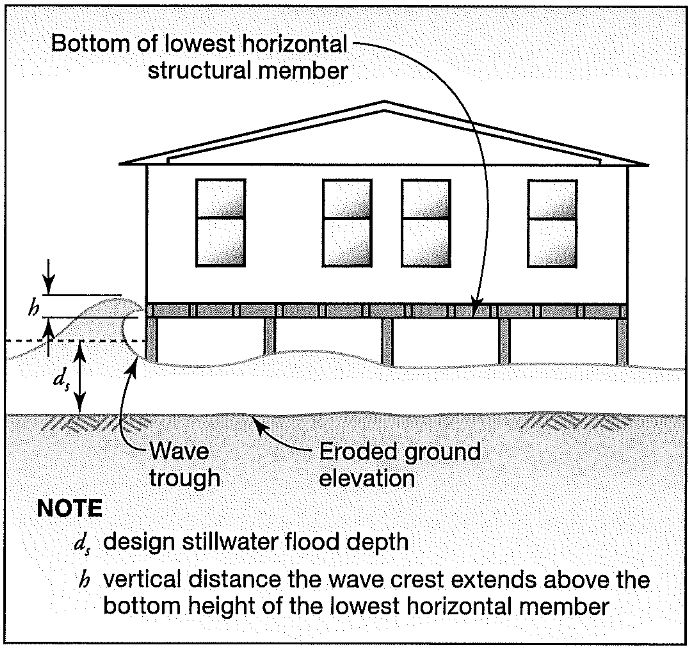
8.5.8.3 Wave Slam

The action of wave crests striking the elevated portion of a structure is known as "wave slam." Wave slam introduces lateral and vertical loads on the lower portions of the elevated structure (Figure 8-12). Wave slam force, which can be large, typically results in damaged floor systems (see Figure 3-26 in Chapter 3). This is one reason freeboard should be included in the design of coastal residential buildings. Lateral wave slam can be calculated using Equation 8.7, but vertical wave slam calculations are beyond the scope of this Manual.

Equation 8.7 is similar to Equation 8.8 (hydrodynamic load) with the wave crest velocity set at the wave celerity (upper-bound flow velocity, given by Equation 8.2b) and a wave slam coefficient instead of a drag coefficient. The wave slam coefficient used in Equation 8.7 is an effective slam coefficient, estimated using information contained in Bea et al. (1999) and McConnell et al. (2004).

Wave slam should not be computed for buildings that are elevated on solid foundation walls (the wave-load-on-wall calculation using Equation 8.6 includes wave slam) but should be computed for buildings that are elevated on piles or columns (wave loads on the piles or columns, and wave slam against the elevated building, can be computed separately and summed).

Figure 8-12.
Lateral wave slam against an elevated building



EQUATION 8.7. LATERAL WAVE SLAM

$$F_s = f_s w = \frac{1}{2}\gamma_w C_s d_s h w \qquad \text{(Eq. 8.7)}$$

where:

F_s = lateral wave slam (lb)

f_s = lateral wave slam (lb/ft)

C_s = slam coefficient incorporating effects of slam duration and structure stiffness for typical residential structure (recommended value is 2.0)

γ_w = unit weight of water (62.4 lb/ft^3 for fresh water and 64.0 lb/ft^3 for saltwater)

d_s = stillwater flood depth (ft)

h = vertical distance (ft) the wave crest extends above the bottom of the floor joist or floor beam

w = length (ft) of the floor joist or floor beam struck by wave crest

EXAMPLE 8.2. WAVE SLAM CALCULATION

Given:

- Zone V building elevated on pile foundation near saltwater
- Bottom of floor beam elevation = 15.0 ft NGVD
- Length of beam (parallel to wave crest) = 50 ft
- Design stillwater elevation = 12.0 ft NGVD
- Eroded ground elevation = 5.0 ft NGVD
- C_s (wave slam coefficient; see Equation 8.7) = 2.0
- γ_w = specific weight of water (62.4 lb/ft^3 for fresh water and 64.0 lb/ft^3 for saltwater)
- A = (8 ft)(0.833 ft) = 6.664 ft^2

Find:

1. Wave crest elevation
2. Vertical height of the beam subject to wave slam
3. Lateral wave slam acting on the elevated floor system

Solution for #1: The wave crest elevation can be calculated as 1.55 times the stillwater depth, above the eroded ground elevation

Wave crest elevation = 5.0 ft NGVD + 1.55 (12.0 ft NGVD – 5.0 ft NGVD) = **15.9 ft NGVD**

Solution for #2: The vertical height of the beam subject to wave slam can be found as follows:

Vertical height = wave crest elevation – bottom of beam elevation = 15.9 ft NGVD – 15.0 ft NGVD = **0.9 ft**

Solution for #3: Using Equation 8-7, the lateral wave slam acting on the elevated floor system can be found as follows:

$$F_s = f_s w = \frac{1}{2}\gamma C_s d_s h w = \left(\frac{1}{2}\right)(64\ \text{lb/ft}^3)\,(2.0)\,(7.0\ \text{ft})\,(0.9\ \text{ft})\,(50\ \text{ft}) = \mathbf{20{,}160\ lb}$$

8.5.9 Hydrodynamic Loads

As shown in Figure 8-13, water flowing around a building (or a structural element or other object) imposes loads on the building. In the figure, note that the lowest floor of the building is above the flood level and the loads imposed by flowing water affect only the foundation walls. However, open foundation systems, unlike that shown in Figure 8-13, can greatly reduce hydrodynamic loading. Hydrodynamic loads, which are a function of flow velocity and structural geometry, include frontal impact on the upstream face, drag along the sides, and suction on the downstream side. One of the most difficult steps in quantifying loads imposed by moving water is determining the expected flood velocity (see Section 8.5.6 for guidance on design flood velocities). In this Manual, the velocity of floodwater is assumed to be constant (i.e., steady-state flow). Hydrodynamic loads can be calculated using Equation 8.8.

