Net open area – The permanently open area of a non-engineered opening intended to provide automatic entry and exit of floodwaters.

Opening, engineered – An engineered opening is an opening that is designed and certified by a registered design professional as meeting certain performance characteristics related to providing automatic entry and exit of floodwaters; the certification requirement may be satisfied by an individual certification or issuance of an Evaluation Report by the ICC Evaluation Service, Inc.

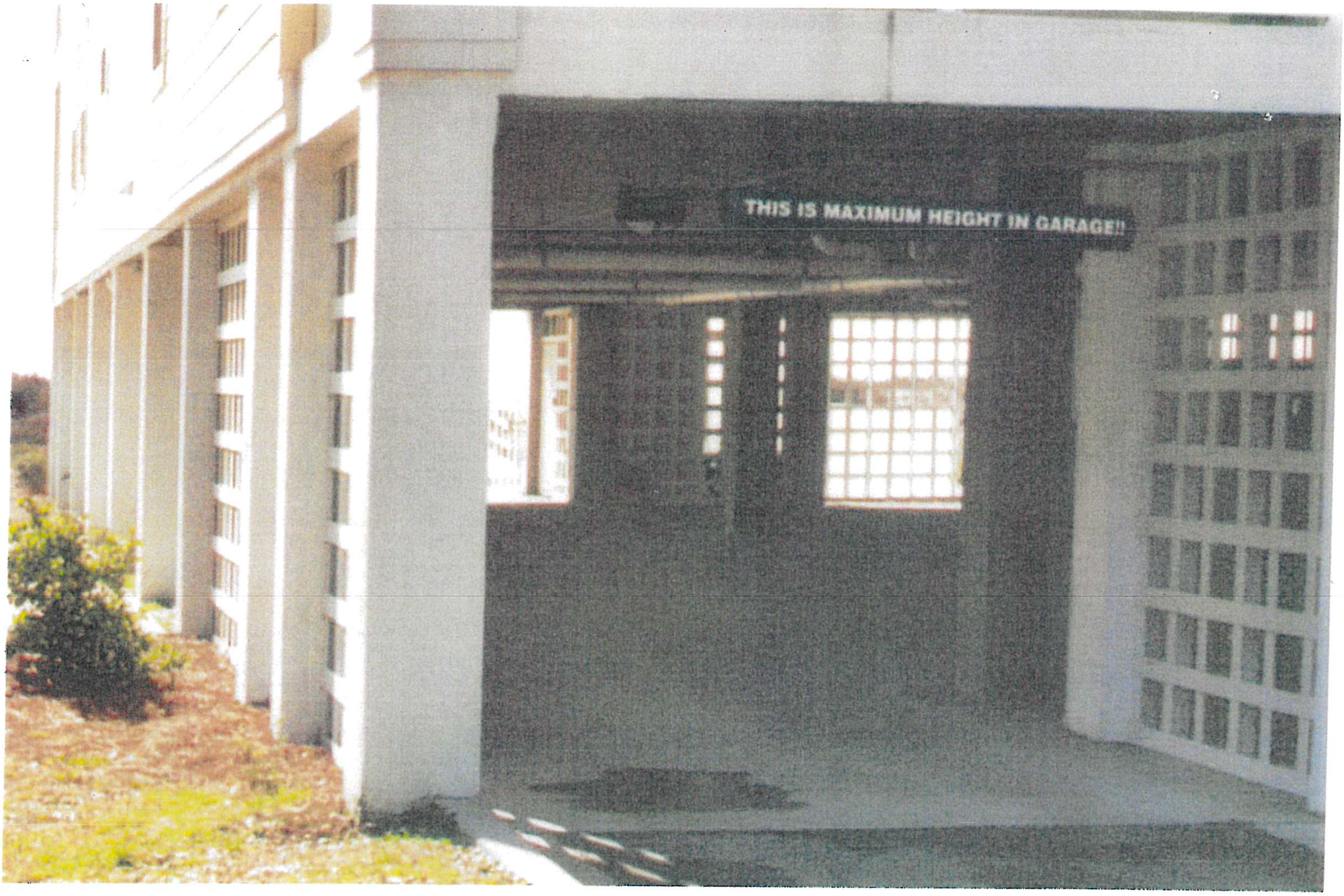
Opening, non-engineered – A non-engineered opening is an opening that is used to meet the NFIP's prescriptive requirement of 1 square inch of net open area for every square foot of enclosed area.

Registered Design Professional – An individual who is registered or licensed to practice their respective design profession as defined by the statutory requirements of the professional registration laws of the State or jurisdiction in which the project is to be constructed.

Special Flood Hazard Area (SFHA) – An area delineated on a FIRM as being subject to inundation by the base flood and designated as Zone A, AE, A1-A30, AR, AO, AH, A99, V, VE, or V1-V30.

Substantial damage – Damage of any origin sustained by a structure whereby the cost of restoring the structure to its before-damaged condition would equal or exceed 50 percent of the market value of the structure before the damage occurred. Structures that are determined to be substantially damaged are considered to be substantial improvements, regardless of the actual repair work performed.

Substantial improvement – Any reconstruction, rehabilitation, addition, or other improvement of a structure, the cost of which equals or exceeds 50 percent of the market value of the structure (or smaller percentage if established by the community) before the "start of construction" of the improvement. This term includes structures that have incurred "substantial damage," regardless of the actual repair work performed.



Free-of-Obstruction Requirements

for Buildings Located in Coastal High Hazard Areas in accordance with the National Flood Insurance Program

Technical Bulletin 5 / August 2008

FEMA

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Comments on the Technical Bulletins should be directed to:

Department of Homeland Security
FEMA Mitigation Directorate
500 C Street, SW.
Washington, D.C. 20472

Technical Bulletin 5-08 replaces Technical Bulletin 5-93, *Free-of-Obstruction Requirements*.

Cover photo: Area beneath an elevated building that is free of obstructions.

Introduction

Protecting buildings that are constructed in special flood hazard areas (SFHAs) from damage caused by flood forces is an important objective of the National Flood Insurance Program (NFIP). In support of this objective, the NFIP regulations include minimum building design criteria that apply to new construction, repair of substantially damaged buildings, and substantial improvement of existing buildings in SFHAs. The base flood is used to delineate SFHAs on Flood Insurance Rate Maps (FIRMs) prepared by the NFIP. The base flood is the flood that has a 1-percent chance of being equaled or exceeded in any given year (commonly called the "100-year" flood). Certain terms used in this Technical Bulletin are defined in the Glossary.

Coastal waves and flooding can exert strong hydrodynamic forces on any building element that is exposed to the waves or flow of water. Therefore, foundations that offer minimal resistance to waves and floodwaters passing beneath elevated buildings (e.g., pile and column foundations) are required in Coastal High Hazard Areas (Zones V, VE, and V1 -V30). Standard foundations such as solid masonry or concrete or wood-frame walls will generally obstruct flow and be at risk of damage from high-velocity flood forces. In addition, these solid foundations and other obstructions may cause wave runup or reflection, or divert floodwaters, into the elevated portion of the building or into adjacent buildings. Use of structural fill to support buildings in V zones is prohibited because fill will be subject to erosion during a flood event. In either case, the result is generally structural damage to, or catastrophic failure of, the affected buildings.

> For *floodplain management* purposes, an area beneath a structure elevated on an open foundation is considered to be free of obstructions if flood flow and waves can pass through the area relatively freely. Some flow diversion, wave reflection, and wave runup will occur as flood flow and waves encounter the foundation, but the effects will be small and localized, and will not lead to flood damage to the elevated structure.

Under the NFIP general requirement that buildings be constructed by methods that will minimize flood damage, the placement of any construction element (as described later in this bulletin) on a building site in a V zone must include consideration of the potential effects on the building and adjacent buildings. In addition to potential wave and floodwater diversion effects, obstructions can become floodborne debris that may strike other buildings, resulting in large impact forces on the buildings.

> This Technical Bulletin discusses obstructions below the BFE. Readers should check with the community to determine whether a higher elevation standard is enforced. For example, communities may add freeboard or may regulate to the design flood elevation (DFE). In those cases, references in this Technical Bulletin should be construed as references to the community's regulatory requirement.

The NFIP requires that all new and substantially improved structures in V zones be elevated to or above the base flood elevation (BFE), on open foundations (pilings, columns, or piers, and, sometimes, shear walls) that allow floodwaters and waves to pass beneath the elevated structures. The NFIP further requires that the area beneath these elevated structures remain free of any obstructions that would prevent the free flow of coastal floodwaters and waves during a base flood event. These requirements have been instituted to minimize the transfer of flood forces to the building foundation and to preclude the deflection or redirection of flood forces that could damage the elevated building or neighboring buildings.

This Technical Bulletin provides specific guidance concerning the NFIP's free-of-obstruction requirement in V zones, as well as the general requirement for construction that will minimize flood damage potential, as it applies to V zone construction. Typical building elements and site development issues discussed in this Technical Bulletin include:

Below-BFE Building Elements

- Access stairs and ramps
- Decks and patios
- Elevators
- Enclosed areas
- Equipment
- Foundation bracing
- Grade beams
- Shear walls
- Slabs

Site Development: Practices and Issues

- Accessory structures
- Detached garages
- Erosion control structures
- Fences and privacy walls
- Fill
- Ground elevations at or above the BFE
- Restroom buildings and comfort stations
- Septic systems
- Swimming pools and spas

Under the free-of-obstruction requirements in the NFIP regulations, any type of lower area enclosure or other construction practice (as described below) that prevents the free flow of coastal floodwaters and waves beneath an elevated building during a base flood event is not allowed.

Any construction element that is structurally dependent on, that is attached to, or upon which a V zone building depends, is considered to be part of that building and must meet the requirements of Sections 60.3(e)(4), (5), and (6). If any of these elements are attached to the building and located below the lowest horizontal structural member of the building, they may constitute an obstruction and may be prohibited. The attachment of any feature that is prohibited by NFIP regulations to an otherwise compliant building will result in a significantly higher flood insurance premium because of the increased risk of damage to the building. Further, if a community is found to have a pattern and practice of failing to address such violations, the NFIP may exercise its authority to place the community on probation or under suspension, which affects the cost and availability of Federal flood insurance.

Construction elements outside the perimeter (footprint) of and not attached to a coastal building (such as bulkheads, swimming pools, and accessory structures) and site development practices (e.g., the addition of fill) may alter the physical characteristics of flooding or significantly increase wave or debris impact forces affecting nearby buildings. As part of the certification process for V zone buildings, the design professional must consider the effects that these elements and practices will have on the building in question and on nearby buildings. Construction elements and practices that will increase flood-related loadings on the building (and that are not specifically prohibited by the NFIP regulations) may be constructed if the impacted buildings are designed to withstand the additional flood and wave forces. Increased foundation element embedment depth, size, and number might be employed to compensate for increased flood forces. Such compensatory design calculations must be made by the registered design professional, who must provide a V zone certification for the structure prior to construction.

NFIP Regulations

The NFIP regulations for V zone construction are codified in Title 44 of the Code of Federal Regulations. Specific to this Technical Bulletin, Section 60.3(a)(3) of the NFIP regulations states:

> *"If a proposed building site is in a floodprone area, all new construction and substantial improvements shall . . . (iii) be constructed by methods and practices that minimize flood damages . . ."*

Section 60.3(e)(4) states that a community shall require:

> *". . . that* ***all new construction and substantial improvements*** *in Zones V1-V30, VE, and also Zone V if base flood elevation data is available, on the community's FIRM,* ***are elevated on pilings or columns so that: (i) the bottom of the lowest horizontal structural member of the lowest floor (excluding pilings or columns) is elevated to or above the base flood level; and (ii) the pile or column foundation and the structure attached thereto is anchored to resist flotation, collapse, and lateral movement due to the combined effects of wind and water loads acting simultaneously on all building components.*** *Water loading values used shall be those associated with the base flood. Wind loading values used shall be those required by applicable State or local building standards. A registered professional engineer or architect shall develop or review the structural design, specifications, and plans for the construction, and shall certify that the design and methods of construction to be used are in accordance with accepted standards of practice for meeting the provisions of paragraphs (e)(4)(i) and (ii) of this section."*

Section 60.3(e)(5) further states that a community shall require:

> ***". . . that all new construction and substantial improvements within Zones V1-V30, VE, and V on the community's FIRM have the space below the lowest floor either free of obstruction or constructed with non-supporting breakaway walls, open wood lattice-work, or insect screening intended to collapse under wind and water loads without causing collapse, displacement, or other structural damage to the elevated portion of the building or supporting foundation system.*** *For the purpose of this section, a breakaway wall shall have a design safe loading resistance of not less than 10 and no more than 20 pounds per square foot. Use of breakaway walls which exceed a design safe loading resistance of 20 pounds per square foot (either by design or when so required by local or State codes) may be permitted only if a registered professional engineer or architect certifies that the designs*

proposed meet the following conditions: (i) Breakaway wall collapse shall result from a water load less than that which would occur during the base flood; and (ii) The elevated portion of the building and supporting foundation system shall not be subject to collapse, displacement, or other structural damage due to the effects of wind and water loads acting simultaneously on all building components (structural and non-structural). Water loading values used shall be those associated with the base flood. Wind loading values used shall be those required by applicable State or local building standards. ***Such enclosed space shall be useable solely for parking of vehicles, building access, or storage.*** *"*

Section 60.3(e)(6) states that a community shall:

> ***"Prohibit the use of fill for structural support of buildings within Zones V1-30, VE, and V on the community's FIRM."***

The NFIP Technical Bulletins provide guidance on the minimum requirements of the NFIP regulations. Community or State requirements that exceed those of the NFIP take precedence. Design professionals should contact the community to determine whether more restrictive provisions apply to the building or site in question. All other applicable requirements of the State or local building codes must also be met for buildings in all flood hazard areas.

Further guidance on coastal construction can be found in the *Coastal Construction Manual* (FEMA 55) and in the *Home Builder's Guide to Coastal Construction* (FEMA 499). Further guidance on the breakaway wall requirements of Section 60.3(e)(5) can be found in Technical Bulletin 9, *Design and Construction Guidance for Breakaway Walls Below Elevated Buildings.*

It is important to note that building materials used below the BFE must meet the flood damage-resistant materials requirement of Section 60.3(a)(3). Further guidance on this requirement can be found in Technical Bulletin 2, *Flood Damage-Resistant Materials Requirements for Buildings Located in Special Flood Hazard Areas.*

Flood Insurance Implications

The floodplain management and insurance programs of the NFIP may treat some below-BFE building elements differently. NFIP floodplain management regulations allow certain construction elements below the BFE, which may or may not break away during the base flood, and which may or may not be considered obstructions for Federal flood insurance rating purposes (e.g., stairwells, elevator shafts, shear walls).

Design professionals and owners may wish to contact a qualified insurance agent or the NFIP – before a building is designed and constructed – regarding the flood insurance premium implications of obstructions. For example:

- The NFIP floodplain management regulations in 44 CFR Section 60.3 allow open wood lattice, insect screening, and non-load-bearing solid breakaway walls below an elevated building in the Coastal High Hazard Area. These features have been judged not to be obstructions to flood flow or waves, but building designers and owners should be aware that solid breakaway walls and garage doors – even though permitted by floodplain management regulations – can result in significantly higher flood insurance premiums. Thus, use of breakaway construction below the BFE will not allow a structure to be classified as "free of obstructions" for flood insurance rating purposes (a free-of-obstruction classification makes the building eligible for the lowest V zone flood insurance premium rate).
- NFIP floodplain management regulations restrict uses of space below the BFE to parking of vehicles, building access, and storage. Stairs, ramps, and elevators are permitted. However, depending on how they are constructed, stairs, ramps, and elevators may be considered obstructions for flood insurance rating purposes, and could result in significantly higher flood insurance premiums.

For *flood insurance rating* purposes, an area beneath a structure elevated on an open foundation is considered to be free of obstructions only if the following criteria are satisfied:

- There are no solid walls of any kind – including breakaway walls – below the BFE (insect screening, open lattice, and open slats are not considered obstructions).
- Any stairs below the BFE are open (any stairs enclosed by or containing solid walls are considered obstructions).
- There is no machinery or equipment below the BFE. Machinery and equipment include any items permanently affixed to the structure and that provide utility services to the building (e.g., furnaces, hot water heaters, heat pumps, air conditioners, elevators, etc.).

Obstruction Considerations

Several of the NFIP's flood-resistant design and construction requirements are performance requirements, not prescriptive requirements. In other words, the expected building performance is stated, but the ways by which that performance may be achieved are not prescribed. It is up to the community official to determine whether a specific design submitted by a design professional satisfies the performance requirements.

Any construction or development practice below the BFE (even piles and columns permitted by the NFIP) will cause a localized disruption of flow and waves during the base flood. Whether the localized disruption is great enough to harm the elevated building or surrounding buildings is the central question.

In the case of the free-of-obstruction requirement, it is not always clear whether a particular building element or site development practice will be a significant obstruction that prevents the free passage of floodwaters and waves. The term "significant" is used here because *any* construction or development practice below the flood level will cause a localized disruption of flow and waves during the base flood. Determining whether the disruption is significant is not always easy. In some cases, the analytical tools necessary to answer the question with certainty are not available and local experience, post-disaster investigations, and coastal process and building science principles must be relied upon in order to reach a conclusion.

Many local floodplain management ordinances contain language that calls for evaluating potential obstructions below or near a building for their effects on flow deflection and wave runup (or "ramping"). Standard fluid mechanics texts and coastal engineering references such as the U.S. Army Corps of Engineers (USACE) *Coastal Engineering Manual* provide some guidance, but the methods contained therein generally are not capable of evaluating the potential effects of small building elements, small amounts of fill, etc., on flooding and waves during a base flood. Numerical models for coastal storm surge and waves do not have the resolution required to resolve building element-sized disruptions to flow and wave fields, and constructing such models at this time would be technically challenging, time-consuming and cost-prohibitive. Recently developed, sophisticated numerical models show some promise of being able to resolve and analyze flow around potential obstructions, but their use at present is not economically feasible for communities, owners, or designers interested in examining potential obstructions such as those discussed in this Technical Bulletin.

Potential flow diversion – and wave runup or wave reflection – toward pre-FIRM buildings at or near grade is problematic. Many of these buildings may be damaged or destroyed during a base flood, regardless of the presence of new NFIP-compliant structures.

Communities must determine whether and how to weigh the presence of low-elevation pre-FIRM buildings when construction and development decisions are made.

This Technical Bulletin does not recommend a blanket prohibition of below-BFE building elements and site development practices when pre-FIRM buildings at or near grade are nearby.

Below-BFE Building Elements

The sections that follow discuss common building elements that may significantly affect the free passage of flood flow and waves under elevated buildings. By following the guidance below, potential obstructive effects are minimized and the elements are judged to comply with the NFIP free-of-obstruction requirement.

Access Stairs and Ramps

Access stairs and ramps that are attached to or beneath an elevated building may be enclosed with breakaway walls or may be unenclosed, without walls. However, stairs and ramps, like foundation bracing, can impede the intended failure of breakaway walls. Unenclosed stairs and ramps are preferred.