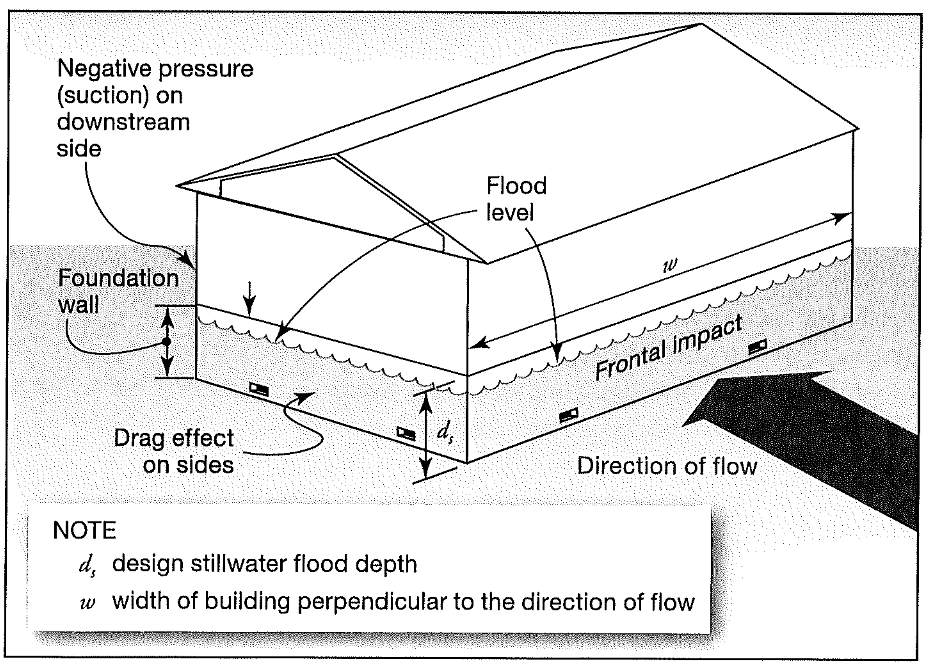
Elevating above the DFE provides additional protection from hydrodynamic loads for elevated enclosed areas.

The drag coefficient used in Equation 8.8 is taken from the *Shore Protection Manual, Volume 2* (USACE 1984). Additional guidance is provided in Section 5.4.3 of ASCE 7-10 and in FEMA 259, *Engineering Principles and Practices for Retrofitting Floodprone Residential Buildings* (FEMA 2001). The drag coefficient is a function of the shape of the object around which flow is directed. When an object is something other than a round, square, or rectangular pile, the coefficient is determined by one of the following ratios (see Table 8-2):

1. The ratio of the width of the object (w) to the height of the object (h) if the object is completely immersed in water

2. The ratio of the width of the object (w) to the stillwater flood depth of the water (d_s) if the object is not fully immersed

Figure 8-13. Hydrodynamic loads on a building



EQUATION 8.8. HYDRODYNAMIC LOAD (FOR ALL FLOW VELOCITIES)

$$F_{dyn} = \frac{1}{2} C_d \rho V^2 A \qquad \text{(Eq. 8.8)}$$

where:

F_{dyn} = horizontal drag force (lb) acting at the stillwater mid-depth (half way between the stillwater elevation and the eroded ground surface)

C_d = drag coefficient (recommended values are 2.0 for square or rectangular piles and 1.2 for round piles; for other obstructions, see Table 8-2)

ρ = mass density of fluid (1.94 slugs/ft^3 for fresh water and 1.99 slugs/ft^3 for saltwater)

V = velocity of water (ft/sec); see Equation 8.2

A = surface area of obstruction normal to flow (ft^2) = $(w)(d_s)$(see Figure 8-13) or $(w)(h)$ if the object is completely immersed

Flow around a building or building element also creates flow-perpendicular forces (lift forces). When a building element is rigid, lift forces can be assumed to be small. When the element is not rigid, lift forces can be greater than drag forces. The equation for lift force is the same as that for hydrodynamic force except that the drag coefficient (C_d) is replaced with the lift coefficient (C_l). In this Manual, the foundations of coastal residential buildings are considered rigid, and hydrodynamic lift forces can therefore be ignored.

Equation 8.8 provides the total force against a building of a given surface area, A. Dividing the total force by either length or width yields a force per linear unit; dividing by surface area, A, yields a force per unit area. Example 8.3 shows the difference between the loads imposed on a vertical pile by nonbreaking and breaking waves. As noted in Section 8.5.8, nonbreaking wave forces on piles can be calculated as hydrodynamic forces.