Stairs and ramps are not required to break away themselves, but this is a design option. Stairs and ramps must be designed and constructed to either:

- Break away during base flood conditions without causing damage to the building or its foundation, or

- Resist flood loads and remain in place during the base flood. If this option is selected, the elevated building and its foundation must be designed to resist any flood loads that are transferred from the stairs or ramp to the building.

Figure 1 shows an example of stairs that did not break away cleanly – the stairs pulled out the exterior wall of the elevated building as they failed.

Construction of access stairs with sides and risers open (to the extent that building codes allow) will minimize flood loads acting on the stairs themselves, thereby minimizing flood damage, and also minimize transfer of flood loads to the elevated building. Open stairs should be considered whenever possible (see Figure 2).

Ramps must be designed and constructed to minimize the obstruction of floodwaters and waves, and configured so that floodwaters and waves cannot flow directly up the ramp toward the elevated building. This means that ramps must be positioned to avoid a straight alignment that extends from the elevated building down toward a likely direction of wave and surge approach.

A solid entry door capable of resisting all design loads must be installed at the top of any access stairs or ramps.

Access stairs are sometimes constructed inside a breakaway enclosure, with an entry door at the bottom of the enclosure, but without an entry door into the elevated building. This practice leads to building damage. The lack of an entry door at the top results in a large opening in the building envelope when the enclosure breaks away. This exposes the building interior to higher internal wind pressures and wind-driven rain, and provides floodwaters an easy path into the building.

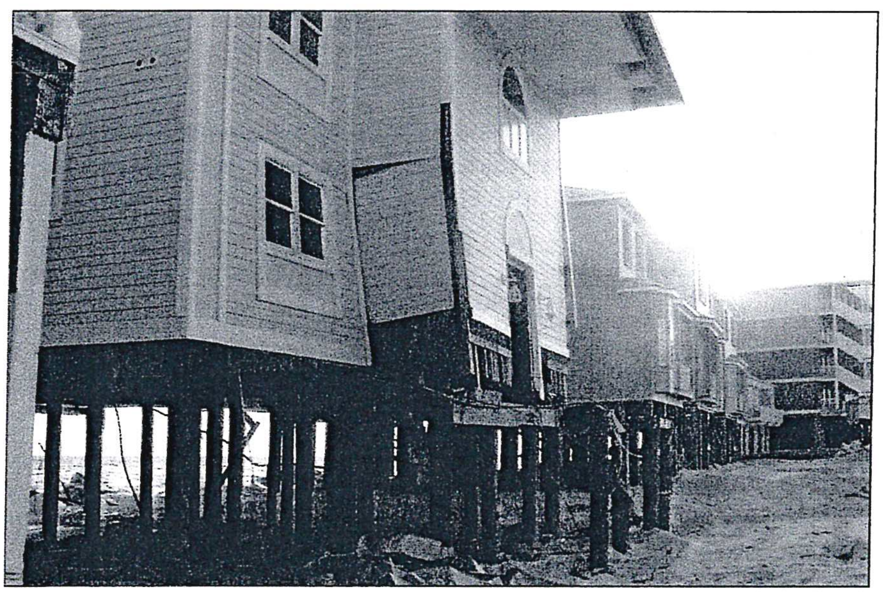
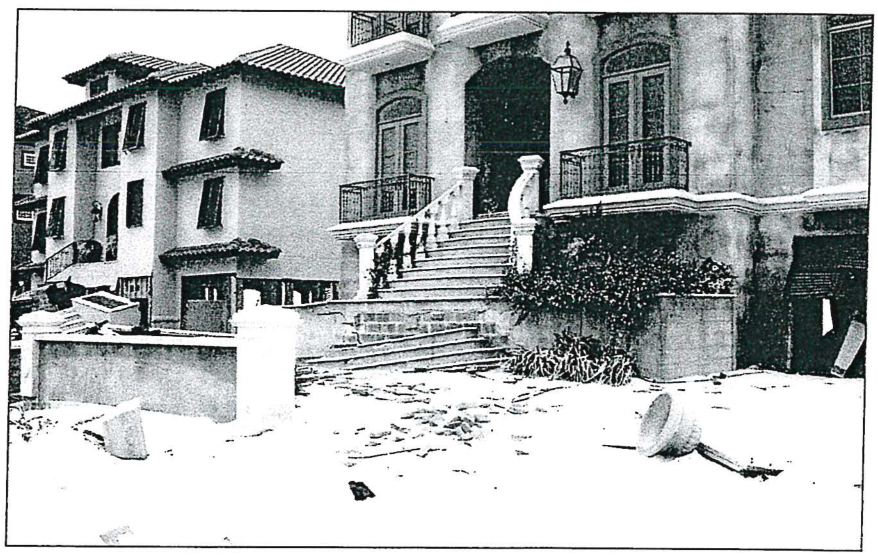


Figure 1. Stairs did not break away cleanly, resulting in damage to the elevated building.

Figure 2. Example of open stairs that minimize transfer of flood and wave forces (note that building codes enforced by most communities require use of risers that prevent passage of a 4-inch sphere).

Massive exterior stairs have been constructed for some elevated homes in V zones (see Figure 3). Stairs such as these clearly act as obstructions and increase the likelihood of trapping or deflecting waves and flood flow beneath the elevated buildings. They are not necessary for building access purposes and are not permitted because they are obstructions that increase the potential for damage.

Figure 3. Massive stairs adjacent to an elevated coastal home are an obstruction.



Note that, in some cases, life-safety code requirements will dictate that stairs and stairwells in certain occupancy structures have to be constructed to be fire-resistant and structurally stable even if portions of the adjacent structure fail. Stairs and stairwells that meet these requirements are usually constructed of some combination of steel, reinforced masonry, and reinforced concrete, and will not break away under expected base flood loads and conditions. These stairs and stairwells, typically found in mid- and high-rise buildings, must be designed to withstand all flood loads, including wave impact and floodborne debris impact.

Decks and Patios

Decks and patios typically lie outside the footprint of elevated V zone residential and commercial buildings, and can be constructed at elevations varying from at grade, to above grade but below the BFE, to at or above the BFE.

- If a deck is structurally attached to a structure, the bottom of the lowest horizontal supporting member of the deck must be at or above the BFE; deck supports that extend below the BFE (e.g., pilings and bracing) must comply with V zone design and construction requirements; and the structure must be designed to accommodate any increased loads resulting from the attached deck.
- Some attached decks are located above the BFE but rely on support elements that extend below the BFE. These supports must comply with V zone design and construction requirements.
- If a deck or patio (not counting its supports) lies in whole or in part below the BFE, it must be structurally independent from the structure and its foundation system.

Decks and patios must not adversely affect the adjacent structures or nearby structures during base flood conditions by diverting floodwaters and waves. For floodplain management purposes, "low-profile" decks and patios constructed at natural grade or on small amounts of fill for site drainage purposes (see the section on Fill) will not lead to harmful diversion of floodwaters or wave runup and reflection.

A "low-profile" deck or patio is defined as one where the vertical thickness of the deck or patio is 12 inches or less, some of which may be below the adjacent finished grade. This thickness does not include railings (which should be open). Seats, benches, tables, planters, or other obstructions must not be built into or attached to the deck or patio.

Decks and patios must be designed and constructed so that, when subject to base flood conditions, they do not create debris that will damage NFIP-compliant structures. For floodplain management purposes, this means that decks and patios must either: a) remain intact and in place during the base flood, or b) break apart into small pieces so that the resulting debris will not lead to structural damage of NFIP-compliant structures.

Decks that are structurally attached to V zone structures must be supported to resist the simultaneous action of design wind loads and base flood loads. In some cases, attached decks can be cantilevered but, in most cases, attached decks must be supported on piles, posts, or columns embedded into the ground and capable of surviving anticipated erosion and scour. Post-storm investigations frequently identify decks that were elevated on small diameter posts or were elevated on structural elements without sufficient embedment into the ground. The result of inadequate support is loss of the decks and sometimes damage to the elevated structures as the decks fail. Unless the building code or local community prescribes otherwise, a rule of thumb is the foundation for an elevated deck attached to a V zone structure should be similar to the structure's foundation.

Elevators

Elevators attached to or beneath an elevated V zone structure must comply with building, fire, electrical, and mechanical code requirements. Like access stairs, elevators are excluded from the NFIP breakaway requirement, but must meet the NFIP flood damage-resistant material requirements. Elevator equipment below the BFE will result in higher flood insurance premiums.

Flood loads acting on the elevator components and any non-breakaway shaft walls must be accounted for in the design of the elevated structure and its foundation system; therefore, it is advantageous to minimize the size of residential elevators. Additional details can be found in Technical Bulletin 4, *Elevator Installation for Buildings Located in Special Flood Hazard Areas,* Technical Bulletin 2, *Requirements for Flood Damage-Resistant Materials for Buildings Located in Special Flood Hazard Areas,* and in *Flood Resistant Design and Construction* (ASCE 24). ASCE 24 is referenced by model building codes and has been determined by FEMA to be consistent with the NFIP regulations.

Enclosed Areas

Use of enclosed areas is restricted to parking of vehicles, building access, and storage. Enclosed areas, including foyers, must be constructed of flood damage-resistant materials and not be finished. Enclosed areas must not be used for habitable or recreational purposes.

The NFIP regulations state that the area beneath the elevated portion of a V zone structure may be enclosed only with open lattice, insect screening or non-supporting breakaway walls (see Technical Bulletin 9, *Design and Construction Guidance for Breakaway Walls Below Coastal Buildings*). Guidance on lattice has been developed and incorporated into FEMA documents, including the *Flood Insurance Manual.* The guidance states the following as being acceptable lattice:

- Wooden or plastic lattice, with at least 40 percent of its area open, and made of material no thicker than ½ inch.
- Wooden or plastic slats or shutters, with at least 40 percent of their area open, and made of material no thicker than 1 inch.

Figures 4 and 5 show examples of compliant slats, which typically are installed flat against the foundation pilings (Figure 4) or angled like louvers between the pilings (Figure 5).

> The NFIP does not limit the size of enclosures under elevated structures. However, higher NFIP flood insurance premiums will be assessed for V zone structures with enclosed areas that are 300 square feet or more in size (including stairwells and elevator enclosures), even if enclosed by compliant breakaway walls.
>
> The NFIP does not require flood openings in V zone enclosures; however, some communities may have such a requirement.

Equipment

In general, mechanical, electrical, and plumbing equipment and fixtures are required to be elevated at or above the BFE. There are some exceptions for elevator equipment that cannot be elevated, but these exceptions are very specific and are outlined in Technical Bulletin 4, *Elevator Installation for Buildings Located in Special Flood Hazard Areas* and ASCE 24.

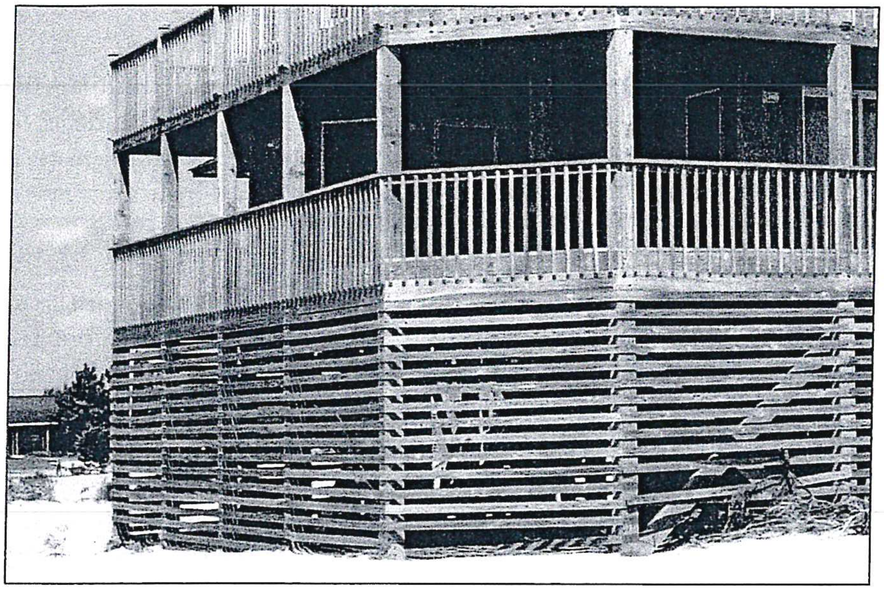


Figure 4. Wood slats installed flat against foundation pilings

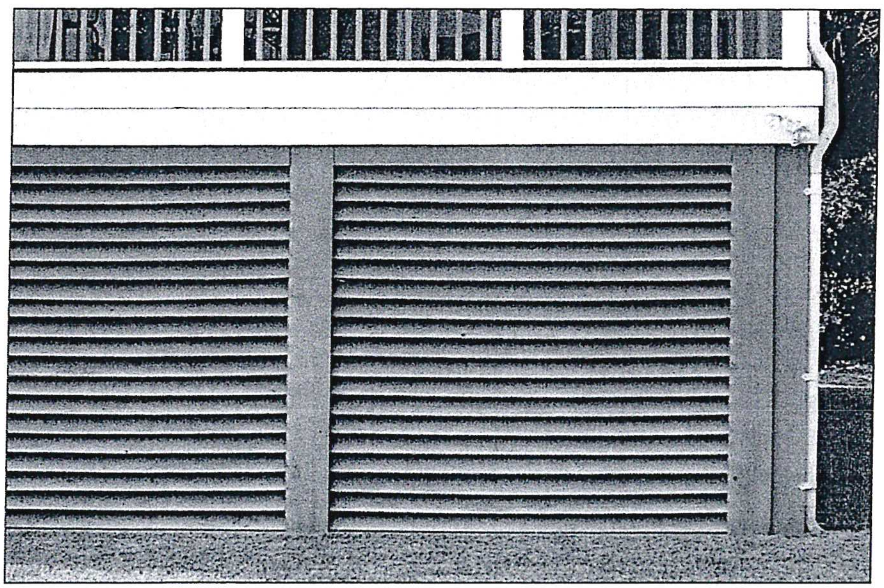


Figure 5. Wood slats installed between pilings at an angle (louvers)

Utility risers, electric meters, and similar elements that must be located below the BFE must be installed to minimize flood damage. The following techniques help to achieve this objective:

- The elements must not be attached to or penetrate through breakaway walls.
- The elements should be located on the sides of piles and columns that are opposite from the anticipated direction of flood flow and wave approach, where possible.

Additional guidance can be found in *Protecting Building Utilities From Flood Damage* (FEMA 348).

Designers and owners should be aware that the presence of equipment below the BFE, even if allowed by permit, can result in higher NFIP flood insurance premiums.

Foundation Bracing

Bracing is often used to stiffen pile foundations and/or to improve comfort and reduce sway in elevated buildings. As a general rule, building designs that do not include bracing will minimize obstructions to flow and waves and are preferred. However, if bracing is required for a stable design, its use should be minimized.

Diagonal timber cross-bracing is the most common type of bracing used on foundations under coastal homes (see Figure 6). Unfortunately, timber braces frequently fail during severe flood events due to wave and or debris impacts. If they survive, they can trap debris and transfer lateral flood loads to the foundation. Metal rod braces, while less susceptible to failure, can also trap floating debris (see Figure 7). Knee braces at the tops of pilings are sometimes preferred since they will likely extend a shorter distance below the flood surface and present less obstruction to flow and waves.

Free-of-obstruction considerations call for using only the minimum amount of bracing that is necessary to add rigidity to the design for the comfort of occupants. Many coastal construction experts and references suggest relying on shore-perpendicular bracing and minimizing the use of shore-parallel bracing. However, since wind and seismic loads can act in any direction, this alternative may not always provide the structural stability that is required in some locations. Increasing the number of piles (by decreasing horizontal spacing), detailing moment connections at the tops of the piling (in the case of concrete piles and beams), using grade beams, and extending pilings above the first elevated floor level are accepted ways of eliminating or reducing the need for bracing.

Where foundation bracing is used below the BFE, it must be placed so as not to interfere with the intended failure of breakaway wall panels. Avoiding interference may require eliminating breakaway walls, shifting the location of breakaway walls, or redesigning the foundation so the need for certain braces is eliminated. Breakaway walls and foundation bracing should not be placed in close proximity if either can affect the intended performance of the other.

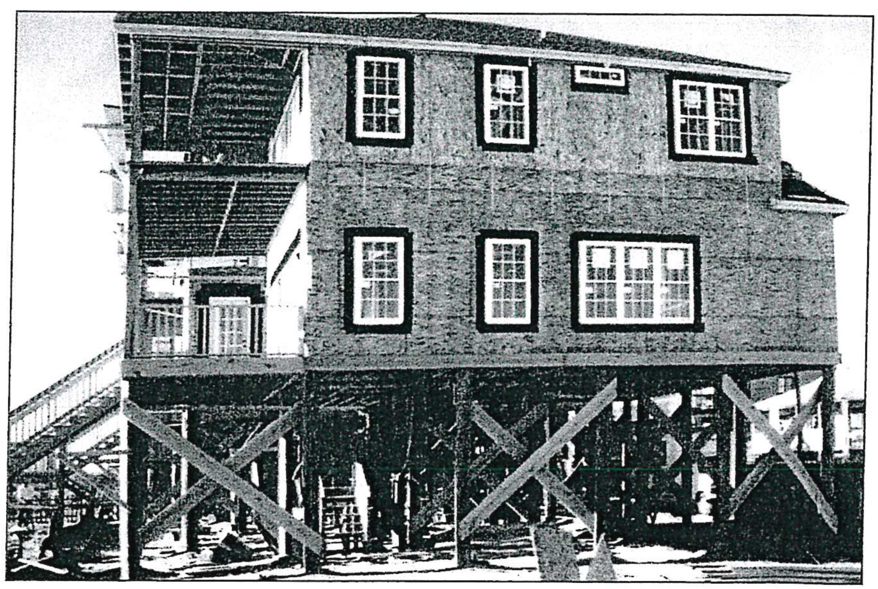


Figure 6. Elevated coastal home with timber cross-bracing, principally in the shore-perpendicular direction

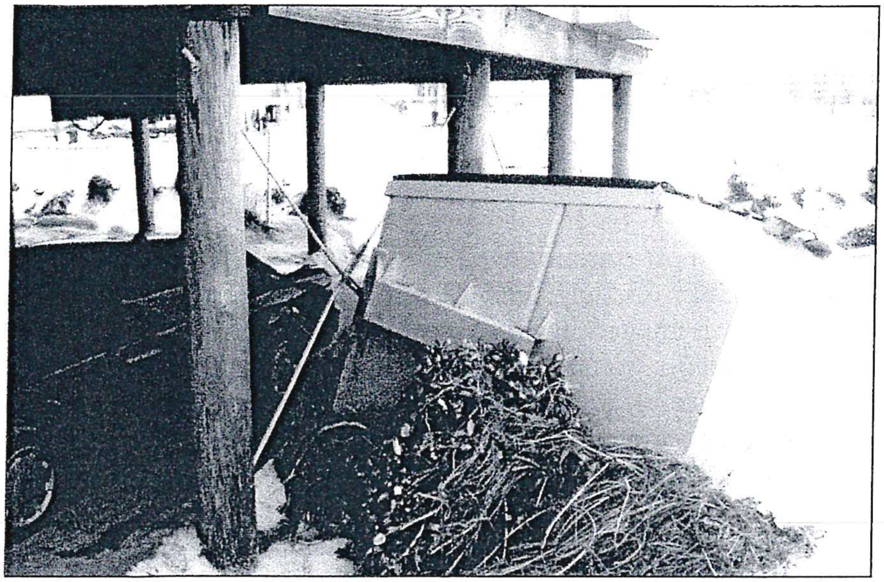


Figure 7. Trapping of floating debris by metal rod cross-bracing

Grade Beams

Grade beams typically are made of reinforced concrete or wood; they are used to tie together the foundation piles or columns to provide additional lateral support. Grade beams that are placed with their upper surfaces flush with or below the natural grade are not considered obstructions and are allowed under the NFIP. However, storm erosion and local scour will often expose and undermine grade beams, leaving them suspended above the post-storm ground profile. Designers must anticipate this circumstance and design grade beams to resist flood, wave, and debris loads and to remain in place and functional when undermined (see Figure 8). Grade beams also must be designed and constructed so that the vertical thickness is minimized, thereby reducing the lateral flood, wave, and debris loads acting on the beam and limiting the transfer of these loads to the foundation. Designers are cautioned that grade beams should not be used as a substitute for adequate number, size, and embedment of piles or columns.

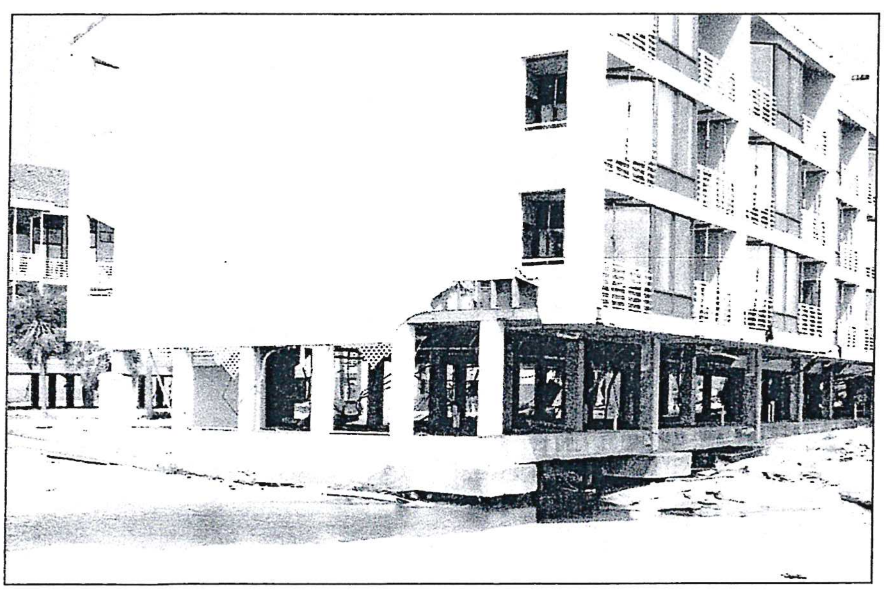


Figure 8. Grade beams must resist flood, wave, and debris loads when undermined.

Shear Walls

A strict interpretation of the NFIP regulations indicates that only pile and column foundations are permitted in V zones. In practice, this requirement has been relaxed to allow solid walls that are necessary to transfer lateral loads acting on the upper stories of tall buildings to the ground, particularly in extreme-wind zones. These walls, called shear walls, are often constructed parallel to the anticipated direction of flood flow and wave attack (i.e., perpendicular to the shoreline) so as to allow floodwaters and waves to pass freely. In some cases, however, building designs require both shore-perpendicular and shore-parallel shear walls. Use of shore-parallel shear wall segments should be limited to that minimum length required to transfer upper story loads to the foundation. Shore-parallel shear walls should be designed with openings in and between shear wall segments, to minimize trapping of floodwaters, waves and debris, and to minimize the total flood load acting on the building. In any case, flood forces on these walls must be certified as part of the overall V zone certification required by a community.

Low-rise, V zone buildings can usually be designed with pile and column foundations only, although some communities allow below-BFE shear walls without regard to building height or size. Thus, some low-rise buildings have been constructed in V zones with shear walls below the BFE (see Figure 9), usually with the walls perpendicular to the shoreline.

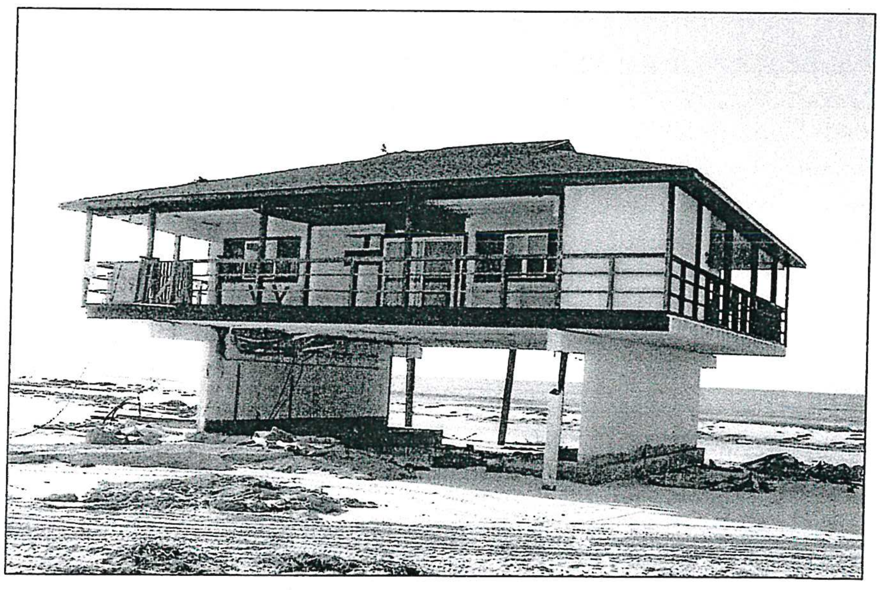


Figure 9. House elevated on shore-perpendicular shear walls. This design approach is risky for low-rise buildings since lateral out-of-plane loads (wind and flood acting on the faces of the shear walls) can be large and special design considerations and detailing are required.

The practice of allowing shear walls beneath low-rise construction is controversial. This is due to the fact that any solid foundation wall below the BFE can act as an obstruction, and these walls can be subject to extreme loads during a base flood event. Indeed, post-flood investigations have found that many such walls do not survive a severe storm event. This is illustrated in Figure 10, which shows an example of a building supported on columns and shore-perpendicular walls, where a wall section failed, leading to failure of the elevated floor beam and floor. In this instance, the building was a pre-FIRM building with the solid walls resting on shallow footings (a means of support not permitted under post-FIRM V zone regulations), and the failure was likely due to both lateral flood loads and foundation undermining.

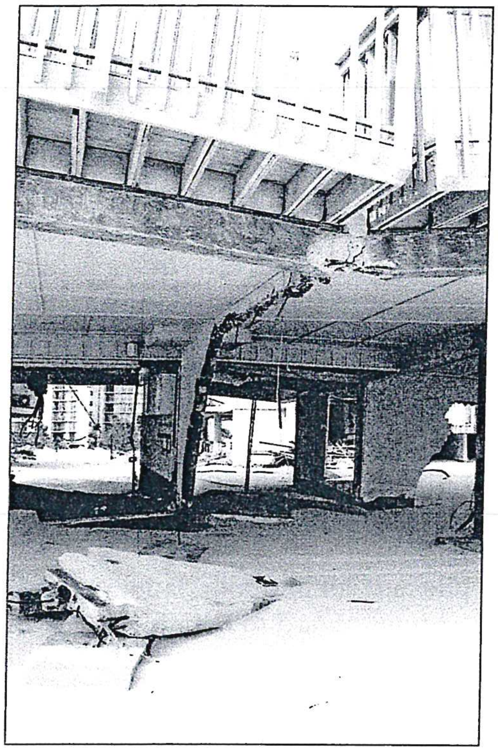


Figure 10. Failure of shore-perpendicular (and shore-parallel) solid foundation walls, and of beam and floor system supported by the shore-perpendicular wall (pre-FIRM structure)

Shear walls beneath low-rise V zone structures, regardless of orientation, are obstructions that are contrary to the NFIP free-of-obstruction requirements. They should not be permitted unless special justification exists, such as the need for a public, military, or functionally dependent, low-rise structure in a V zone, which cannot be supported on piles and columns alone. Even in these cases, they should be allowed only if detailed engineering calculations demonstrate that the foundation and building are designed to resist all base flood conditions (including erosion, which will increase the height of waves and wave forces striking the foundation), all design loads, and all appropriate load combinations.

For floodplain management purposes, below-BFE shear walls should only be permitted below fully-engineered mid- and high-rise structures, where the walls are necessary to transfer lateral loads from upper stories to the ground, and where engineering calculations demonstrate the viability of such an approach under design wind and flood conditions. Below-BFE shear walls should be oriented perpendicular to the shoreline whenever possible. Shore-parallel shear walls below the BFE should be limited to the absolute minimum necessary by designing them to be as narrow as possible with openings, and separated or offset to present the minimum possible obstruction to water and waves.

Slabs

Concrete slabs beneath elevated V zone buildings are commonly used for vehicle parking and as a floor in an enclosed storage area or building access area. FEMA's post-disaster investigations have consistently concluded that reinforced concrete slabs thicker than 4 inches can act as obstructions to the free flow of water and waves under elevated buildings and can transfer flood loads to the foundation if the slabs are undermined, displaced from a horizontal orientation, or fail to break into small pieces (see Figures 11 and 12).

The experience gained in post-storm evaluations suggests that slabs should either:

- Be frangible (break away), "floating" slabs that are supported by compacted soil, are not attached to the building foundation, and are designed and constructed with a maximum thickness (traditionally 4 inches), without reinforcement and without turned down edges, or

- Be designed and constructed to be self-supporting structural slabs capable of remaining intact and functional under base flood conditions, including expected erosion. Building foundations must be capable of resisting any added loads due to the presence of these slabs, and any increase in local scour due to the presence of the slabs.

For most circumstances and for small, low-rise V zone structures (including residences), the first alternative of frangible slabs should be employed. This alternative is also appropriate for other uses of slabs such as pool decks, sidewalks, and patios. Figure 13 illustrates one possible design for such a slab.

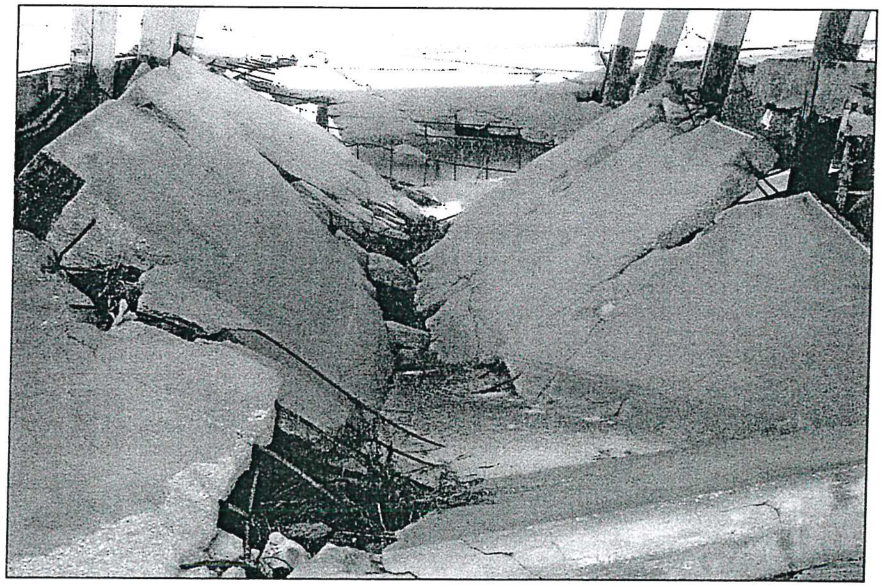


Figure 11. Damage to building foundation, due in part to failure of reinforced slab that imposed loads on the pilings

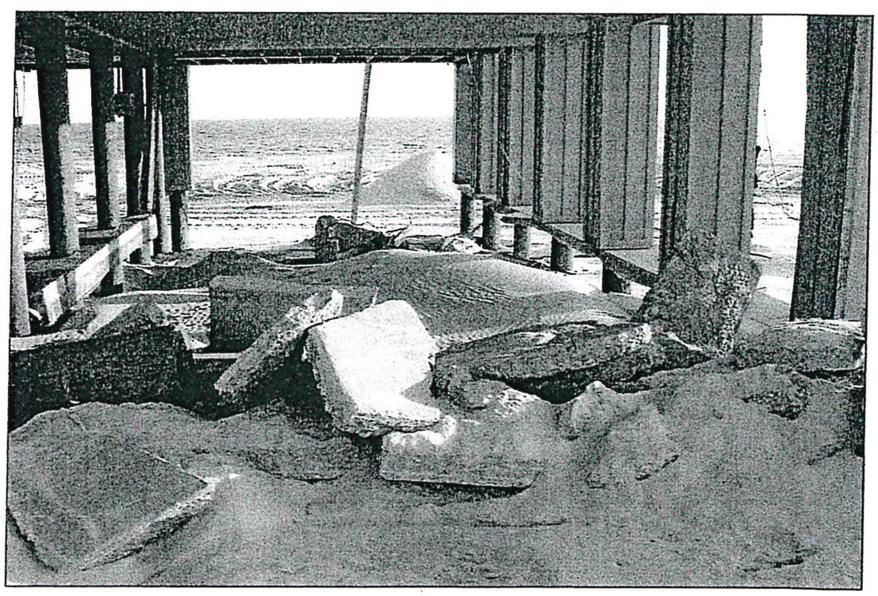


Figure 12. NFIP-compliant, unreinforced slab broke apart and performed well.

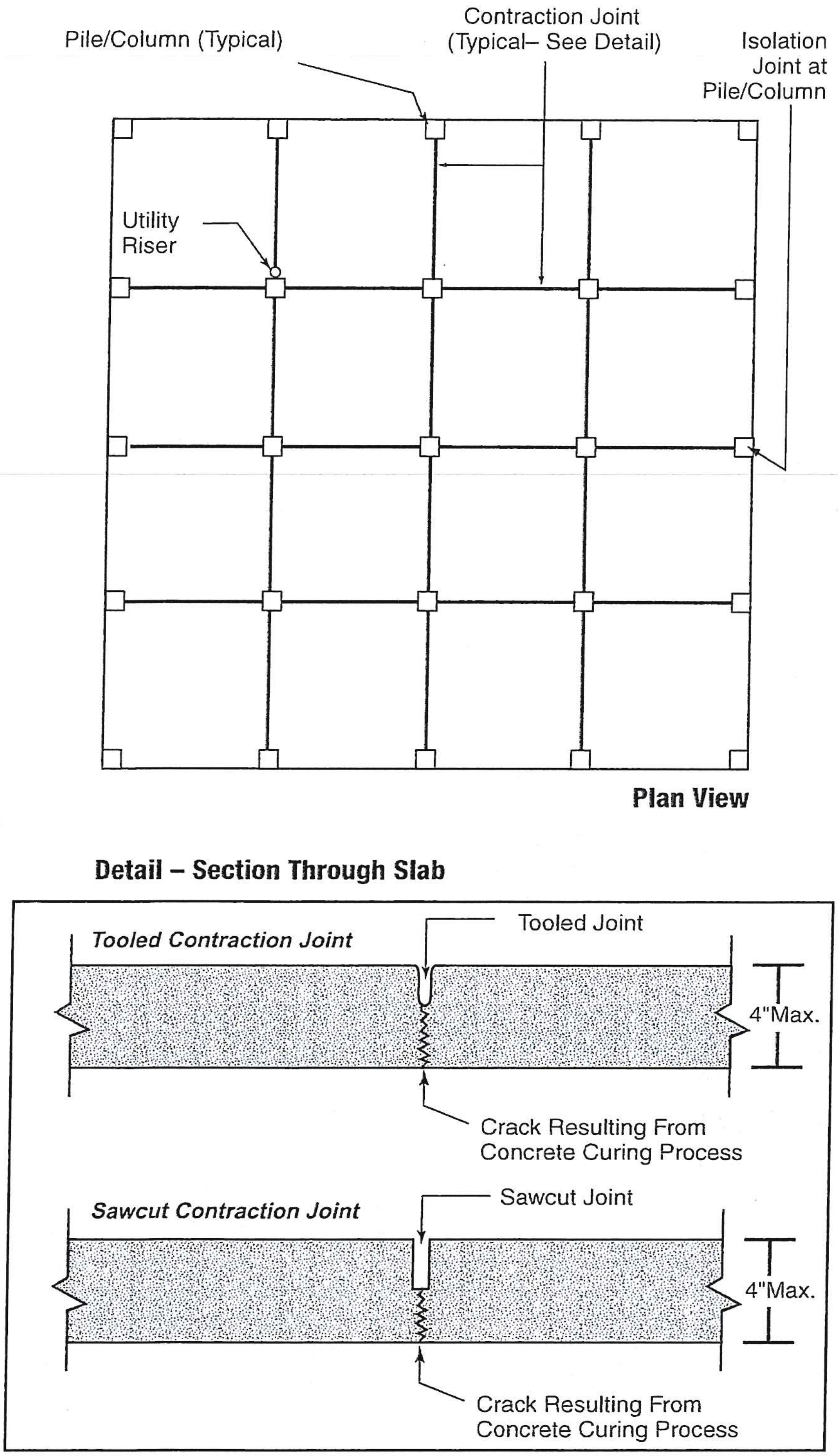


Figure 13. Example of frangible slab (FEMA 55)

NOTE: INSTALL EXPANSION AND ISOLATION JOINTS AS APPROPRIATE IN ACCORDANCE WITH STANDARD PRACTICE OR AS REQUIRED BY STATE AND LOCAL CODES.

For larger mid- and high-rise structures, both alternatives could be considered, although the second option of self-supporting structural slabs will likely mean a significant increase in NFIP flood insurance premiums (since the bottom of the slab – or the bottom of the lowest horizontal member supporting the slab – will become the lowest floor for flood insurance rating purposes). Reinforced, self-supporting structural slabs may be appropriate for large structures that are supported on large concrete piles and columns, since these structures are typically much heavier and are less prone to damage from flood loads. If a frangible parking slab is constructed beneath such a structure, timely reoccupation after a severe coastal storm event – of an otherwise intact and usable structure – may be prevented. A self-supporting structural slab could be considered in such situations

Reinforced, self-supporting structural slabs and beams beneath large buildings should be designed to be only as thick as necessary to support vehicle loads and other design loads, but no thicker. The slabs and beams should be connected and integral to the foundations, and all below BFE components should be designed to act together to resist flood loads and other design loads. Obstructive effects will be minimized as long as the slab systems remain intact and horizontal so that floodwaters and waves pass above and below the slabs.

Site Development: Practices and Issues

The sections that follow discuss common site development practices and issues that may significantly affect the free passage of flood flow and waves under elevated buildings. By following the guidance below, potential obstructive effects are minimized and the practices are judged to comply with the NFIP free-of-obstruction requirement.