Table 8-2. Drag Coefficients for Ratios of Width to Depth (w/d_s) and Width to Height (w/h)

Width-to-Depth Ratio (w/d_s or w/h)	Drag Coefficient (C_d)
1–12	1.25
13–20	1.3
21–32	1.4
33–40	1.5
41–80	1.75
81–120	1.8
>120	2.0

NOTE

Lift coefficients (C_l) are provided in *Introduction to Fluid Mechanics* (Fox and McDonald 1985) and in many other fluid mechanics textbooks.

EXAMPLE 8.3. HYDRODYNAMIC LOAD ON PILES VERSUS BREAKING WAVE LOAD ON PILES

Given:

- Building elevated on round-pile foundation near saltwater
- C_d (drag coefficient for nonbreaking wave on round pile; see Equation 8.8) = 1.2
- C_{db} (drag coefficient for breaking wave on round pile; see Equation 8.5) = 1.75
- D = 10 in. or 0.833 ft
- d_s = 8 ft
- Velocity ranges from 8 ft/sec to 16 ft/sec
- ρ = mass density of fluid (1.94 slugs/ft^3 for fresh water and 1.99 slugs/ft^3 for saltwater)
- γ_w = specific weight of water (62.4 lb/ft^3 for fresh water and 64.0 lb/ft^3 for saltwater)
- A = (8 ft)(0.833 ft) = 6.664 ft^2

Find:

1. The range of loads from hydrodynamic flow around a pile
2. Load from a breaking wave on a pile

Solution for #1: The hydrodynamic load from flow past a pile is calculated using Equation 8.8 as follows:

For a flood velocity of 8 ft/sec:

$$F_{nonbrkp} = \frac{1}{2} C_d \rho V^2 A$$

$$F_{nonbrkp} = \frac{1}{2}(1.2)\left(1.99 \text{ slugs/ft}^3\right)(8 \text{ ft/sec})^2 (6.664 \text{ ft}^2)$$

$$F_{nonbrkp} = 509 \text{ lb/pile}$$

For a flood velocity of 16 ft/sec:

$$F_{nonbrkp} = \frac{1}{2} C_d \rho V^2 A$$

$$F_{nonbrkp} = \left(\frac{1}{2}\right)(1.2)\left(1.99 \text{ slugs/ft}^3\right)(16 \text{ ft/sec})^2 (6.664 \text{ ft}^2)$$

$$F_{nonbrkp} = 2{,}037 \text{ lb/pile}$$

The range of loads from a nonbreaking wave: 509 lb/pile to 2,037 lb/pile

EXAMPLE 8.3. HYDRODYNAMIC LOAD ON PILES VERSUS BREAKING WAVE LOAD ON PILES (concluded)

Solution for #2: The load from a breaking wave on a pile is calculated with Equation 8.5 as follows:

$$F_{brkp} = \left(\frac{1}{2}\right)(1.75)\left(64.0\ \text{lb/ft}^3\right)(0.833\ \text{ft})(0.78)(8\ \text{ft}^2)$$

where:

H_b is the height of the breaking wave or $(0.78)d_s$

F_{brkp} = **1,816 lb/pile**

Note: *The load from the breaking wave is approximately 3.5 times the lower estimate of the hydrodynamic load. The upper estimate of the hydrodynamic load exceeds the breaking wave load only because of the very conservative nature of the upper flood velocity estimate.*

8.5.10 Debris Impact Loads

Debris impact loads are imposed on a building by objects carried by moving water. The magnitude of these loads is very difficult to predict, but some reasonable allowance must be made for them. The loads are influenced by where the building is located in the potential debris stream, specifically if it is:

- Immediately adjacent to or downstream from another building
- Downstream from large floatable objects (e.g., exposed or minimally covered storage tanks)
- Among closely spaced buildings

A familiar equation for calculating debris loads is given in ASCE 7-10, *Commentary*. This equation has been simplified into Equation 8.9 using C_{Str}, the values of which are based on assumptions appropriate for the typical coastal buildings that are covered in this Manual. The parameters in Equation 8.9 are discussed below. See Chapter C5 of ASCE 7-10 for a more detailed discussion of the parameters.

Equation 8.9 contains the following uncertainties, each of which must be quantified before the effect of debris loading can be calculated:

- Size, shape, and weight (W) of the waterborne object
- Design flood velocity (V)
- Velocity of the waterborne object compared to the flood velocity
- Duration of the impact (Δt) (assumed to be equal to 0.03 seconds in the case of residential buildings is incorporated in C_{Str}, which is explained in more detail below)
- Portion of the building to be struck

EQUATION 8.9. DEBRIS IMPACT LOAD

$$F_i = W V C_D C_B C_{Str} \quad \text{(Eq. 8.9)}$$

where:

F_i = impact force acting at the stillwater elevation (lb)

W = weight of the object (lb)

V = velocity of water (ft/sec), approximated by $1/2(gd_s)^{1/2}$

C_D = depth coefficient (see Table 8-3)

C_B = blockage coefficient (taken as 1.0 for no upstream screening, flow path greater than 30 ft; see below for more information)

C_{Str} = Building structure coefficient (refer to the explanation of C_{Str} at the end of this section)

= 0.2 for timber pile and masonry column supported structures 3 stories or less in height above grade

= 0.4 for concrete pile or concrete or steel moment resisting frames 3 stories or less in height above grade

= 0.8 for reinforced concrete foundation walls (including insulated concrete forms)

Designers should consider locally adopted guidance because it may be based on more recent information than ASCE 7-10 or on information specific to the local hazards. Local guidance considerations may include the following:

- **Size, shape, and weight of waterborne debris.** The size, shape, and weight of waterborne debris may vary according to region. For example, the coasts of Washington, Oregon, and other areas may be subject to very large debris in the form of whole trees and logs along the shoreline. The southeastern coast of the United States may be more subject to debris impact from dune crossovers and destroyed buildings than other areas. In the absence of information about the nature of potential debris, a weight of 1,000 pounds is recommended as the value of *W*. Objects with this weight could include portions of damaged buildings, utility poles, portions of previously embedded piles, and empty storage tanks.