Accessory Structures

Unless elevated on piles or columns, accessory structures in V zones should be limited to low-cost and small structures such as metal, plastic, or wooden sheds that are "disposable." Guidance available from the NFIP suggests the term "small" means less than or equal to 100 square feet in size, and "low cost" means $1,000 or less. Some States and communities recommend other values.

If an accessory structure does not meet the criteria established to allow below-BFE installation, or if it is of a significant size and nature that it would likely create either damaging debris or flow and wave diversion problems, it should be constructed and elevated in full compliance with the NFIP requirements. Examples of structures that exceed size and value limits, or contain equipment prohibited below the BFE, or facilitate uses prohibited below the BFE, include detached garages and restroom buildings/comfort stations (see sections that follow).

Small, low-cost accessory structures that are not elevated must be designed and anchored to resist wind loads (see Figure 14), and to resist flotation that may occur even under relatively shallow flood depths. However, because small accessory structures are unlikely to withstand wave loads, their loss should be anticipated during the base flood, and the effects that the resultant debris may have on nearby structures must be considered. In addition, small accessory structures must be unfinished on the interior, constructed of flood damage-resistant materials, used only for storage, and, if provided with electricity, the service must be elevated above the BFE.

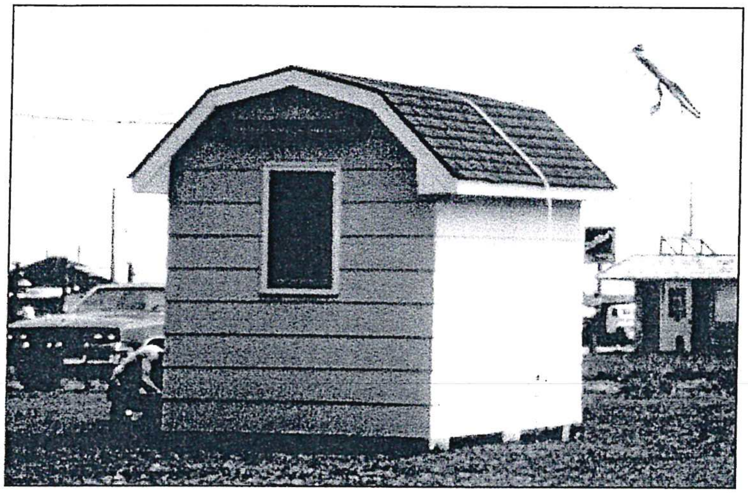


Figure 14. Small accessory structure anchored to resist displacement by wind

An alternative to an accessory structure is to create storage space below the elevated structure by enclosing an area with breakaway walls. However, creation of such an enclosure may result in higher flood insurance premiums. Owners and communities should weigh the alternatives carefully.

Detached Garages

Detached garages, such as those typically built for single-family homes or for multi-family structures, are too large and too costly to be considered accessory structures that may be allowed below the BFE (see guidance for Accessory Structures). Therefore, detached garages must be properly elevated on piles or columns and comply with other requirements for structures in V zones.

> Garages may be constructed under elevated buildings and enclosed with breakaway walls (see Technical Bulletin 9).

Note that large, fully-engineered, free-standing parking garages that satisfy NFIP V zone design and construction requirements are permitted, even if portions lie below the BFE (e.g., vehicle ramps, stairwells, elevator shafts, and parking spaces). These structures are not walled and roofed in the traditional sense, and can be designed to allow the free passage of floodwaters and waves through the structures.

Erosion Control Structures

Erosion control structures such as bulkheads, seawalls, retaining walls, or revetments that are installed beneath elevated coastal buildings are obstructions and are prohibited, even if they are not attached to the building foundations. These erosion control structures can transfer damaging flood loads to building foundations, and greatly increase the potential for redirecting flood flow and wave action onto the elevated portions of coastal buildings. Figure 15 shows an example of timbers attached to a pile foundation (constituting a bulkhead) that are not permitted.

Guidance for evaluating potential effects of erosion control structures on waves is contained in the U.S. Army Corps of Engineers (2002) *Coastal Engineering Manual.* Generally, those devices with a steep face (1:2 [vertical to horizontal] or steeper) will result in the greatest wave runup.

While the NFIP does not prohibit bulkheads, seawalls, retaining walls, or revetments that are outside a building's footprint and that are not attached to the building, communities and design professionals must carefully consider the potentially significant effects of these structures. A general rule of thumb is: the greater the horizontal distance between the erosion control structure and the building, the less likely that wave runup or reflection will adversely affect the building. While some local or State regulations may prohibit the construction of an erosion control structure until erosion is within a few feet of the building foundation (to maximize the recreational beach area seaward of the device), the close proximity of the device to the building may contribute to flood damage.

FEMA's coastal mapping guidance suggests that a 30-foot wide "VE splash zone" (the area where waves breaking on or running up the seaward face of an erosion control structure will land or splash down) should be mapped landward of erosion control structures, but provides for site-specific calculations that can lead to a narrower splash zone width. For floodplain management purposes, a 30-foot splash zone width is desirable for new construction landward of existing erosion control structures, but may not be feasible where an erosion control structure is constructed seaward of an existing building. There is no established minimum distance between a building and an erosion control structure, but a reasonable minimum width would be on the order of 10 to 15 feet. States and communities should take local conditions and observed building damages into account when such determinations are made.

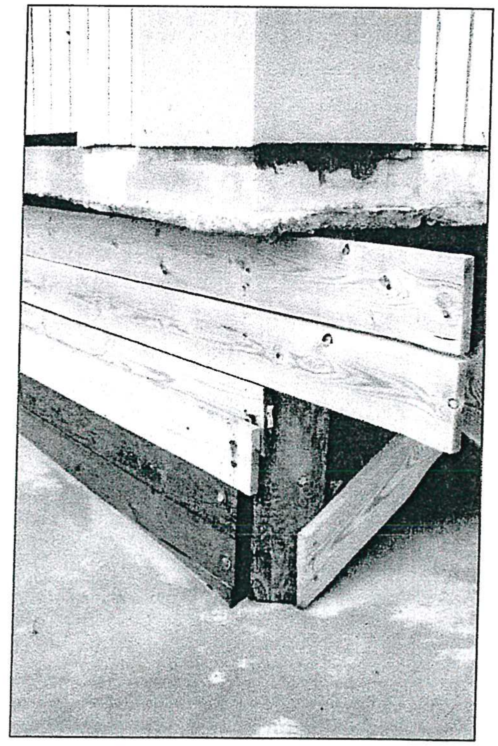


Figure 15. Shore-parallel timbers attached to a pile foundation were intended to act as a bulkhead, but constitute an obstruction and are prohibited.

Options are limited when erosion threatens coastal buildings that are supported by shallow foundations or pile foundations with insufficient embedment. Post-disaster investigations indicate that low-cost and small erosion control structures offer no real protection to erosion-threatened buildings since they are easily overtopped or fail when exposed to severe coastal flooding. Without substantial erosion control structures, foundations may be undermined and buildings may collapse. With substantial erosion control structures in place, building foundations are less likely be undermined, but nearby buildings may be subject to increased damage from wave runup and reflection. More lasting and less damaging solutions to impending erosion damage include landward relocation of buildings and widening and raising beaches through nourishment.

Fences and Privacy Walls

Fences and privacy walls (including walls separating one property from another) may obstruct or divert flood flow and waves. They must be analyzed for their effects on flood conditions and the effects of debris generated by fence/wall failure during flood events. For floodplain management purposes, it can be presumed that open fences (e.g., wood/plastic/metal slat fencing with generous openings, etc.) will not lead to harmful diversion of floodwaters or wave runup and reflection. Fences with smaller openings, and solid fences and walls, may be prone to trapping debris.

Solid fences and privacy walls, and fences prone to trapping debris, must be designed and constructed to fail under base flood conditions without causing harm to adjacent NFIP-compliant buildings. Where building or fire codes require ground level walls for tenant fire separations, efforts should be made to satisfy code requirements while minimizing potential adverse effects due to flood diversion.

Siting of new buildings near existing fences or walls should be reviewed carefully. Figure 16 shows an example of a shore-perpendicular solid wall that failed during a coastal flood event and damaged the pile foundation of an adjacent elevated building.

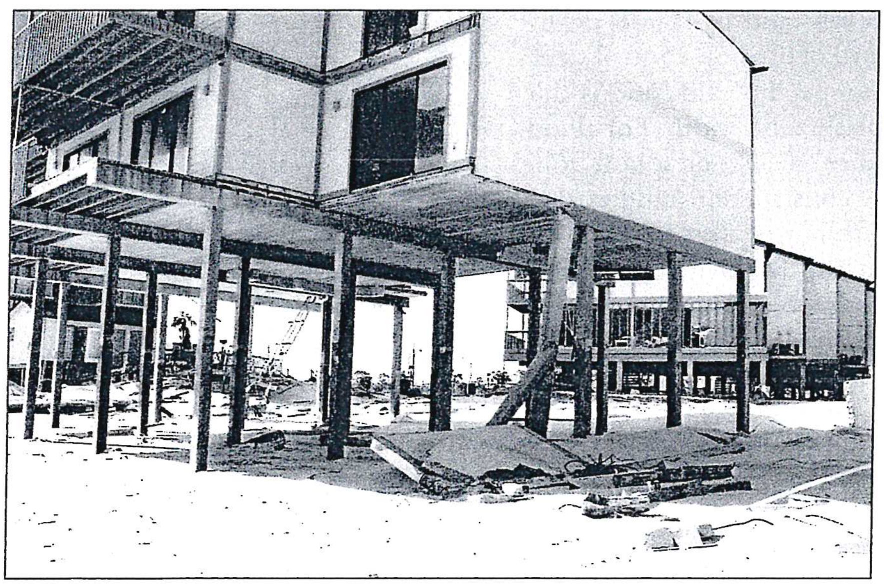


Figure 16. Shore-perpendicular reinforced masonry wall failed and collapsed into the foundation of an adjacent building, contributing to failure of the corner foundation piling and pile cap/beam.

Fill

Non-structural fill described in this Technical Bulletin must be ignored for load calculation and foundation design purposes.

NFIP regulations prohibit the use of fill for structural support of buildings in V zones. However, minor grading, and the placement of minor quantities of fill, is allowed, but only for landscaping, drainage under and around buildings, and support of parking slabs, pool decks, patios, walkways, and similar site elements. Fill must not prevent the free passage of floodwaters and waves beneath elevated buildings. Fill must not divert floodwaters or deflect waves such that increased damage is sustained by adjacent or nearby buildings.

Given the difficulty that many communities and designers have had in determining whether the placement and shaping of non-structural fill will be detrimental, some State and local regulations essentially prohibit placement of any non-structural fill in V zones. This approach may itself lead to problems, such as ponding of rainfall around or under buildings. Other States and communities may accept some (unspecified) amount of non-structural fill, provided an engineering analysis is performed and an engineer will certify that the fill will not lead to damaging flow diversion or wave ramping and deflection. Given the state of engineering methods and models, credible and defensible analyses are almost impossible to perform for small quantities of fill.

> For floodplain management purposes, this Technical Bulletin describes acceptable placements of non-structural fill in V zones, which can be assumed not to lead to damaging flood and wave conditions on a site or adjacent sites.
>
> "Minor grading" shall be that required or allowed by community regulations, subject to the limitations described herein.
>
> "Minor quantities of fill" shall mean the minimum quantity required for: adequate drainage of areas below and around elevated buildings; support of parking slabs, in-ground pool decks, patios, walkways, etc.; and for site landscaping, subject to the limitations described herein.

The following evaluation criteria are recommended for determining acceptable placement of non-structural fill in V zones. Note that there are several criteria listed, and it is possible that some may be in conflict, depending on specific circumstances. The local official is expected to use discretion in such cases to achieve the desired performance while giving deference to the general intent of these criteria.

- **Type of fill.** Fill placed on V zone sites should be similar to natural soils in the area. In many coastal areas, this will be clean sand or sandy soils, free of large quantities of clay, silt, and organic material. Non-structural fill should not contain large rocks and debris. If the fill is similar to and compatible with natural soils, there is no need for communities to require designers to investigate or certify whether the fill has a tendency for "excessive natural compaction" (a common requirement in many floodplain regulations). If the fill material is truly similar to natural soils, its behavior under flood conditions should be similar to the behavior of natural soils, and should not be a subject of debate.

- **Height or elevation of fill at building.** Generally, it is unreasonable to expect that the addition of 1 to 2 feet of site-compatible, non-structural fill in a V zone will lead to adverse effects on buildings. Thus, placement of up to 2 feet of fill under or around an elevated building can be assumed to be acceptable (without engineering analysis or certification) provided basic site drainage principles and vertical clearance limitations are not violated (see below); and provided there are no site-specific conditions or characteristics that would render the placement of the fill as damaging to NFIP-compliant construction (e.g., if local officials have observed the placement of similar quantities of suitable fill has led to building damage during coastal storm events). If additional fill height is proposed for a site, the proposed final grade should be compared to local topography. If the proposed final fill configuration is similar to grades and slopes in the immediate vicinity, a detailed analysis of the effects on flood flow and waves need not be required. If more than 2 feet of fill is proposed and the proposed fill configuration exceeds local grade heights and variations, an analysis must be performed.

- **Grading to prevent ponding.** In addition to requirements to elevate buildings to or above the BFE, most communities have established minimum floor elevations to ensure that water does not collect at or under buildings. The floor elevation requirements frequently are tied to nearby road elevations and, on low-lying or level parcels, the quantity of fill required to raise building footprint areas typically will fall within the 2-foot fill height allowance mentioned above. Even though these floor elevation requirements are implemented across entire jurisdictions, there is no reason to automatically assume that application in a V zone will be detrimental. Even if habitable portions of a building are elevated to satisfy floodplain management requirements (usually several feet above grade in most V zones), there is no compelling reason to restrict the placement of site-compatible non-structural fill beneath those buildings if it will prevent ponding and/or saturated soil conditions, and as long as other drainage requirements for grades and slopes can be satisfied.

- **Site drainage requirements.** Most communities have established minimum slopes for building sites to facilitate drainage away from buildings (typically 5 percent [one unit vertical to 20 units horizontal]). Shallow slopes such as these will not lead to wave ramping, runup, or deflection. Indeed, much steeper slopes (generally one unit vertical to three units horizontal, or steeper) are required to enhance wave runup. For floodplain management purposes, site slopes shallower than one unit vertical to five units horizontal (regardless of fill height) are assumed not to cause or worsen wave runup, or reflection capable of damaging adjacent buildings. Figure 17 shows an example of fill placement that is considered acceptable; the fill height is modest and the side slopes are gentle. Although an adjacent pre-FIRM building is lower, the pre-FIRM building would likely sustain structural damage during a coastal flood, even if the fill was not present. Swales and conventional site drainage practices should be used to mitigate potential effects of runoff from the fill area.

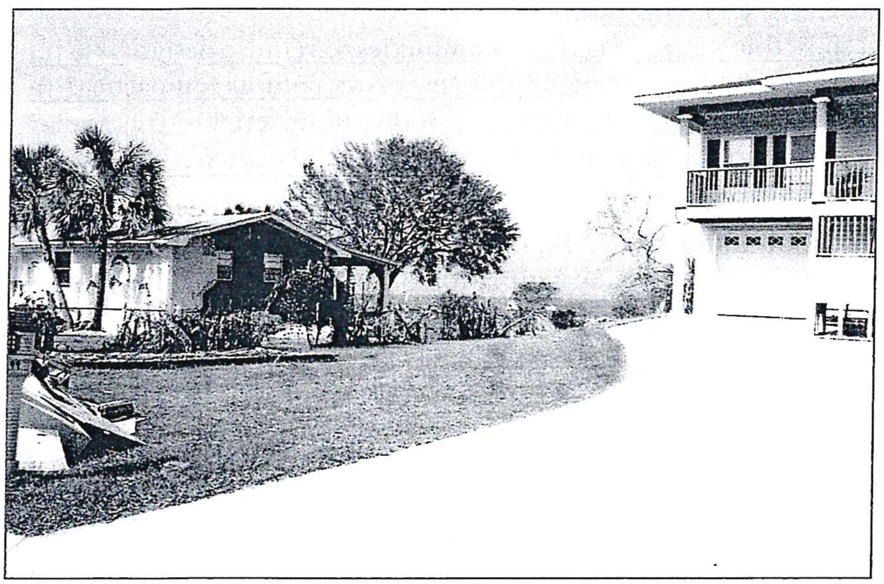


Figure 17. Post-hurricane photo showing elevated building surrounded by gently sloping fill, with adjacent damaged pre-FIRM building (the presence and configuration of the fill were judged by the damage inspection team not to have led to flood or wave damage to the elevated building or the nearby pre-FIRM building).

- **Vertical clearance between top of fill and the elevated lowest floor.** Regardless of whether fill is used for drainage or landscaping purposes, it should not be placed to an elevation that buries any portion of the lowest floor system (i.e., beams, girders, trusses, or joists supporting the walking surface of the floor). While the likelihood of such fill leading to structural damage is deemed to be small, it is considered good practice to provide some vertical clearance between the top of the fill and the bottom of the lowest floor system. This clearance will allow for sheet flow (such as that caused by waves overtopping a dune or barrier) to pass beneath the building. There are no established rules as to what constitutes acceptable vertical clearance but, for floodplain management purposes, a vertical clearance of 2 feet is considered adequate in most cases.

> Under the NFIP, the "lowest floor" is the floor of the lowest enclosed area of a building. An unfinished or flood-resistant enclosure that is used solely for parking of vehicles, building access, or storage is not the lowest floor, provided the enclosure is built in compliance with applicable requirements.

- **Compaction of fill.** The NFIP regulations are very explicit – fill shall not be used for structural support of buildings in V zones. However, for floodplain management purposes, compaction of fill below and around elevated buildings in order to support parking slabs, in-ground pool decks, patios, sidewalks, and similar site amenities is consistent with the intent of the regulations.

- **Dune construction, repair, or reconstruction.** Dunes are natural features in many coastal areas, and they can erode during storms and recover naturally over time. The natural recovery process can be accelerated by replacing the eroded dune with compatible sand, planting dune grasses, and installing sand fences (see Chapter 5 of Rogers and Nash, 2003). In general, these activities should not be considered as detrimental, even if part of the dune lies under a building's footprint. The addition of sand to restore a site to its pre-storm grades and stabilization with dune vegetation will likely do more good than potential harm in terms of flood damage reduction. Concerns about placement of nonstructural, clean sand under and around beachfront buildings should not be the basis for prohibiting dune maintenance and construction, beach nourishment, or similar activities. Dune construction, repair, and reconstruction under or around an elevated building may be assumed to be acceptable (without engineering analysis or certification) as long as: 1) the scale and location of the dune work is consistent with local beach-dune morphology, and 2) vertical clearance is maintained between the top of the dune and the building's floor system. Note, however, this guidance is not intended to give license to violate the other limitations on use of fill where buildings are distant from the shoreline and where dunes would not otherwise occur naturally.

Ground Elevations At or Above the BFE

In some V zones, it is not uncommon to have ground elevations at or above the BFE, particularly along shorelines with well-developed dune fields. Having a mapped V zone with a BFE at or below grade seems counterintuitive, but it is possible because of two V zone mapping considerations:

- **Dune erosion.** Dunes can erode during the base flood (or lesser floods), resulting in a substantial lowering of the pre-storm grade to a level below the mapped BFE. The BFE is mapped based on surge and waves passing over the lowered ground surface.
- **The presence of a primary frontal dune.** V zones are mapped to the inland extent (heel) of the primary frontal dune. The BFE on the seaward face of the dune will be extended as a horizontal line from the seaward toe, through the dune feature, to the location of the heel.

Having grade elevations at or above the BFE may complicate, but does not eliminate, the need to comply with V zone design and construction requirements. But this prompts a question: how does the free-of-obstruction requirement apply in this situation? Because the soil at the site may erode during a severe coastal flood event, the area under the building will be exposed – this exposed area must be free of obstructions.

> Excavation to place the lowest floor at the BFE is not recommended, and may in fact violate the NFIP regulation not to alter sand dunes if such alteration increases potential flood hazards.

The same free-of-obstruction considerations that apply to buildings elevated far above grade apply to elevated buildings where the lowest floors are at or near grade. The buildings must still be designed and constructed on pile or column foundations that are embedded deep into the ground, and the bottoms of the lowest horizontal supporting members must still be at or above the BFE. As noted in the section on Fill, a 2-foot vertical clearance between the bottom of the lowest horizontal supporting member and the ground is recommended. The soil around such buildings should be graded to drain water away from the foundations.

Restroom Buildings and Comfort Stations

One question that arises is whether restroom buildings or comfort stations can be treated differently than other types of V zone structures and be constructed below the BFE, particularly when those facilities are situated in public parks or recreation areas. The answer is no. These structures must meet the same V zone design and construction requirements as other buildings.

Septic Systems

Post-disaster assessments show that buried septic systems and mounded septic systems in V zones frequently are exposed and/or displaced. In addition to compromising their subsequent use, damage to these systems can release their contents. Septic systems frequently are destroyed if they are near the shoreline. Therefore, septic systems should be located either outside areas subject to erosion during the base flood or, if placed in an area subject to erosion, below the depth of expected erosion. This latter stipulation may conflict with septic system groundwater considerations, in which case a septic system is not appropriate for the area.

Septic system tanks must not be structurally attached to building foundations. Plumbing and piping connections will be required, and these items are allowed in V zones. However, plumbing and piping components must not be attached to or pass through breakaway wall panels.

Mounded septic systems can require significant volumes of fill, which, if placed under or immediately adjacent to buildings, likely will constitute an obstruction that diverts flood flow and waves. Mounded septic systems may be allowed in V zones if they will not worsen flood and wave conditions for the buildings they serve, or for other nearby buildings (see the discussion in the section on Fill for guidance on evaluating mounded systems near elevated buildings).

An additional consideration for septic systems in V zones is addressed by Section 60.3(a)(6)(ii) of the NFIP regulations, which requires "on-site waste disposal systems to be located to avoid impairment to them or contamination from them during flooding." FEMA 348 provides additional guidance.

Swimming Pools and Spas

Two primary considerations are related to the placement of swimming pools and spas under or adjacent to buildings in V zones:

- Whether the pool and/or spa configuration is subject to NFIP use limitations for enclosed areas under elevated buildings, and
- Whether the pool or spa will lead to increased flood loads on buildings or exacerbate scour and erosion near buildings.

> Pools and spas are allowed adjacent to coastal buildings only if these amenities will not act as obstructions that lead to damage to nearby buildings. This effectively means that most pools and spas must be installed in-ground (either frangible or immovable), or completely elevated above the BFE. This constraint applies where the ground level is below, at, or above the BFE.

The NFIP permits a swimming pool or spa to be placed beneath an elevated building only if the top of the pool/spa and accompanying deck or walkway are flush with the existing grade, and only if the space around the pool/spa remains unenclosed. However, some states and communities may prohibit restrict pools and spas beneath elevated buildings – designers should check with the jurisdiction for any additional requirements.

The NFIP limits the use of enclosures to parking of vehicles, building access, and storage. Because pools and spas are for recreational use, they are not allowed to be enclosed, even if enclosed by glass or breakaway walls. Use of lattice and insect screening around pools and spas is permitted.

Registered design professionals must certify to local officials that a pool or spa beneath or near a V zone building will not be subject to flotation or displacement that will damage building foundations during a coastal flood. Figure 18 shows a case where a spa was displaced and likely caused failure of two piles that supported an elevated deck. Pools, pool decks, and walkways that are placed under or adjacent to coastal buildings must be structurally independent of the building and its foundation.

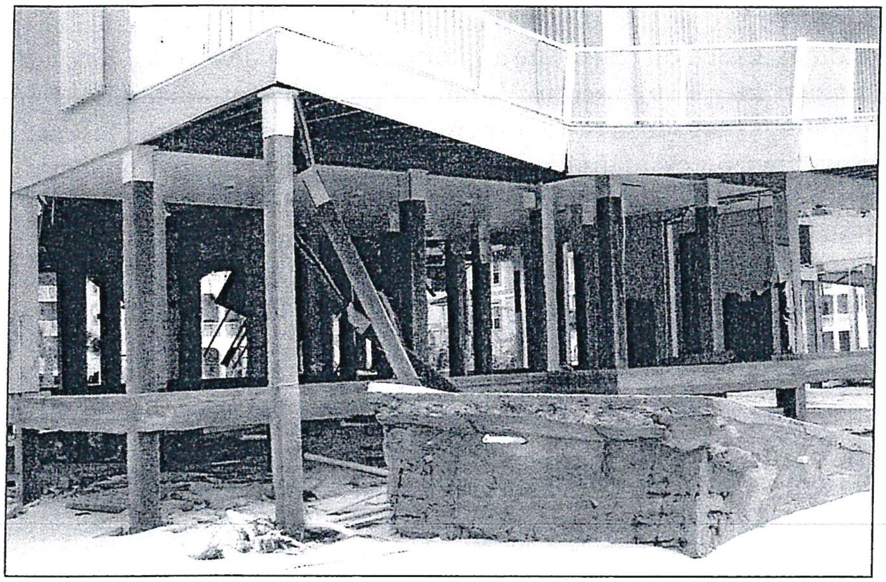


Figure 18. Movement of a spa likely caused failure of two piles supporting an elevated deck.

The NFIP

The U.S. Congress established the NFIP with the passage of the National Flood Insurance Act of 1968. The NFIP is a Federal program enabling property owners in participating communities to purchase insurance as protection against flood losses, in exchange for State and community floodplain management regulations that reduce future flood damages. Participation in the NFIP is based on an agreement between communities and the Federal Government. If a community adopts and enforces adequate floodplain management regulations, FEMA will make flood insurance available within the community.

Title 44 of the U.S Code of Federal Regulations contains the NFIP criteria for floodplain management, including design and construction standards for new and substantially improved buildings located in SFHAs identified on the NFIP's Flood Insurance Rate Maps. FEMA encourages communities to adopt floodplain management regulations that exceed the minimum NFIP criteria. As an insurance alternative to disaster assistance, the NFIP reduces the escalating costs of repairing damage to buildings and their contents caused by floods.

NFIP Technical Bulletins

This is one of a series of Technical Bulletins that FEMA has produced to provide guidance concerning the building performance requirements of the NFIP. These requirements are contained in Title 44 of the U.S. Code of Federal Regulations at Section 60.3. The bulletins are intended for use by State and local officials responsible for interpreting and enforcing the requirements in their floodplain management regulations and building codes, and by members of the development community, such as design professionals and builders. New bulletins, as well as updates of existing bulletins, are issued periodically, as necessary. The bulletins do not create regulations; rather, they provide specific guidance for complying with the requirements of existing NFIP regulations. Users of the Technical Bulletins who need additional guidance should contact their NFIP State Coordinator or the appropriate FEMA regional office. The *User's Guide to Technical Bulletins* (http://www.fema.gov/pdf/fima/guide01.pdf) lists the bulletins issued to date.

Ordering Technical Bulletins

The quickest and easiest way to acquire copies of FEMA's Technical Bulletins is to download them from the FEMA website (http://www.fema.gov/plan/prevent/floodplain/techbul.shtm).

Technical Bulletins also may be ordered free of charge from the FEMA Publications Warehouse by calling 1-800-480-2520, or by faxing a request to 301-362-5355, Monday through Friday between 8 a.m. and 5 p.m. EST. Please provide the FEMA publication number, title, and quantity of each publication requested, along with your name, address, zip code, and daytime telephone number. Written requests may be also be submitted by mail to the following address:

FEMA Publications
P.O. Box 2012
Jessup, MD 20794

Further Information

The following sources provide further information concerning free-of-obstruction requirements.

American Society of Civil Engineers, Structural Engineering Institute. 2005. *Flood Resistant Design and Construction*, ASCE/SEI 24-05.

FEMA. 1993. NFIP Technical Bulletin 4-93, *Elevator Installation for Buildings in Special Flood Hazard Areas*.

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FEMA. 2008. NFIP Technical Bulletin 2-08, *Flood Damage-Resistant Material Requirements for Buildings Located in Special Flood Hazard Areas*.

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FEMA. 2008. *Flood Insurance Manual.*

Rogers, S.M., Jr. and D. Nash. 2003. *The Dune Book.* North Carolina Sea Grant Report SG-03-03.

USACE. 2002. *Coastal Engineering Manual.*

Glossary

Accessory structure — A structure that is on the same parcel of property as a principal structure, the use of which is incidental to the use of the principal structure.

Base flood — The flood having a 1-percent chance of being equaled or exceeded in any given year, commonly referred to as the "100-year flood." The base flood is the national standard used by the NFIP and all Federal agencies for the purposes of requiring the purchase of flood insurance and regulating new development.

Base flood elevation (BFE) — The height of the base (1-percent annual chance or 100-year) flood in relation to the datum specified on the community's flood hazard map, usually the National Geodetic Vertical Datum of 1929 (NGVD), or the North American Vertical Datum of 1988 (NAVD).

Coastal High Hazard Area — An area of special flood hazard extending from offshore to the inland limit of a primary frontal dune along an open coast and any other area subject to high-velocity wave action from storms or seismic sources.

Design flood elevation (DFE) — Elevation of the design flood, including wave effects, relative to the datum specified on a community's flood hazard map.

Enclosure or enclosed area — Areas created by a crawlspace or solid walls that fully enclose areas below the BFE.

Federal Emergency Management Agency (FEMA) — The Federal agency that, in addition to carrying out other activities, administers the National Flood Insurance Program.

Flood Insurance Rate Map (FIRM) — The official map of a community on which FEMA has delineated both the special flood hazard areas (SFHAs) and the risk premium zones applicable to the community.

Flow diversion — Change in course of flood flow when it encounters an object or structure. Diversion can be accompanied by an increase in the local flood level and/or flood velocity when the blockage is large relative to the area through which the flow would otherwise pass.

Hydrodynamic load — The load imposed on an immersed object, such as a foundation element or enclosure wall, by water flowing against and around it. The magnitude of the hydrodynamic load varies as a function of velocity and other factors.

Lowest floor — The lowest floor of the lowest enclosed area of a building, including a basement. Any NFIP-compliant unfinished or flood-resistant enclosure usable solely for parking of vehicles, building access, or storage (in an area other than a basement) is not considered a building's lowest floor, provided the enclosure does not render the structure in violation of the applicable design requirements of the NFIP.

Mitigation Directorate — The component of FEMA directly responsible for administering the flood hazard identification and floodplain management aspects of the NFIP.

Primary frontal dune — The Primary Frontal Dune is a continuous or nearly continuous mound or ridge of sand with relatively steep seaward and landward slopes immediately landward and adjacent to the beach and subject to erosion and overtopping from high tides and waves during major coastal storms. The landward limit of the primary frontal dune, also known as the toe or heel of the dune, occurs at a point where there is a distinct change from a relatively steep slope to a relatively mild slope. The primary frontal dune toe represents the landward extension of the Zone VE coastal high hazard velocity zone.

Registered Design Professional — An individual who is registered or licensed to practice their respective design profession as defined by the statutory requirements of the professional registration laws of the State or jurisdiction in which the project is to be constructed.

Special Flood Hazard Area (SFHA) — An area delineated on a Flood Insurance Rate Map as being subject to inundation by the base flood and designated as Zone A, AE, A1-A30, AR, AO, AH, A99, V, VE, or V1-V30.

Substantial damage — Damage of any origin sustained by a structure whereby the cost of restoring the structure to its before-damaged condition would equal or exceed 50 percent of the market value of the structure before the damage occurred. Structures that are determined to be substantially damaged are considered to be substantial improvements, regardless of the actual repair work performed.

Substantial improvement — Any reconstruction, rehabilitation, addition, or other improvement of a structure, the cost of which equals or exceeds 50 percent of the market value of the structure (or smaller percentage if established by the community) before the "start of construction" of the improvement. This term includes structures that have incurred "substantial damage," regardless of the actual repair work performed.

Wave reflection — Return or redirection of a wave striking an object.

Wave runup — Rush of a wave up a slope or structure.

Flood Damage-Resistant Materials Requirements

for Buildings Located in Special Flood Hazard Areas in accordance with the National Flood Insurance Program

Technical Bulletin 2 / August 2008

Class 4 & 5 materials are acceptable

FEMA

Table of Contents

Revision to Table 2 footnote (*) made in October 2010.

Comments on the Technical Bulletins should be directed to:

Department of Homeland Security
FEMA Federal Insurance and Mitigation Administration
500 C Street, SW.
Washington, D.C. 20472

Technical Bulletin 2-08 replaces Technical Bulletin 2-93. *Flood-Resistant Materials Requirements for Buildings Located in Special Flood Hazard Areas in accordance with the National Flood Insurance Program.*

Introduction

Protecting buildings that are constructed in special flood hazard areas (SFHAs) from damage caused by flood forces is an important objective of the National Flood Insurance Program (NFIP). In support of this objective, the NFIP regulations include minimum building design criteria that apply to new construction, repair of substantially damaged buildings, and substantial improvement of existing buildings in SFHAs. The base flood is used to delineate SFHAs on Flood Insurance Rate Maps (FIRMs) prepared by the NFIP. The base flood is the flood that has a 1-percent chance of being equaled or exceeded in any given year (commonly called the "100-year" flood). Certain terms used in this Technical Bulletin are defined in the Glossary.

> Under the NFIP, the "lowest floor" is the floor of the lowest enclosed area of a building. An unfinished or flood-resistant enclosure that is used solely for parking of vehicles, building access, or storage is not the lowest floor, provided the enclosure is built in compliance with applicable requirements.
>
> As used by the NFIP, an "enclosure" is an area that is enclosed on all sides by walls.
>
> The NFIP defines a "basement" as any area that is below-grade on all sides. The regulations do not allow basements to extend below the BFE.

The NFIP regulations require the use of construction materials that are resistant to flood damage. The lowest floor of a residential building must be elevated to or above the base flood elevation (BFE), while the lowest floor of a non-residential building must be elevated to or above the BFE or dry floodproofed to the BFE.

All construction below the BFE is susceptible to flooding and must consist of flood damage-resistant building materials. The purpose of this Technical Bulletin is to provide current guidance on what constitute "materials resistant to flood damage" and how and when these materials must be used to improve a building's ability to withstand flooding.

Table 1 describes five classes of materials ranging from those that are highly resistant to floodwater damage, to those that have no resistance to flooding. Materials are broadly described as structural materials and finish materials based on how they are used in normal construction practices. Table 2 lists materials by generic names, and notes whether the materials are acceptable or unacceptable for use below the BFE. All building materials are in some way fastened or connected to the structure. Fasteners and connectors, as described in this Technical Bulletin, also must be resistant to flood damage.

A brief description of the process used to identify or determine whether the materials listed are flood damage-resistant is provided, followed by some simplified examples with diagrams to illustrate the use of these materials below the BFE. Three additional circumstances where flood damage-resistant materials are used or recommended are described: accessory structures, limited use of wet floodproofing, and buildings outside of SFHAs.

Questions about use of flood damage-resistant materials should be directed to the appropriate local official, NFIP State Coordinating Office, or one of the Federal Emergency Management Agency's (FEMA's) Regional Offices.

NFIP Regulations

The NFIP regulations for flood damage-resistant materials are codified in Title 44 of the Code of Federal Regulations, in Section 60.3(a)(3), which states that a community shall:

> *"Review all permit applications to determine whether proposed building sites will be reasonably safe from flooding. If a proposed building site is in a floodprone area, all new construction and substantial improvements shall...(ii) be constructed with materials resistant to flood damage..."*

Proposals for substantial improvement of existing buildings in SFHAs, and proposals to repair those that have sustained substantial damage, must comply with the requirements for new construction. As part of issuing permits, community officials must review such proposals to determine whether they comply with the requirements, including the use of flood damage-resistant materials. Refer to the "Classification of Flood Damage-Resistant Materials" section of this Technical Bulletin for additional details. Further information on substantial improvement and substantial damage is found in *Answers to Questions About Substantially Damaged Buildings* (FEMA 213).

> The NFIP Technical Bulletins provide guidance on the minimum requirements of the NFIP regulations. Community or State requirements that exceed those of the NFIP take precedence. Design professionals should contact the community to determine whether more restrictive provisions apply to the building or site in question. All other applicable requirements of the State or local building codes must also be met for buildings in all flood hazard areas.

Required Use of Flood Damage-Resistant Materials

Flood Damage-Resistant Material

"Flood [damage]-resistant material" is defined by the NFIP as "any building product [material, component or system] capable of withstanding direct and prolonged contact with floodwaters without sustaining significant damage." The term "prolonged contact" means at least 72 hours, and the term "significant damage" means any damage requiring more than cosmetic repair. "Cosmetic repair" includes cleaning, sanitizing, and resurfacing (e.g., sanding, repair of joints, repainting) of the material. The cost of cosmetic repair should also be less than the cost of replacement of affected materials and systems. In addition to these requirements, individual materials that are considered flood damage-resistant must not cause degradation of adjacent materials or the systems of which the material is a part.

> The *International Building Code*® (IBC®), by reference to ASCE 24 *Flood Resistant Design and Construction*, and the *International Residential Code*® (IRC®), require the use of flood damage-resistant materials.

All building materials below the BFE must be flood damage-resistant, regardless of the expected or historic flood duration. For example, buildings in coastal areas that experience relatively short-duration flooding (generally, flooding with a duration of less than 24 hours) must be constructed with flood damage-resistant materials below the BFE. As noted in Table 2, **only Class 4 and Class 5 materials are acceptable for areas below the BFE in buildings in SFHAs**.

In some instances, materials that are not flood damage-resistant materials, such as wiring for fire alarms and emergency lighting, are allowed below the BFE if specifically required to address life safety and electric code requirements for building access and storage areas.

How Flood Damage-Resistant Materials Affect Flood Insurance Rates

Careful attention to compliance with the NFIP regulations for flood damage-resistant materials is important during design, plan review, construction, and inspection. Compliance influences both the building's vulnerability to flood damage and the cost of NFIP flood insurance. Flood insurance will not pay a claim for finish materials located in basements or in enclosed areas below the lowest floor of elevated buildings, even if such materials are considered to be flood damage-resistant. NFIP claims for damage below the BFE are limited to utilities and equipment, such as furnaces and water heaters.