- **Debris velocity.** As noted in Section 8.5.6, flood velocity can be approximated within the range given by Equation 8.2. For calculating debris loads, the velocity of the waterborne object is assumed to be the same as the flood velocity. Although this assumption may be accurate for small objects, it may overstate debris velocities for large objects that drag on the bottom or that strike nearby structures.

- **Portion of the building to be struck.** The object is assumed to be at or near the water surface level when it strikes the building and is therefore assumed to strike the building at the stillwater elevation.

- **Depth coefficient.** The depth coefficient (C_D) accounts for reduced debris velocity as water depth decreases. For buildings in Zone A with stillwater flood depths greater than 5 feet or for buildings in Zone V, the depth coefficient = 1.0. For other conditions, the depth coefficient varies, as shown in Table 8-3.

Table 8-3. Depth Coefficient (C_D) by Flood Hazard Zone and Water Depth

Flood Hazard Zone and Water Depth	C_D
Floodway[(a)] or Zone V	1.0
Zone A, stillwater flood depth $\geq$ 5 ft	1.0
Zone A, stillwater flood depth = 4 ft	0.75
Zone A, stillwater flood depth = 2.5 ft	0.375
Zone A, stillwater flood depth $\leq$ 1 ft	0.00

(a) Per ASCE 24-05, a "floodway" is a "channel and that portion of the floodplain reserved to convey the base flood without cumulatively increasing the water surface elevation more than a designated height."

Blockage coefficient. The blockage coefficient (C_B) is used to account for the reduction in debris velocity expected to occur because of the screening provided by trees and other structures upstream from the structure or building on which the impact load is being calculated. The blockage coefficient varies, as shown in Table 8-4.

Table 8-4. Values of Blockage Coefficient C_B

Degree of Screening or Sheltering within 100 Ft Upstream	C_B
No upstream screening, flow path wider than 30 ft	1.0
Limited upstream screening, flow path 20-ft wide	0.6
Moderate upstream screening, flow path 10-ft wide	0.2
Dense upstream screening, flow path less than 5-ft wide	0.0

Building structure coefficient. The building structure coefficient, C_{str}, is derived from Equation C5-3, Chapter C5, ASCE 7-10. Coefficient values for C_{str}, (0.2, 0.4, and 0.8 as defined above for Equation 8.9) were generated by selecting input values recommended in ASCE 7-10, Chapter C5, with appropriate assumptions made to model typical coastal residential structures. The derived building structure coefficient formula with inputs is defined as follows:

$$C_{Str} = \frac{3.14 C_I C_O R_{\max}}{2 g \Delta t}$$

where:

C_I = importance coefficient = 1.0

C_O = orientation coefficient = 0.80

Δt = duration of impact = 0.03 sec

g = gravitational constant (32.2 ft/sec^2)

R_{max} = maximum response ratio assuming approximate natural period, T, of building types as follows: for timber pile and masonry column, T = 0.75 sec; for concrete pile or concrete or steel moment resisting frames, T = 0.35 sec; and for reinforced concrete foundation walls, T = 0.2 sec. The ratio of impact duration (0.03 sec) to approximate natural period (T) is entered into Table C5-4 of ASCE 7-10 to yield the R_{max} value.

8.5.11 Localized Scour

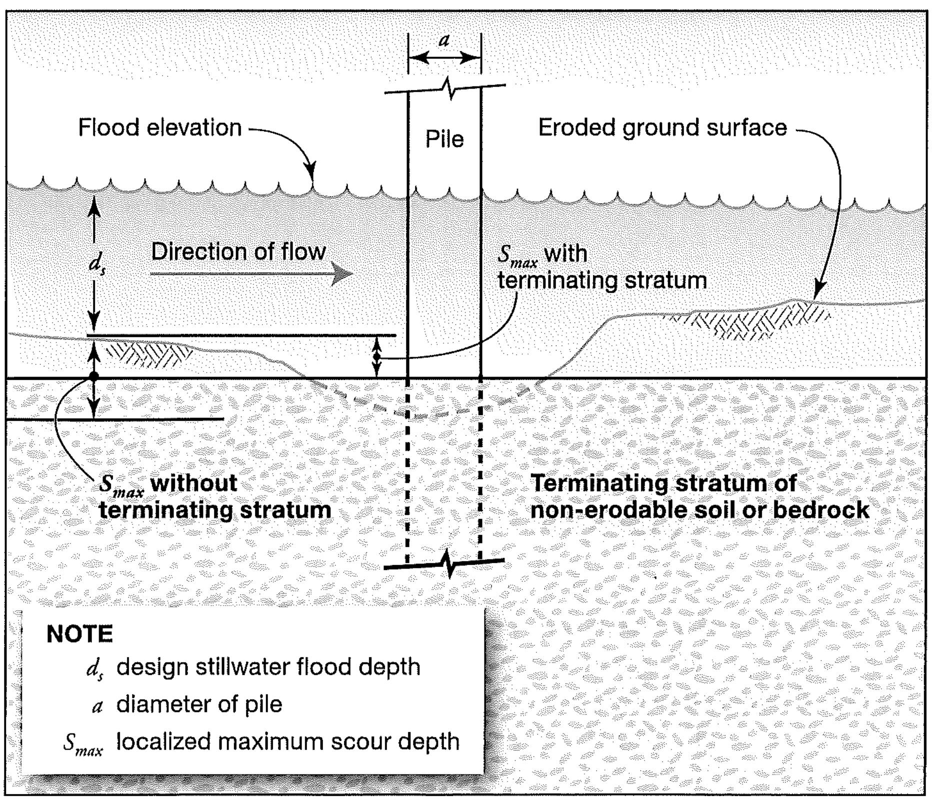
Waves and currents during coastal flood conditions create turbulence around foundation elements, causing localized scour around those elements. Determining potential scour is critical in designing coastal foundations to ensure that failure does not occur as a result of the loss in either bearing capacity or anchoring resistance around the posts, piles, piers, columns, footings, or walls. Localized scour determinations will require knowledge of the flood conditions, soil characteristics, and foundation type.