Classification of Flood Damage-Resistant Materials

The information in this Technical Bulletin was initially developed based on information in the U.S. Army Corps of Engineers' *Flood Proofing Regulations* (1995), and has been updated based on additional information from FEMA-funded studies and reports, technical experts, and industry and trade groups. Table 1 classifies building materials according to their ability to resist flood damage.

Table 1. Class Descriptions of Materials

NFIP	Class	Class Description
ACCEPTABLE	5	Highly resistant to floodwater[1] damage, including damage caused by moving water.[2] These materials can survive wetting and drying and may be successfully cleaned after a flood to render them free of most harmful pollutants.[3] Materials in this class are permitted for partially enclosed or outside uses with essentially unmitigated flood exposure.
ACCEPTABLE	4	Resistant to floodwater[1] damage from wetting and drying, but less durable when exposed to moving water.[2] These materials can survive wetting and drying and may be successfully cleaned after a flood to render them free of most harmful pollutants.[3] Materials in this class may be exposed to and/or submerged in floodwaters in interior spaces and do not require special waterproofing protection.
UNACCEPTABLE	3	Resistant to clean water[4] damage, but not floodwater damage. Materials in this class may be submerged in clean water during periods of flooding. These materials can survive wetting and drying, but may not be able to be successfully cleaned after floods to render them free of most[3] harmful pollutants.
UNACCEPTABLE	2	Not resistant to clean water[4] damage. Materials in this class are used in predominantly dry spaces that may be subject to occasional water vapor and/or slight seepage. These materials cannot survive the wetting and drying associated with floods.
UNACCEPTABLE	1	Not resistant to clean water[4] damage or moisture damage. Materials in this class are used in spaces with conditions of complete dryness. These materials cannot survive the wetting and drying associated with floods.

Notes:

1. Floodwater is assumed to be considered "black" water; black water contains pollutants such as sewage, chemicals, heavy metals, or other toxic substances that are potentially hazardous to humans.
2. Moving water is defined as water moving at low velocities of 5 feet per second (fps) or less. Water moving at velocities greater than 5 fps may cause structural damage to building materials.
3. Some materials can be successfully cleaned of most of the pollutants typically found in floodwater. However, some individual pollutants such as heating oil can be extremely difficult to remove from uncoated concrete. These materials are flood damage-resistant except when exposed to individual pollutants that cannot be successfully cleaned.
4. Clean water includes potable water as well as "gray" water; gray water is wastewater collected from normal uses (laundry, bathing, food preparation, etc.).

MODIFIED FROM: USACE 1995 *Flood Proofing Regulations*

Table 2 lists structural materials and finish materials commonly used in construction of floors, walls, and ceilings. For the purpose of this Technical Bulletin, structural materials and finish materials are defined as follows:

- **Structural materials** include all elements necessary to provide structural support, rigidity, and integrity to a building or building component. Structural materials include floor slabs, beams, subfloors, framing, and structural building components such as trusses, wall panels, I-joists and headers, and interior/exterior sheathing.

- **Finish materials** include all coverings, finishes, and elements that do not provide structural support or rigidity to a building or building component. Finish materials include floor coverings, wall and ceiling surface treatments, insulation, cabinets, doors, partitions, and windows.

Notes Regarding Classification of Materials

The classifications in Table 2 are based on the best information available at the time of publication. However, flood damage-resistance is determined by factors that may be a function of the specific application and by the characteristics of the floodwaters. Each situation requires sound judgment and knowledge of probable contaminants in local floodwaters to select materials that are required to resist flood damage. For materials and products that are listed in Table 2, manufacturers' use and installation instructions must be followed to ensure maximum performance. Masonry and wood products used below the BFE must comply with the applicable standards published by the American Society for Testing and Materials (ASTM), the American Concrete Institute (ACI), the Truss Plate Institute (TPI), the American Forest & Paper Association (AF&PA), and other appropriate organizations.

1. **Materials Not Listed:** Table 2 does not list all available structural materials and finish materials. For materials and products not listed, manufacturers' literature (i.e., specifications, materials safety data sheets, test reports) should be evaluated to determine if the product meets flood damage-resistance requirements. Materials and products that are not listed in Table 2 may be used if accepted by the local official. Acceptance should be based on sufficient evidence, provided by the applicant, that the materials proposed to be used below the BFE will resist flood damage without requiring more than cosmetic repair and cleaning.

2. **Unacceptable Materials:** Class 1, 2, and 3 materials are unacceptable for below-BFE applications for one or more of the following reasons:

   - Normal adhesives specified for above-grade use are water soluble or are not resistant to alkali or acid in water, including groundwater seepage and vapor.

   - The materials contain wood or paper products, or other materials that dissolve or deteriorate, lose structural integrity, or are adversely affected by water.

   - Sheet-type floor coverings (linoleum, rubber tile) or wall coverings (wallpaper) restrict drying of the materials they cover.

   - Materials are dimensionally unstable.

   - Materials absorb or retain excessive water after submergence.

3. **Impact of Material Combinations:** In some cases, the combination of acceptable structural and finish materials can negatively impact the classification of individual materials. This is illustrated by the following examples:

- Vinyl tile with chemical-set adhesives is an acceptable finish flooring material when placed on a concrete structural floor. However, when the same vinyl tile is applied over a plywood structural floor, it is no longer considered acceptable because the vinyl tile must be removed to allow the plywood to dry.

- Polyester-epoxy or oil-based paints are acceptable wall finishes when applied to a concrete structural wall. However, when the same paint is applied to a wood wall, it is no longer considered acceptable. Recent FEMA-supported studies by Oak Ridge National Laboratory have found that low-permeability paint can inhibit drying of the wood wall.

4. **Impact of Long-Duration Exposure and/or Contaminants:** The classifications of materials listed in Table 2 do not take into account the effects of long-duration exposure to floodwaters or contaminants carried by floodwaters. This is illustrated by the following examples:

   - Following Hurricane Katrina, FEMA deployed a Mitigation Assessment Team (MAT) to examine how building materials performed after long-duration exposure (2 to 3 weeks) to floodwaters (FEMA 549). The field survey revealed that some materials absorbed floodborne biological and chemical contaminants. However, it is not known at this time if a shorter duration flood event would have significantly altered the absorption rates of those contaminants.

   - Building owners, design professionals, and local officials should consider potential exposure to floodborne contaminants when selecting flood damage-resistant materials. For example, Table 2 lists cast-in-place concrete, concrete block, and solid structural wood (2x4s, etc.), as acceptable flood damage-resistant materials. However, experience has shown that buildings with those materials can be rendered unacceptable for habitation after being subjected to floodwaters with significant quantities of petroleum-based products such as home heating oil. Commonly used cleaning and remediation practices do not reduce the "off-gassing" of volatile hydrocarbons from embedded oil residues to acceptable levels that are established by the U.S. Environmental Protection Agency. Other materials, when exposed to these types of contaminants, may also not perform acceptably as flood damage-resistant materials.

Table 2. Types, Uses, and Classifications of Materials

Types of Building Materials	Uses of Building Materials		Classes of Building Materials				
			Acceptable		Unacceptable		
	Floors	Walls/ Ceilings	5	4	3	2	1
Structural Materials (floor slabs, beams, subfloors, framing, and interior/exterior sheathing)							
Asbestos-cement board		■	■				
Brick							
Face or glazed		■	■				
Common (clay)		■		■			
Cast stone (in waterproof mortar)		■	■				
Cement board/fiber-cement board		■	■				
Cement/latex, formed-in-place	■			■			
Clay tile, structural glazed		■	■				
Concrete, precast or cast-in-place	■	■	■				
Concrete block[1]		■	■				
Gypsum products							
Paper-faced gypsum board		■			■		
Non-paper-faced gypsum board		■		■			
Greenboard		■				■	
Keene's cement or plaster		■			■		
Plaster, otherwise, including acoustical		■				■	
Sheathing panels, exterior grade		■			■		
Water-resistant, fiber-reinforced gypsum exterior sheathing		■		■			
Hardboard (high-density fiberboard)							
Tempered, enamel or plastic coated		■				■	
All other types		■					■
Mineral fiberboard		■					■
Oriented-strand board (OSB)							
Exterior grade	■	■				■	
Edge swell-resistant OSB	■	■				■	
All other types	■	■					■
Particle board	■						■
Plywood							
Marine grade	■	■	■				
Preservative-treated, alkaline copper quaternary (ACQ) or copper azole (C-A)	■	■		■			

Table 2. Types, Uses, and Classifications of Materials (continued)

Types of Building Materials	Uses of Building Materials		Classes of Building Materials				
			Acceptable		Unacceptable		
	Floors	Walls/ Ceilings	5	4	3	2	1
Structural Materials (floor slabs, beams, subfloors, framing, and interior/exterior sheathing)							
Preservative-treated, Borate[2]	■	■	■				
Exterior grade/Exposure1 (WBP – weather and boil proof)	■	■		■			
All other types	■	■					■
Recycled plastic lumber (RPL)							
Commingled, with 80-90% polyethylene (PE)	■		■				
Fiber-reinforced, with glass fiber strands	■		■				
High-density polyethylene (HDPE), up to 95%	■		■				
Wood-filled, with 50% sawdust or wood fiber	■				■		
Stone							
Natural or artificial non-absorbent solid or veneer, waterproof grout	■	■	■				
All other applications		■				■	
Structural Building Components							
Floor trusses, wood, solid (2x4s), decay-resistant or preservative-treated	■	■		■			
Floor trusses, steel[3]	■		■				
Headers and beams, solid (2x4s) or plywood, exterior grade or preservative-treated		■		■			
Headers and beams, OSB, exterior grade or edge-swell resistant		■				■	
Headers and beams, steel[3]		■	■				
I-joists	■					■	
Wall panels, plywood, exterior grade or preservative-treated		■		■			
Wall panels, OSB, exterior grade or edge-swell resistant		■				■	
Wall panels, steel[3]		■		■			

Table 2. Types, Uses, and Classifications of Materials (continued)

Types of Building Materials	Uses of Building Materials		Classes of Building Materials				
			Acceptable		Unacceptable		
	Floors	Walls/ Ceilings	5	4	3	2	1
Structural Materials (floor slabs, beams, subfloors, framing, and interior/exterior sheathing)							
Wood							
Solid, standard, structural (2x4s)		■		■			
Solid, standard, finish/trim		■			■		
Solid, decay-resistant[4]	■	■	■				
Solid, preservative-treated, ACQ or C-A		■		■			
Solid, preservative-treated, Borate[2]		■		■			
Finish Materials (floor coverings, wall and ceiling finishes, insulation, cabinets, doors, partitions, and windows)							
Asphalt tile[5]							
With asphaltic adhesives	■				■		
All other types	■						■
Cabinets, built-in							
Wood		■				■	
Particle board		■					■
Metal[3]		■		■			
Carpeting	■						■
Ceramic and porcelain tile							
With mortar set	■	■		■			
With organic adhesives	■	■				■	
Concrete tile, with mortar set	■		■				
Corkboard		■				■	
Doors							
Wood, hollow		■				■	
Wood, lightweight panel construction		■				■	
Wood, solid		■				■	
Metal, hollow[3]		■		■			
Metal, wood core[3]		■		■			
Metal, foam-filled core[3]		■		■			
Fiberglass, wood core		■		■			
Epoxy, formed-in-place	■		■				

Table 2. Types, Uses, and Classifications of Materials (continued)

Types of Building Materials	Uses of Building Materials		Classes of Building Materials				
			Acceptable		Unacceptable		
	Floors	Walls/ Ceilings	5	4	3	2	1
Finish Materials (floor coverings, wall and ceiling finishes, insulation, cabinets, doors, partitions, and windows)							
Glass (sheets, colored tiles, panels)		■		■			
Glass blocks		■	■				
Insulation							
Sprayed polyurethane foam (SPUF) or closed-cell plastic foams	■	■	■				
Inorganic – fiberglass, mineral wool: batts, blankets, or blown	■	■			■		
All other types (cellulose, cotton, open-cell plastic foams, etc.)	■	■				■	
Linoleum	■						■
Magnesite (magnesium oxychloride)	■						■
Mastic felt-base floor covering	■						■
Mastic flooring, formed-in-place	■		■				
Metals, non-ferrous (aluminum, copper, or zinc tiles)		■			■		
Metals							
Non-ferrous (aluminum, copper, or zinc tiles)		■			■		
Metals, ferrous[3]		■		■			
Paint							
Polyester-epoxy and other oil-based waterproof types		■		■			
Latex		■		■			
Partitions, folding							
Wood		■				■	
Metal[3]		■		■			
Fabric-covered		■					■
Partitions, stationary (free-standing)							
Wood frame		■		■			
Metal[3]		■		■			
Glass, unreinforced		■		■			
Glass, reinforced		■		■			
Gypsum, solid or block		■					■

Table 2. Types, Uses, and Classifications of Materials (continued)

Types of Building Materials	Uses of Building Materials		Classes of Building Materials				
			Acceptable		Unacceptable		
	Floors	Walls/ Ceilings	5	4	3	2	1
Finish Materials (floor coverings, wall and ceiling finishes, insulation, cabinets, doors, partitions, and windows)							
Polyurethane, formed-in-place	■		■				
Polyvinyl acetate (PVA) emulsion cement	■						■
Rubber							
Moldings and trim with epoxy polyamide adhesive or latex-hydraulic cement		■		■			
All other applications		■					■
Rubber sheets or tiles[5]							
With chemical-set adhesives[6]	■		■				
All other applications	■						■
Silicone floor, formed-in-place	■		■				
Steel (panels, trim, tile)							
With waterproof adhesives[3]		■	■				
With non-waterproof adhesives		■				■	
Terrazo	■			■			
Vinyl asbestos tile (semi-flexible vinyl)[5]							
With asphaltic adhesives	■		■				
All other applications	■						■
Vinyl sheets or tiles (coated on cork or wood product backings)	■						■
Vinyl sheets or tiles (homogeneous)[5]							
With chemical-set adhesives[6]	■			■			
All other applications	■						■
Wall coverings							
Paper, burlap, cloth types		■					■
Vinyl, plastic, wall paper		■					■
Wood floor coverings							
Wood (solid)	■						■
Engineered wood flooring	■					■	
Plastic laminate flooring	■					■	
Wood composition blocks, laid in cement mortar	■					■	
Wood composition blocks, dipped and laid in hot pitch or bitumen	■					■	

Notes*:

1 Unfilled concrete block cells can create a reservoir that can hold water following a flood, which can make the blocks difficult or impossible to clean if the floodwaters are contaminated.

2 Borate preservative-treated wood meets the NFIP requirements for flood damge-resistantce; however, the borate can leach out of the wood if the material is continuously exposed to standing or moving water.

3 Not recommended in areas subject to salt-water flooding.

4 Examples of decay-resistant lumber include heart wood of redwood, cedar, and black locust. Refer to Section 2302 of the International Building Code® (IBC®) and Section R202 of the International Residential Code® (IRC®) for guidance.

5 Using normally specified suspended flooring (i.e., above-grade) adhesives, including sulfite liquor (lignin or "linoleum paste"), rubber/asphaltic dispersions, or "alcohol" type resinous adhesives (culmar, oleoresin).

6 Examples include epoxy-polyamide adhesives or latex-hydraulic cement.

* In addition to the requirements of TB 2 for flood damage resistance, building materials must also comply with any additional requirements of applicable building codes. For example, for wood products such as solid 2x4s and plywood, applicable building code requirements typically include protection against decay and termites and will specify use of preservative-treated or decay-resistant wood for certain applications. Applications that require preservative-treated or decay-resistant species include wood in contact with the ground, wood exposed to weather, wood on exterior foundation walls, or wood members close to the exposed ground. In some cases, applicable building code requirements (such as those in ASCE 24-05 and IRC 2006) do not reflect updated guidance in TB 2 and specify that all wood used below the design flood elevation be preservative-treated or naturally decay-resistant regardless of proximity to ground or exposure to weather. (Revision made in October 2010)

Fasteners and Connectors

The term "fasteners" typically refers to nails, screws, bolts, and anchors. The term "connectors" typically refers to manufactured devices used to connect two or more building components. Joist hangers, post bases, hurricane ties and clips, and mud-sill anchors are examples of connectors. Fasteners and connectors are materials and thus must be made of flood damage-resistant materials in order to comply with the NFIP requirements.

> Specifications for fasteners and connectors used in buildings in SFHAs are in ASCE 24, a standard referenced by the IBC. Chapter 23 of the IBC has specific requirements for connections and fasteners used with wood, including preservative-treated wood. Similar specifications are in Chapter 3 of the IRC.

Table 2 does not specifically address fasteners and connectors. However, it is clear that the performance of buildings that are exposed to flooding is, at least in part, a function of the fasteners and connectors used to put the components together. When preservative-treated woods are used, particular attention is required for fasteners and connectors because some treatments are more corrosive than others, which could shorten the service life of the fasteners and connectors. For example, alkaline copper quaternary (ACQ) treatments are more corrosive than traditional acid copper chromate (ACC) treatments. If corrosion occurs, buildings are less likely to withstand flood loads and other loads. Fasteners and connectors made of stainless steel, hot-dipped zinc-coated galvanized steel, silicon bronze, or copper are recommended for use with preservative-treated wood.

This Technical Bulletin, consistent with ASCE 24 and the International Code Series, recommends that stainless steel or hot-dip galvanized fasteners and connectors be used below the BFE in both inland (noncorrosive) and coastal (corrosive) areas. In coastal environments where airborne salts contribute to corrosion, it is recommended that corrosion-resistant fasteners and connectors be used throughout the building where they may be exposed. For additional guidance, see Technical Bulletin 8, *Corrosion Protection for Metal Connectors in Coastal Areas*. Also see TPI/WTCA *Guidelines for Use of Alternative Preservative Treatments with Metal Connector Plates* for further guidance on metal plate connected wood trusses manufactured with preservative treated lumber (http://www.sbcindustry.com/images/PTWGuidelines.pdf).

Construction Examples

Buildings in Zones A, AE, A1-A30, AR, AO, and AH

Figure 1 illustrates a solid foundation wall (crawlspace) elevated to meet the minimum requirement that the lowest floor be at the BFE. Figure 2 illustrates framed walls that may be used for enclosures below the BFE that are used for parking of vehicles, building access, and storage.