At some locations, soil at or below the ground surface can be resistant to localized scour, and the scour depths calculated as described below would be excessive. When the designer believes the soil at a site may be scour-resistant, the assistance of a geotechnical engineer should be sought before calculated scour depths are reduced.

- **Localized scour around vertical piles.** Generally, localized scour calculation methods in coastal areas are based largely on laboratory tests and empirical evidence gathered after storms.

  The evidence suggests that the localized scour depth around a single pile or column or other thin vertical members is equal to approximately 1.0 to 1.5 times the pile diameter. In this Manual, a ratio of 2.0 is recommended (see Equation 8.10), consistent with the rule of thumb given in the *Coastal Engineering Manual* (USACE 2008). Figure 8-14 illustrates localized scour at a pile, with and without a scour-resistant terminating stratum.

Figure 8-14.
Scour at single vertical foundation member, with and without underlying scour-resistant stratum



EQUATION 8.10. LOCALIZED SCOUR AROUND A SINGLE VERTICAL PILE

$$S_{\max} = 2.0a \qquad \text{(Eq. 8.10)}$$

where:

S_{max} = maximum localized scour depth (ft)

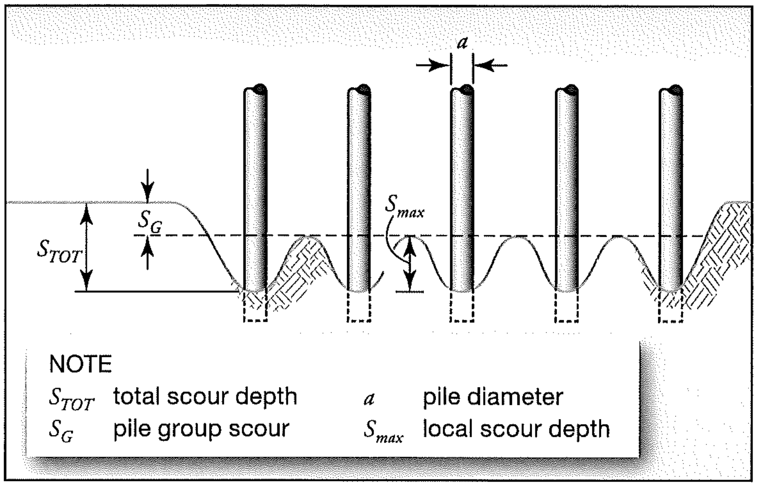
a = diameter of a round foundation element or the maximum diagonal cross-section dimension for a rectangular element

Observations after some hurricanes have shown cases in which localized scour around foundations far exceeded twice the diameter of any individual foundation pile. This was probably a result of flow and waves interacting with the group of foundation piles. In some cases, scour depressions were observed or reported to be 5 to 10 feet deep (see Figure 8-15). This phenomenon has been observed at foundations with or without slabs on grade but appears to be aggravated by the presence of the slabs.

Figure 8-15. Deep scour around foundation piles, Hurricane Ike (Bolivar Peninsula, TX, 2008)

Some research on the interaction of waves and currents on pile groups suggests that the interaction is highly complex and depends on flow characteristics (depth, velocity, and direction), wave conditions (wave height, period, and direction), structural characteristics (pile diameter and spacing) and soil characteristics (Sumer et al. 2001). Conceptually, the resulting scour at a pile group can be represented as shown in Figure 8-16. In this Manual, the total scour depth under a pile group is estimated to be 3 times the single pile scour depth, plus an allowance for the presence of a slab or grade beam, as shown in Equation 8.11. The factor of 3 is consistent with data reported in the literature and post-hurricane observations.

**Figure 8-16.
Scour around a group of foundation piles**
SOURCE: ADAPTED FROM SUMER ET AL. 2001



EQUATION 8.11. TOTAL LOCALIZED SCOUR AROUND VERTICAL PILES

$$S_{TOT} = 6a + 2 \text{ ft (if grade beam and/or slab-on-grade present)} \quad \text{(Eq. 8.11a)}$$

$$S_{TOT} = 6a \text{ (if no grade beam or slab-on-grade present)} \quad \text{(Eq. 8.11b)}$$

where:

S_{TOT} = total localized scour depth (ft)

a = diameter of a round foundation element or the maximum diagonal cross-section dimension for a rectangular element

$2 ft$ = allowance for vertical scour due to presence of grade beam or slab-on-grade

One difficulty for designers is determining whether local soils and coastal flood conditions will result in pile group scour according to Equation 8.11. Observations after Hurricanes Rita and Ike suggest that such scour is widespread along the Gulf of Mexico shoreline in eastern Texas and southwestern Louisiana, and observations after Hurricanes Opal and Ivan suggest that it occurs occasionally along the Gulf of Mexico shoreline in Alabama and Florida. Deep foundation scour has also been observed occasionally on North Carolina barrier islands (Hurricane Fran) and American Samoa (September 2009 tsunami).

These observations suggest that some geographic areas are more susceptible than others, but deep foundation scour can occur at any location where there is a confluence of critical soil, flow, and wave conditions. Although these critical conditions cannot be identified precisely, designers should (1) be aware of the phenomenon, (2) investigate historical records for evidence of deep foundation scour around pile groups, and (3) design for such scour when the building site is low-lying, the soil type is predominantly silty, and the site is within several hundred feet of a shoreline.

- **Localized scour around vertical walls and enclosures.** Localized scour around vertical walls and enclosed areas (e.g., typical Zone A construction) can be greater than that around single vertical piles, but it usually occurs at a corner or along one or two edges of the building (as opposed to under the entire building). See Figure 8-16.

Scour depths around vertical walls and enclosed areas should be calculated in accordance with Equation 8.12, which is derived from information in *Coastal Engineering Manual* (USACE 2006). The equation is based on physical model tests conducted on large-diameter vertical piles exposed to waves and currents ("large" means round and square objects with diameters/side lengths corresponding to several tens of feet in the real world, which is comparable to the coastal residential buildings considered in this Manual). Equation 8.12, like Equation 8.11, has no explicit consideration of soil type, so designers must consider whether soils are highly erodible and plan accordingly.

EQUATION 8.12. TOTAL SCOUR DEPTH AROUND VERTICAL WALLS AND ENCLOSURES

$$S_{TOT} = 0.15L \qquad \text{(Eq. 8.12)}$$

where:

S_{TOT} = total scour depth (ft), maximum value is 10 ft

L = horizontal length along the side of the building or obstruction exposed to flow and waves

8.5.12 Flood Load Combinations

Designers should be aware that not all of the flood loads described in Section 8.5 act at certain locations or against certain building types. Table 8-5 provides guidance for calculating appropriate flood loads in Zone V and Coastal A Zones (flood load combinations for the portion of Zone A landward of the Limit of Moderate Wave Action [LiMWA] are shown for comparison).

Table 8-5. Selection of Flood Loads for F_a in ASCE 7-10 Load Combinations for Global Forces

Description	Load Combination
Pile or open foundation in Zone V or Coastal A Zone	Greater of F_{brkp} or F_{dyn} (on front row of piles only) + F_{dyn} (on all other piles) + F_i (on one pile only)
Solid (perimeter wall) foundation	Greater of F_{brkw} or F_{dyn} + F_i (in one corner)

As discussed in Section 8.5.7, hydrostatic loads are included only when standing water will exert lateral or vertical loads on the building; these situations are usually limited to lateral forces being exerted on solid walls or buoyancy forces being exerted on floors and do not dominate in the Zone V or Coastal A Zone environment. Section 8.5.7 includes a discussion about how to include these hydrostatic flood loads in the ASCE 7-10 load combinations.

The guidance in ASCE 7-10, Sections 2.3 and 2.4 (Strength Design and Allowable Stress Design, respectively) also indicates which load combinations the flood load should be applied to. In the portion of Zone A landward of the LiMWA, the flood load F_a could either be hydrostatic or hydrodynamic loads. Both of these loads could be lateral loads; only hydrostatic will be a vertical load (buoyancy). When designing for global forces that will create overturning, sliding or uplift reactions, the designer should use F_a as the flood load that creates the most restrictive condition. In sliding and overturning, F_a should be determined by the type of expected flooding. Hydrostatic forces govern if the flooding is primarily standing water possibly saturating the ground surrounding a foundation; hydrodynamic forces govern if the flooding is primarily from moving water.

When designing a building element such as a foundation, the designer should use F_a as the greatest of the flood forces that affect that element (F_{sta} or F_{dyn}) + F_i (impact loads on that element acting at the stillwater level). The combination of these loads must be used to develop the required resistance that must be provided by the building element.

The designer should assume that breaking waves will affect foundation elements in both Zone V and Zone A. In determining total flood forces acting on the foundation at any given point during a flood event, it is generally unrealistic to assume that impact loads occur on all piles at the same time as breaking wave loads. Therefore, it is recommended that the load be calculated as a single wave impact load acting in combination with other sources of flood loads.

For the design of foundations in Zone V or Coastal A Zone, load combination cases considered should include breaking wave loads alone, hydrodynamic loads alone, and the greater of hydrodynamic loads and breaking wave loads acting in combination with debris impact loads. The value of flood load, F_a, used in ASCE 7-10 load combinations, should be based on the greater of F_{brk} or F_{dyn}, as applicable for global forces (see Table 8-5) or F_i + (F_{brk} or F_{dyn}), as applicable for an individual building element such as a pile.