To maximize allowable use of enclosures below the BFE, it is a common practice to extend the foundation a full story, even though that puts the lowest floor well above the BFE. In such cases, while the NFIP requirement is that flood damage-resistant materials be used only below the BFE, it is strongly recommended that such materials be used for all construction below the lowest floor. This will reduce flood damage to the enclosed area in the event flooding exceeds the BFE. For additional guidance on enclosures in A zones, see Technical Bulletin 1, *Openings in Foundation Walls and Walls of Enclosures Below Elevated Buildings in Special Flood Hazard Areas.*

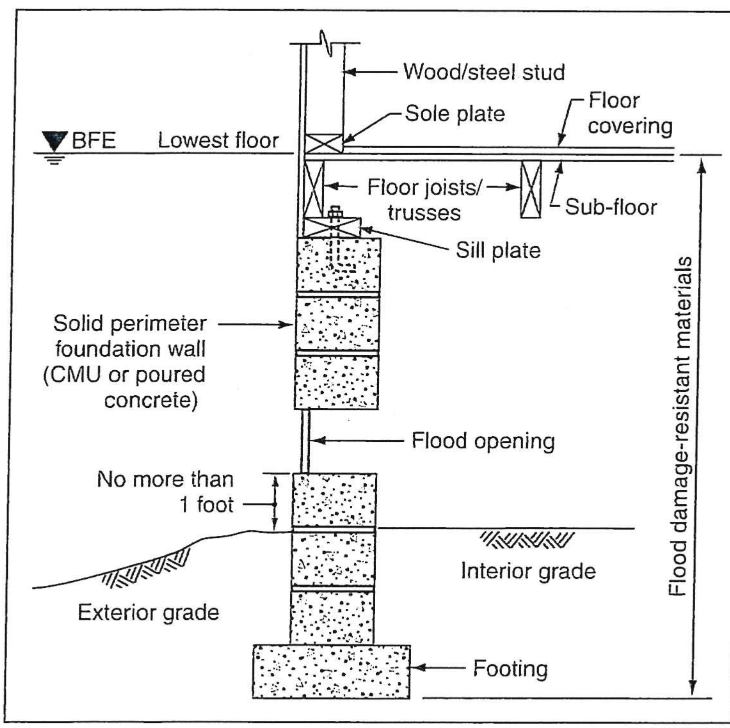

Figure 1. Building elevated on solid foundation walls meeting the minimum NFIP requirements for Zones A, AE, A1-A30, AR, AO, and AH

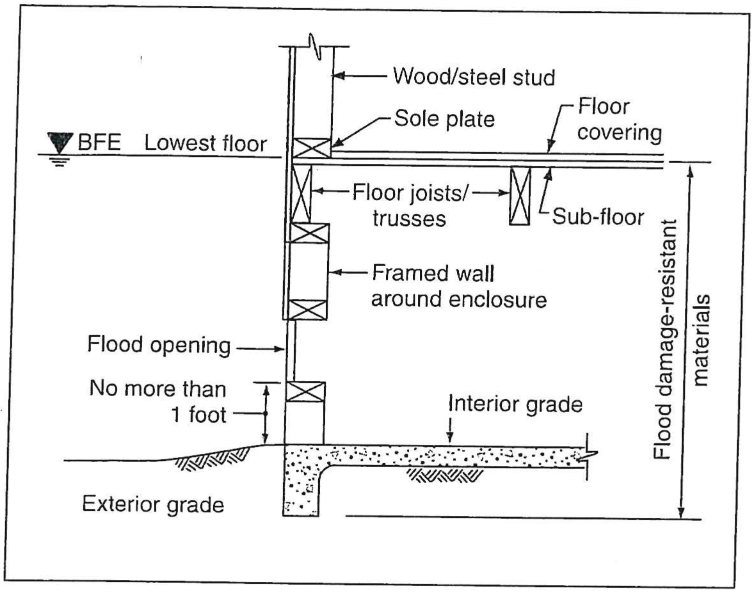

Figure 2. Framed enclosure under building elevated in accordance with NFIP requirements for Zones A, AE, A1-A30, AO, and AH

Buildings in Zones V, VE, and V1-V30

The NFIP regulations require that the bottom of the lowest horizontal structural member of the lowest floor (usually the floor beam or girder) of buildings in Zones V, VE, and V1-V30 be at or above the BFE. Therefore, all materials below the bottom of those members must be flood damage-resistant materials. This requirement applies to lattice work and screening, and also to materials used to construct breakaway walls that enclose areas below the lowest floor. Depending on the design parameters selected, breakaway walls may remain in place during low-level floods and must be flood damage-resistant so that they can be readily cleaned and not deteriorate over time due to wetting. Figure 3 illustrates the requirement. For additional guidance on breakaway walls used to enclose areas under buildings in V zones, see Technical Bulletin 9, *Design and Construction Guidance for Breakaway Walls Below Elevated Coastal Buildings*.

Additional Uses of Flood Damage-Resistant Materials

Accessory Structures

Accessory structures may be allowed in SFHAs provided they are located, installed, and constructed in ways that comply with NFIP requirements. Some communities allow accessory structures that are limited to the uses specified for enclosures below the BFE: parking of vehicles and storage. As with other buildings, accessory structures below the BFE are required to be constructed with flood damage-resistant materials. In addition, accessory structures must be anchored to resist flotation, collapse, and lateral movement and comply with other requirements based on the flood zone. For additional information and requirements, contact the appropriate community permitting office.

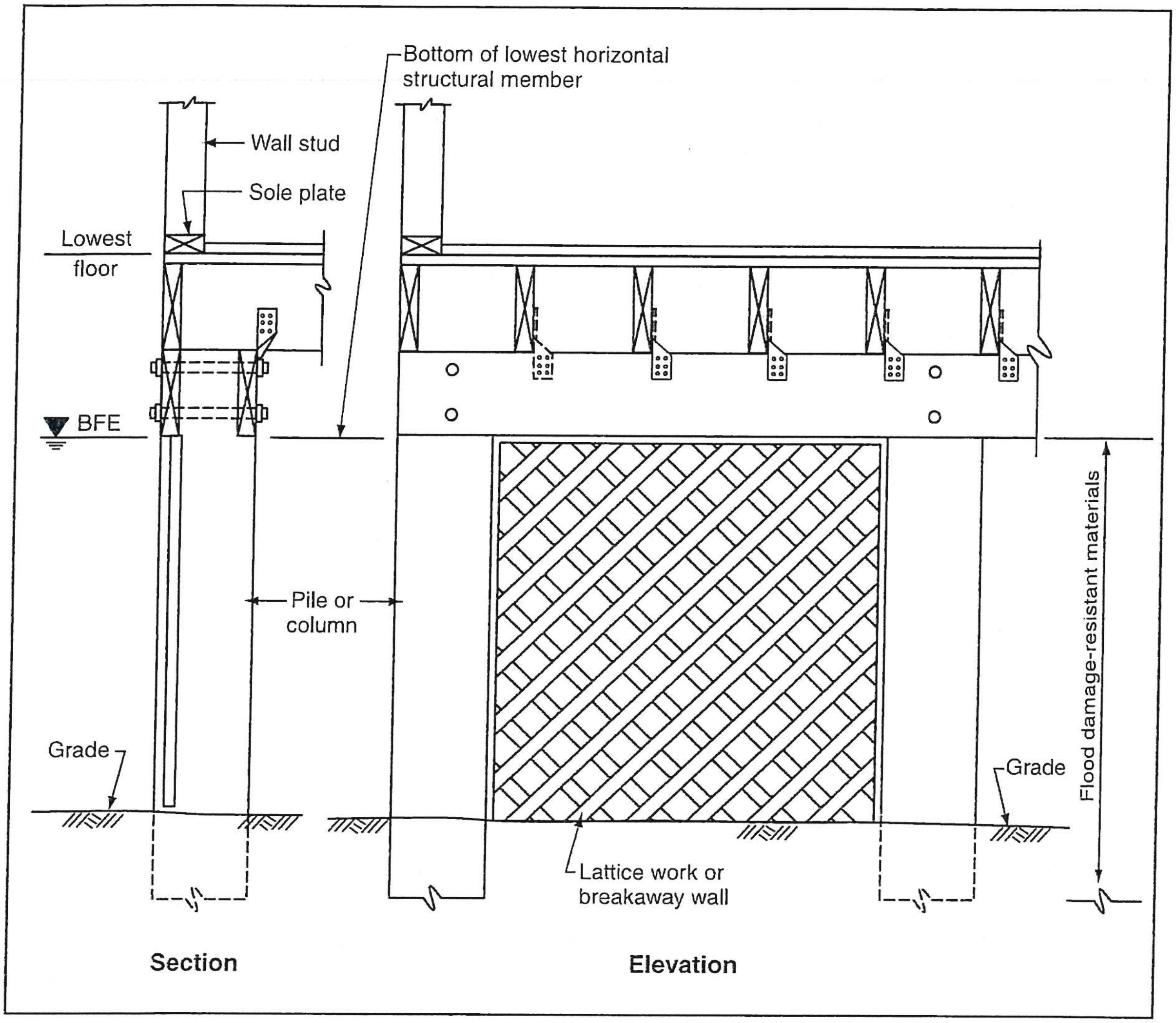

Figure 3. Flood damage-resistant building material requirements for buildings elevated in accordance with NFIP requirements for Zones V, VE, and V1-V30

Wet Floodproofing

Wet floodproofing is a method to reduce damage that typically involves three elements: allowing floodwaters to enter and exit to minimize structural damage, using flood damage-resistant materials, and elevating utility service and equipment. When a building is retrofitted to be wet floodproofed, non-flood damage-resistant materials that are below the BFE should be removed and replaced with flood damage-resistant materials. This will reduce the costs of repair and facilitate faster recovery.

Wet floodproofing is not allowed in lieu of complying with the lowest floor elevation requirements for new residential buildings (or dry floodproofing of nonresidential buildings in A zones). The exception is accessory structures, as noted on the previous page. Wet floodproofing may also be used to voluntarily retrofit buildings that are older than the date of the community's first FIRM (commonly referred to as "pre-FIRM"), provided the requirement to bring such buildings into compliance is not triggered (called "substantial improvement"). Figure 4 illustrates some suggested retrofitting of interior walls in a pre-FIRM building. However, please note that the techniques illustrated in Figure 4 cannot be used to bring a substantially damaged or substantially improved building into compliance with the NFIP. For additional information on wet floodproofing, see Technical Bulletin 7, *Wet Floodproofing Requirements.*

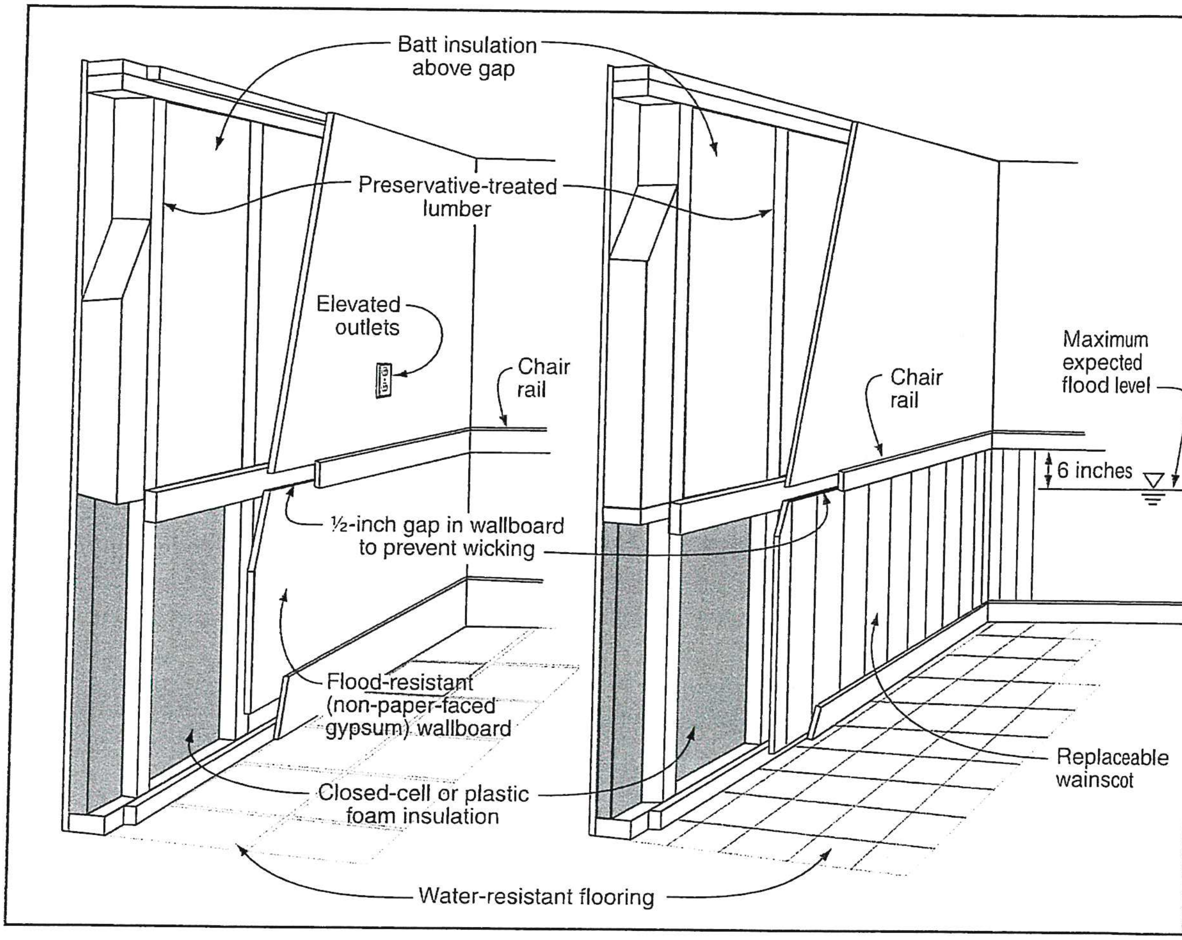

Figure 4. Partial wet floodproofing technique using flood damage-resistant materials for finished wall construction.

Buildings Outside of SFHAs

FEMA reports that up to 25 percent of NFIP flood insurance claims are paid on buildings that are outside of the mapped SFHA. This occurs for many reasons, including out-of-date maps and local drainage problems. In areas known to be prone to flooding that are not subject to the NFIP requirements, it is recommended that flood damage-resistant materials be used for construction of new buildings and for repair or renovation of existing buildings. Figure 4 illustrates some options.

The NFIP

The U.S. Congress established the NFIP with the passage of the National Flood Insurance Act of 1968. The NFIP is a Federal program enabling property owners in participating communities to purchase insurance as protection against flood losses, in exchange for State and community floodplain management regulations that reduce future flood damages. Participation in the NFIP is based on an agreement between communities and the Federal Government. If a community adopts and enforces adequate floodplain management regulations, FEMA will make flood insurance available within the community.

Title 44 of the U.S. Code of Federal Regulations contains the NFIP criteria for floodplain management, including design and construction standards for new and substantially improved buildings located in SFHAs identified on the NFIP's FIRMs. FEMA encourages communities to adopt floodplain management regulations that exceed the NFIP criteria. As an insurance alternative to disaster assistance, the NFIP reduces the escalating costs of repairing damage to buildings and their contents caused by floods.

NFIP Technical Bulletins

This is one of a series of Technical Bulletins that FEMA has produced to provide guidance concerning the building performance requirements of the NFIP. These requirements are contained in Title 44 of the U.S. Code of Federal Regulations at Section 60.3. The bulletins are intended for use by State and local officials responsible for interpreting and enforcing the requirements in their floodplain management regulations and building codes, and by members of the development community, such as design professionals and builders. New bulletins, as well as updates of existing bulletins, are issued periodically, as necessary. The bulletins do not create regulations; rather, they provide specific guidance for complying with the requirements of existing NFIP regulations. Users of the Technical Bulletins who need additional guidance should contact their NFIP State Coordinator or the appropriate FEMA regional office. *The User's Guide to Technical Bulletins* (http://www.fema.gov/pdf/fima/guide01.pdf) lists the bulletins issued to date.

Ordering Technical Bulletins

The quickest and easiest way to acquire copies of FEMA's Technical Bulletins is to download them from the FEMA website (http://www.fema.gov/plan/prevent/floodplain/techbul.shtm).

Technical Bulletins also may be ordered free of charge from the FEMA Distribution Center by calling 1-800-480-2520, or by faxing a request to 1-240-699-0525, Monday through Friday between 8 a.m. and 5 p.m. EST. Please provide the FEMA publication number, title, and quantity of each publication requested, along with your name, address, zip code, and daytime telephone number. Written requests may be submitted by email to: FEMA-Publications-Warehouse@dhs.gov

Further Information

The following publications provide further information concerning the use of flood damage-resistant materials.

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U.S. Army Corps of Engineers. 1995. *Flood Proofing Regulations*, Chapters 9 and 10, U.S. Army Corps of Engineers, EP 1165-2-314.

Wood Truss Council of America (WTCA). 2005. *The Load Guide: Guide to Good Practice for Specifying and Applying Loads to Structural Building Components*, (http://www.sbcindustry.com/loads.php).

World Floor Covering Association (WFCA). n.d., Anaheim, California (http://www.wfca.org/index.html).

Glossary

Accessory structure — A structure that is on the same parcel of property as a principal structure, the use of which is incidental to the use of the principal structure.

Base flood — The flood having a 1-percent chance of being equaled or exceeded in any given year, commonly referred to as the "100-year flood." The base flood is the national standard used by the NFIP and all Federal agencies for the purposes of requiring the purchase of flood insurance and regulating new development.

Base flood elevation (BFE) — The height of the base (1-percent annual chance or 100-year) flood in relation to a specified datum, usually the National Geodetic Vertical Datum of 1929, or the North American Vertical Datum of 1988.

Basement — Any area of a building having its floor subgrade (below ground level) on all sides.

Enclosure or enclosed area — Areas created by a crawlspace or solid walls that fully enclose areas below the BFE.

Federal Emergency Management Agency (FEMA) — The Federal agency that, in addition to carrying out other activities, administers the National Flood Insurance Program.

Federal Insurance and Mitigation Administration (FIMA) — The component of FEMA directly responsible for administering the flood hazard identification and floodplain management aspects of the NFIP.

Flood Insurance Rate Map (FIRM) — The official map of a community on which FEMA has delineated both the special flood hazard areas (SFHAs) and the risk premium zones applicable to the community.

Floodprone area — Any land area susceptible to being inundated by floodwater from any source.

Lowest floor — The lowest floor of the lowest enclosed area of a building, including a basement. Any NFIP-compliant unfinished or flood-resistant enclosure usable solely for parking of vehicles, building access, or storage (in an area other than a basement) is not considered a building's lowest floor, provided the enclosure does not render the structure in violation of the applicable design requirements of the NFIP.

Registered Design Professional — An individual who is registered or licensed to practice their respective design profession as defined by the statutory requirements of the professional registration laws of the State or jurisdiction in which the project is to be constructed.

Special Flood Hazard Area (SFHA) — An area delineated on a FIRM as being subject to inundation by the base flood and designated as Zone A, AE, A1-A30, AR, AO, AH, A99, V, VE, or V1-V30.

Substantial damage — Damage of any origin sustained by a structure whereby the cost of restoring the structure to its before-damaged condition would equal or exceed 50 percent of the market value of the structure before the damage occurred. Structures that are determined to be substantially damaged are considered to be substantial improvements, regardless of the actual repair work performed.

Substantial improvement — Any reconstruction, rehabilitation, addition, or other improvement of a structure, the cost of which equals or exceeds 50 percent of the market value of the structure (or smaller percentage if established by the community) before the "start of construction" of the improvement. This term includes structures that have incurred "substantial damage," regardless of the actual repair work performed.