Example 8-4 is a summary of the information regarding flood loads and the effects of flooding on an example building.

EXAMPLE 8.4. FLOOD LOAD EXAMPLE PROBLEM

Given:

- Oceanfront building site on landward side of a primary frontal dune (see Example 8.1, Illustration A)
- Topography along transect perpendicular to shoreline is shown in Example 8.1, Illustration B; existing ground elevation at seaward row of pilings = 7.0 ft NGVD
- Soil is dense sand; no terminating stratum above –25 ft NGVD
- Data from FIRM are as follows: flood hazard zone at site is Zone VE, BFE = 14.0 ft NGVD
- Data from FIS are as follows: 100-year stillwater elevation = 10.1 ft NGVD, 10-year stillwater elevation = 5.0 ft NGVD

EXAMPLE 8.4. FLOOD LOAD EXAMPLE PROBLEM (continued)

- Local government requires 1.0 ft freeboard; therefore DFE = 14.0 ft NGVD (BFE) + 1.0 ft = 15.0 ft NGVD
- Building to be supported on 8-in. × 8-in. square piles, as shown in Illustration A
- Direction of wave and flow approach during design event is perpendicular to shoreline (see Illustration A)
- The assumption is no grade beam or slab-on-grade present

Find:

1. Primary frontal dune reservoir: determine whether dune will be lost or provide protection during design event
2. Eroded ground elevation beneath building resulting from storm erosion
3. Design flood depth (d_s) at seaward row of piles
4. Probable range of design event flow velocities
5. Local scour depth (S) around seaward row of piles
6. Total localized scour (S_{TOT}) around piles
7. Design event breaking wave height (H_b) at seaward row of piles
8. Hydrodynamic (velocity flow) loads (F_{dyn}) on a pile (not in seaward row)
9. Breaking wave loads (F_{brk}) on the seaward row of piles
10. Debris impact load (F_i) from a 1,000-lb object acting on one pile

Solution for #1: Whether the dune will be lost or provides protection can be determined as follows:

- The cross-sectional area of the frontal dune reservoir is above the 100-year stillwater elevation and seaward of the dune crest.
- The area (see Example 8.1, Illustration B) can be approximated as a triangle with the following area:

$$A = \frac{1}{2}bh$$

Where b is the base dimension and h is the height dimension of the approximate triangle:

$$= \frac{1}{2}(16 \text{ ft NGVD dune crest elevation} - 10.1 \text{ ft NGVD 100-year stillwater elevation})(15 \text{ ft})$$

A = 44 ft² but the area shown is slightly larger than that of the triangular area, so assume A = 50 ft²

EXAMPLE 8.4. FLOOD LOAD EXAMPLE PROBLEM (continued)

- According to this Manual, the cross-sectional area of the frontal dune reservoir must be at least 1,100 ft^2 to survive a 100-year flood event.
- 50 ft^2 <1,100 ft^2 and therefore, **the dune will be lost and provide no protection during the 100-year event.**

Solution for #2: The eroded ground elevation beneath building can be found as follows:

- Remove dune from transect by drawing an upward-sloping (1:50 *v:h*) line landward from the lower of the dune toe or the intersection of the 10-year stillwater elevation and the pre-storm profile.
- The dune toe is 4.1 ft NGVD. The intersection of the 10-year stillwater elevation and pre-storm profile is 5.0 ft NGVD.
- The dune toe is lower (4.1 ft NGVD < 5.0 ft NGVD).
- Draw a line from the dune toe (located 75 ft from the shoreline at an elevation of 4.1 ft NGVD) sloping upward at a 1:50 (*v:h*) slope and find where the seaward row of piles intersects this line.

$$\text{Elevation} = 4.1 \text{ ft NGVD} + (145 \text{ ft} - 75 \text{ ft})\left(\frac{1}{50}\right) = 5.5 \text{ ft NGVD}$$

Therefore, the eroded ground elevation at the seaward row of pilings = **5.5 ft NGVD**

Note: *This value does not include local scour around the piles.*

Solution for #3: The design stillwater flood depth (d_s) at seaward row of pilings can be calculated with Equation 8.1 as follows:

$$d_s = E_{sw} - GS$$

Using the 100-year stillwater elevation (NGVD):

$$d_s = 10.1 \text{ ft NGVD} - 5.5 \text{ ft NGVD}$$

$$d_s = \mathbf{4.6 \text{ ft}}$$

Note: *This is the same solution as calculated in Example 8.1, Solution #1.*

Solution for #4: Use Equations 8.2a and 8.2b to determine the range of design flow velocities (V) as follows:

- Lower-bound velocity:

$$V = \frac{d_s}{t}$$

$$V = \frac{4.6 \text{ ft}}{1 \text{ sec}}$$

EXAMPLE 8.4. FLOOD LOAD EXAMPLE PROBLEM (continued)

Lower-bound $V = 4.6$ ft/sec

- Upper-bound velocity:

$$V = (gd_s)^{0.5}$$

$$\text{Upper-bound } V = \left(32.2 \text{ ft/sec}^2\right)(4.6 \text{ ft})^{0.5} = 12.2 \text{ ft/sec}$$