(/) **National Ocean Service (/welcome.html)** Search
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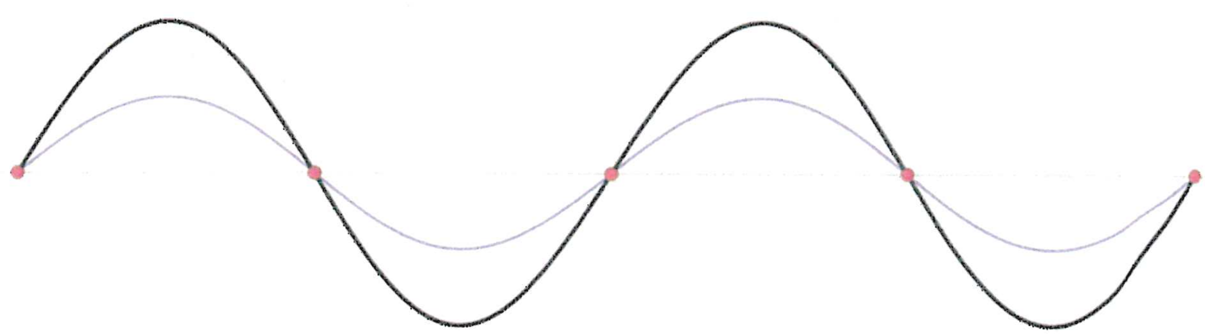
HOME (/) » OCEAN FACTS (/FACTS/) » WHAT IS A SEICHE?

What is a seiche?

pronounce SAYSH

A seiche is a **standing wave** oscillating in a body of water.



This animation shows a standing wave (black) depicted as a sum of two propagating waves traveling in opposite directions (blue and red). Similar in motion to a seesaw, a seiche is a standing wave in which the largest vertical oscillations are at each end of a body of water with very small oscillations at the "node," or center point, of the wave. Standing waves can form in any enclosed or semi-enclosed body of water, from a massive lake to a small coffee cup.

Seiches and meteotsunamis. What's the difference?

Seiches and meteotsunamis (/facts/meteotsunami.html) are often grouped together, but they are two different events. Winds and atmospheric pressure can contribute to the formation of both seiches and meteotsunamis; however, winds are typically more important to a seiche motion, while pressure often plays a substantial role in meteotsunami formation.

Sometimes a seiche and a meteotsunami can even occur at the same time. Seiches are standing waves with longer periods of water-level oscillations (typically exceeding periods of three or more hours), whereas meteotsunamis are progressive waves limited to the tsunami frequency band of wave periods (two minutes to two hours). Seiches are usually limited to partially or fully enclosed basins, such as Lake Erie. Meteotsunamis can occur in such basins but are also prevalent on the open coast. A single meteotsunami can travel long distances and influence a very large range of the coastline.

If you have observed water sloshing back and forth in a swimming pool, bathtub, or cup of water, you may have witnessed a small-scale seiche (pronounced saysh). On a much grander scale, the same phenomenon occurs in large bodies of water such as bays and lakes. A seiche may occur in any semi- or fully-enclosed body of water.

Seiches are typically caused when strong winds and rapid changes in atmospheric pressure push water from one end of a body of water to the other. When the wind stops, the water rebounds to the other side of the enclosed area. The water then continues to oscillate back and forth for hours or even days. In a similar fashion, earthquakes, tsunamis, or severe storm fronts may also cause seiches along ocean shelves and ocean harbors.

Lake Erie is known for seiches, especially when strong winds blow from southwest to northeast. In 1844, a 22-foot (6.7 meter) seiche breached a 14-foot-high (4.3 meter) sea wall killing 78 people and damming the ice to the extent that Niagara Falls temporarily stopped flowing. As recently as 2008, strong winds created waves 12 to 16 feet (3.66 to 4.88 meter) high in Lake Erie, leading to flooding near Buffalo, New York. Lake Pontchartrain, Louisiana, is also known to routinely form small seiches after the passage of afternoon squall lines during summer months.

In some of the Great Lakes and other large bodies of water, the time period between the "high" and "low" of a seiche can be as much as four to seven hours. This is very similar to the time period between a high and low tide in the oceans, and is often mistaken as a tide.

Search Our Facts

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Seiche

A **seiche** (/ˈseɪʃ/ *SAYSH*) is a standing wave in an enclosed or partially enclosed body of water. Seiches and seiche-related phenomena have been observed on lakes, reservoirs, swimming pools, bays, harbours and seas. The key requirement for formation of a seiche is that the body of water be at least partially bounded, allowing the formation of the standing wave.

The term was promoted by the Swiss hydrologist François-Alphonse Forel in 1890, who was the first to make scientific observations of the effect in Lake Geneva, Switzerland.[1] The word originates in a Swiss French dialect word that means "to sway back and forth", which had apparently long been used in the region to describe oscillations in alpine lakes. According to Wilson (1972),[2][3] this Swiss French dialect word comes from the Latin word "siccus" meaning "to dry", i.e. as the water recedes, the beach dries. The term is probably also related to the French word "sèche ".

Seiches in harbours can be caused by *long period* or *infragravity waves*, which are due to subharmonic nonlinear wave interaction with the wind waves, having periods longer than the accompanying wind-generated waves.[4]

Contents

A standing wave (black) depicted as a sum of two propagating waves traveling in opposite directions (blue and red).

Causes and nature

Seiches are often imperceptible to the naked eye, and observers in boats on the surface may not notice that a seiche is occurring due to the extremely long wavelengths.

The effect is caused by resonances in a body of water that has been disturbed by one or more factors, most often meteorological effects (wind and atmospheric pressure variations), seismic activity, or tsunamis.[5] Gravity always seeks to restore the horizontal surface of a body of liquid water, as this represents the configuration in which the water is in hydrostatic equilibrium.

Vertical harmonic motion results, producing an impulse that travels the length of the basin at a velocity that depends on the depth of the water. The impulse is reflected back from the end of the basin, generating interference. Repeated reflections produce standing waves with one or more nodes, or points, that experience no vertical motion. The frequency of the oscillation is determined by the size of the basin, its depth and contours, and the water temperature.

The longest natural period of a seiche is the period associated with the fundamental resonance for the body of water—corresponding to the longest standing wave. For a surface seiche in an enclosed rectangular body of water this can be estimated using Merian's formula:[6][7]

$$T = \frac{2L}{\sqrt{gh}}$$

where T is the longest natural period, L is the length, h the average depth of the body of water, and g the acceleration of gravity.[8]

Higher order harmonics are also observed. The period of the second harmonic will be half the natural period, the period of the third harmonic will be a third of the natural period, and so forth.

Occurrence

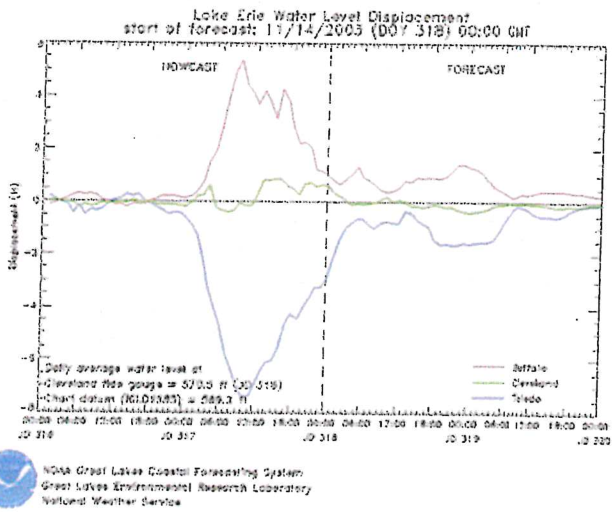
Seiches have been observed on both lakes and seas. The key requirement is that the body of water be partially constrained to allow formation of standing waves. Regularity of geometry is not required; even harbours with exceedingly irregular shapes are routinely observed to oscillate with very stable frequencies.

Lake seiches

Low rhythmic seiches are almost always present on larger lakes. They are usually unnoticeable among the common wave patterns, except during periods of unusual calm. Harbours, bays, and estuaries are often prone to small seiches with amplitudes of a few centimetres and periods of a few minutes.

The original studies in Lake Geneva by François-Alphonse Forel found the longitudinal period to have a 73-minute cycle, and the transversal seiche to have a period of around 10 minutes.[9] Other lakes well known for their regular seiches is New Zealand's Lake Wakatipu, which varies its surface height at Queenstown by 20 centimetres in a 27-minute cycle. Seiches can also form in semi-enclosed seas; the North Sea often experiences a lengthwise seiche with a period of about 36 hours.

The National Weather Service issues low water advisories for portions of the Great Lakes when seiches of 2 feet or greater are likely to occur.[10] Lake Erie is particularly prone to wind-caused seiches because of its shallowness and its elongation on a northeast-southwest axis, which frequently matches the direction of prevailing winds and therefore maximises the fetch of those winds. These can lead to extreme seiches of up to 5 metres (16 ft) between the ends of the lake.



Differences in water level caused by a seiche on Lake Erie, recorded between Buffalo, New York (*red*) and Toledo, Ohio (*blue*) on November 14, 2003

The effect is similar to a storm surge like that caused by hurricanes along ocean coasts, but the seiche effect can cause oscillation back and forth across the lake for some time. In 1954, the remnants of Hurricane Hazel piled up water along the northwestern Lake Ontario shoreline near Toronto, causing extensive flooding, and established a seiche that subsequently caused flooding along the south shore.

Lake seiches can occur very quickly: on July 13, 1995, a large seiche on Lake Superior caused the water level to fall and then rise again by three feet (one metre) within fifteen minutes, leaving some boats hanging from the docks on their mooring lines when the water retreated.[11] The same storm system that caused the 1995 seiche on Lake Superior produced a similar effect in Lake Huron, in which the water level at Port Huron changed by 6 feet (1.8 m) over two hours.[12] On Lake Michigan, eight fishermen were swept away from piers at Montrose and North Avenue Beaches and drowned when a 10-foot (3.0 m) seiche hit the Chicago waterfront on June 26, 1954.[13]

Lakes in seismically active areas, such as Lake Tahoe in California/Nevada, are significantly at risk from seiches. Geological evidence indicates that the shores of Lake Tahoe may have been hit by seiches and tsunamis as much as 10 metres (33 ft) high in prehistoric times, and local researchers have called for the risk to be factored into emergency plans for the region.[14]

Earthquake-generated seiches can be observed thousands of miles away from the epicentre of a quake. Swimming pools are especially prone to seiches caused by earthquakes, as the ground tremors often match the resonant frequencies of small bodies of water. The 1994 Northridge earthquake in California caused swimming pools to overflow across southern California. The massive Good Friday earthquake that hit Alaska in 1964 caused seiches in swimming pools as far away as Puerto Rico.[15] The earthquake that hit Lisbon, Portugal in 1755 caused seiches 2,000 miles (3,200 km) away in Loch Lomond, Loch Long, Loch Katrine and Loch Ness in Scotland[16] and in canals in Sweden. The 2004 Indian Ocean earthquake caused seiches in standing water bodies in many Indian states as well as in Bangladesh, Nepal and northern Thailand.[17] Seiches were again observed in Uttar Pradesh, Tamil Nadu and West Bengal in India as well as in many locations in Bangladesh during the 2005 Kashmir earthquake.[18]

The 1950 Assam–Tibet earthquake is known to have generated seiches as far away as Norway and southern England. Other earthquakes in the Indian sub-continent known to have generated seiches include the 1803 Kumaon-Barahat, 1819 Allah Bund, 1842 Central Bengal, 1905 Kangra, 1930 Dhubri, 1934 Nepal-Bihar, 2001 Bhuj, 2005 Nias, 2005 Teresa Island earthquakes. The February 27, 2010 Chile earthquake produced a seiche on Lake Pontchartrain, Louisiana with a height of around 0.5 feet. The 2010 Sierra El Mayor earthquake produced large seiches that quickly became an internet phenomenon.[19]

Seiches up to at least 1.8 m (6 feet) were observed in Sognefjorden, Norway during the 2011 Tōhoku earthquake in Japan.[20][21]

Sea and bay seiches

Seiches have been observed in seas such as the Adriatic Sea and the Baltic Sea. This results in the flooding of Venice and St. Petersburg, respectively, as both cities are constructed on former marshland. In St. Petersburg, seiche-induced flooding is common along the Neva River in the autumn. The seiche is driven by a low pressure region in the North Atlantic moving onshore, giving rise to cyclonic lows on the Baltic Sea. The low pressure of the cyclone draws greater-than-normal quantities of water into the virtually land-locked Baltic. As the cyclone continues inland, long, low-frequency seiche waves with wavelengths up to several hundred kilometres are established in the Baltic. When the waves reach the narrow and shallow Neva Bay, they become much higher — ultimately flooding the Neva embankments.[22] Similar phenomena are observed at Venice, resulting in the MOSE Project, a system of 79 mobile barriers designed to protect the three entrances to the Venetian Lagoon.

Nagasaki Bay is a typical area in Japan where seiches have been observed from time to time, most often in the spring — especially in March. On 31 March 1979, the Nagasaki tide station recorded a maximum water-level displacement of 2.78 metres (9.1 ft), at that location due to the seiche. The maximum water-level displacement in the whole bay during this seiche event is assumed to have reached 4.70 metres (15.4 ft), at the bottom of the bay. Seiches in Western Kyushu – including Nagasaki Bay — are often induced by a low in the atmospheric pressure passing South of Kyushu island.[23] Seiches in Nagasaki Bay have a period of about 30 to 40 minutes. Locally, seiche (副振動, *fukushindō*) is called abiki (あびき). The word of *abiki* is considered to have been derived from 網引き (*amibiki*), which literally means: the dragging-away (引き (*biki*)) of a fishing net (網 (*ami*)). Seiches not only cause damage to the local fishery but also may result in flooding of the coast around the bay, as well as in the destruction of port facilities.

On occasion, tsunamis can produce seiches as a result of local geographic peculiarities. For instance, the tsunami that hit Hawaii in 1946 had a fifteen-minute interval between wave fronts. The natural resonant period of Hilo Bay is about thirty minutes. That meant that every second wave was in phase with the motion of Hilo Bay, creating a seiche in the bay. As a result, Hilo suffered worse damage than any other place in Hawaii, with the combined tsunami and seiche reaching a height of 26 feet along the Hilo Bayfront, killing 96 people in the city alone. Seiche waves may continue for several days after a tsunami.

Tide-generated internal solitary waves (solitons) can excite coastal seiches at the following locations: Magueyes Island in Puerto Rico,[24][25][26] Puerto Princesa in Palawan Island,[27] Trincomalee Bay in Sri Lanka,[28][29] and in the Bay of Fundy in eastern Canada, where seiches cause some of the highest recorded tidal fluctuations in the world.[30] A dynamical mechanism exists for the generation of coastal seiches by deep-sea internal waves. These waves can generate a sufficient current at the shelf break to excite coastal seiches.[31]

Underwater (internal) waves

Seiches are also observed beneath the lake surface acting along the thermocline[32] in constrained bodies of water.

In analogy with the Merian formula, the expected period of the internal wave can be expressed as:[33]

$$T = \frac{2L}{c} \text{ with } c^2 = g\frac{\rho_2 - \rho_1}{\rho_2}\frac{h_1 h_2}{h_1 + h_2}$$

where T is the natural period, L is the length of the water body, h_1, h_2 the average thicknesses of the two layers separated by stratification (e.g. epilimnion and hypolimnion), ρ_1, ρ_2 the densities of these two same layers and g the acceleration of gravity.

As the thermocline moves up and down a sloping lake bed, it creates a 'swash zone' on the lake bed where temperatures can rapidly vary,[34] potentially influencing fish habitat usage. As the thermocline rises up a sloping lake bed, it can also cause enhance benthic turbulence by convective overturning, whereas the falling thermocline experiences greater stratification and low turbulence at the lake bed.[35][36] Internal waves can also degenerate into non-linear internal waves on sloping lake-beds.[37] When such non-linear waves break on the lake bed, they can be an important source of turbulence and have the potential for sediment resuspension[38]

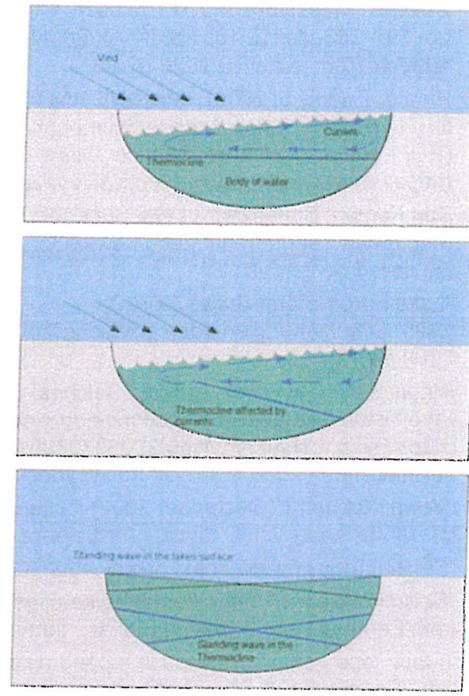


Illustration of the initiation of surface and subsurface thermocline seiches.

Engineering for seiche protection

Engineers consider seiche phenomena in the design of flood protection works (e.g., Saint Petersburg Dam), reservoirs and dams (e.g., Grand Coulee Dam), potable water storage basins, harbours and even spent nuclear fuel storage basins.

See also

- Clapotis – A non-breaking standing wave pattern
- Earthquake engineering
- Severe weather terminology (United States) – Terminology used by the National Weather Service to describe severe weather in the US
- Severe weather terminology (Canada)
- Tsunamis in lakes
- Vajont Dam
- Villa Epecuén

Notes

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External links

- "Seiche" (https://en.wikisource.org/wiki/1911_Encyclop%C3%A6dia_Britannica/Seiche). *Encyclopædia Britannica*. **24** (11th ed.). 1911.

General

- What is a *seiche*? (https://web.archive.org/web/20040125065554/http://www.seagrant.wisc.edu/Communications/LakeLevels/seiche.htm)
- Seiche. Encyclopædia Britannica. Retrieved January 24, 2004, from Encyclopædia Britannica Premium Service. (http://www.britannica.com/eb/article?eu=68339)
- Seiche calculator (https://web.archive.org/web/19970514200816/http://www.coastal.udel.edu/faculty/rad/seiche.html)
- Bonanza for Lake Superior: Seiches Do More Than Move Water (http://www.seagrant.umn.edu/newsletter/2000/02/bonanza_for_lake_superior_seiches_do_more_than_move_water.html)
- Great Lakes Storms Photo Gallery Seiches, Storm Surges, and Edge Waves from (http://www.glerl.noaa.gov/seagrant/glwlphotos/Seiche/SeicheHome.html)NOAA
- Shelf Response for an identical pair of incident KdV solitons (http://www.mathworks.com/matlabcentral/fileexchange/44603-shelf-response-for-two-kdv-solitons)

Relationship to aquatic "monsters"

- The Unmuseum (http://www.unmuseum.org/mwave.htm)

- "The Legend of the Lake Champlain Monster" (http://www.csicop.org/si/show/legend_of_the_lake_champlain_monster/) in *The Skeptical Inquirer*
- Geological page (http://geology.about.com/library/weekly/aa070101a.htm)