The range of velocities: **4.6 ft/sec to 12.2 ft/sec**

Note: t *is assumed to be equal to 1 sec, as given in Equation 8.2.*

Solution for #5: Local scour depth (S) around seaward row of pilings can be found using Equation 8.10 as follows:

$$S = 2.0a$$

where:

$$a = \frac{\sqrt{7.5^2 \text{ in.} + 7.5^2 \text{ in.}}}{12 \text{ in./ft}} = \frac{10.6 \text{ in.}}{12 \text{ in./ft}} = 0.88 \text{ ft}$$

$$S = (2.0)(0.88 \text{ ft}) = \mathbf{1.76\ ft}$$

Solution for #6: To find the total localized scour (S_{TOT}) around piles, use Equation 8.11b as follows:

$$S_{TOT} = 6a = 6(0.88 \text{ ft}) = \mathbf{5.28\ ft}$$

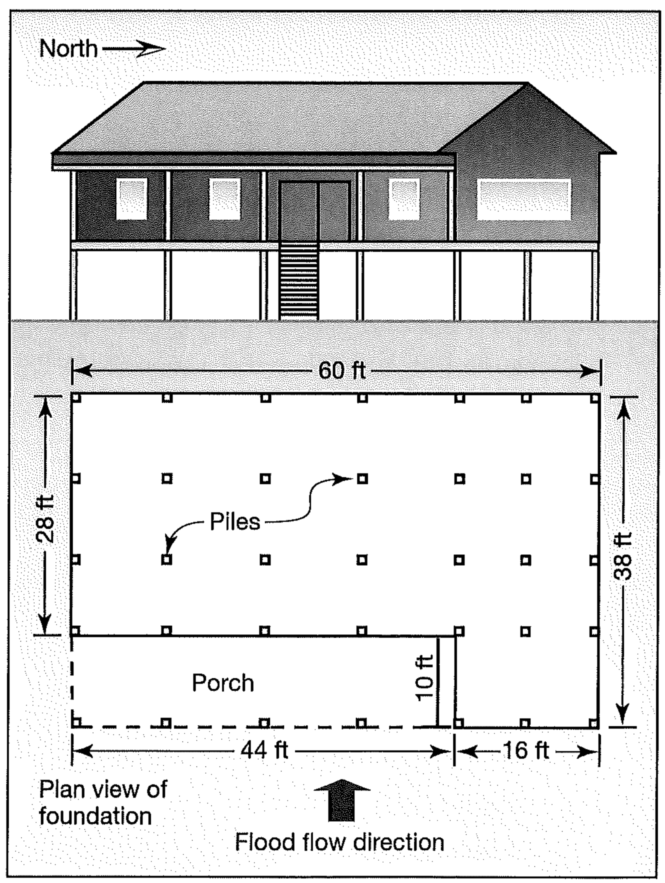


Illustration A. Building elevation and plan view of pile foundation

EXAMPLE 8.4. FLOOD LOAD EXAMPLE PROBLEM (continued)

Solution for #7: Breaking wave height (H_b) at seaward row of pilings can be found as follows:

At seaward row of pilings, H_b = (d_s)(0.78) where d_s = 4.6 ft from Solution #3

$H_b = (4.6 \text{ ft})(0.78) = \mathbf{3.6 \text{ ft}}$

Solution for #8: Hydrodynamic (velocity flow) loads (F_{dyn}) on a pile (not in seaward row) can be calculated using Equation 8.8 as follows:

On one pile: $F_{dyn} = \frac{1}{2} C_d \rho V^2 A$

where:

C_d = 2.0 for a square pile

ρ = 1.99 slugs/ft^3

$A = \frac{8 \text{ in.}}{12 \text{ in.}}(10.1 \text{ ft} - 5.5 \text{ ft}) = 3.07 \text{ ft}^2$

V = 12.2 ft/sec (because the building is on oceanfront, use the upper bound flow velocity for calculating loads)

$$F_{dyn} = \frac{1}{2}(2.0)(1.99)(12.2)^2(3.07)$$

F_{dyn} on one pile = **909 lb**

Solution for #9: Breaking wave loads (F_{brkp}) on seaward row of pilings can be found using Equation 8.5 as follows:

F_{brkp} on one pile $= \frac{1}{2} C_{db} \gamma_w D H_b^2$

where:

C_{db} = 2.25 for square piles

γ_w = 64.0 lb/ft^3 for saltwater

$D = \frac{8 \text{ in.}}{12 \text{ in.}}(1.4) = 0.93 \text{ ft}$

H_b = 3.6 ft from Solution #7

$$F_{brkp} = \frac{1}{2}(2.25)\left(64.0 \text{ lb/ft}^3\right)(0.93 \text{ ft})(3.6 \text{ ft})^2$$

F_{brkp} on one pile = 868 lb

F_{brkp} on seaward row of piles (i.e., 7 piles) = (625 lb)(7) = **6,076 lb**

EXAMPLE 8.4. FLOOD LOAD EXAMPLE PROBLEM (concluded)

Solution for #10: Debris impact load (F_i) from a 1,000-lb object on one pile can be determined using Equation 8.9 as follows: $F_i = W V C_D C_B C_{Str}$

where:

W = 1,000 lb

C_D = 1.0

C_B = 1.0

C_{Str} = 0.2 (timber pile)

Debris impact load = $(1{,}000 \text{ lb})(12.2 \text{ ft/sec})(1.0)(1.0)(0.2)$

Debris impact load = **2,440 lb**

Note: *C_D and C_B are each assumed to be 1.0.*

The following worksheets will facilitate flood load computations.